

**THE APPLICATION OF THE UNITED STATES BUREAU OF RECLAMATION
TYPE III STILLING BASIN ENERGY DISSIPATOR DESIGN IN EARTH DAM
SPILLWAYS**

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BENIN CITY.**

JULY, 2021

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**A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF MASTERS DEGREE IN CIVIL ENGINEERING (WATER
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UNIVERSITY OF BENIN, BENIN CITY.**

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JULY, 2021

CERTIFICATION

This is to certify that this research was carried out by Eichie, Christopher Ehibhanre in partial fulfillment of the requirement for the award of Master’s Degree in Civil Engineering (Water Resources and Environmental Health Engineering), Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

This research is dedicated to God Almighty who kept me under the shadow of His wings in mercy and love and in whom I found grace, fortitude and hope. To Him be all the honour and glory! Amen.

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LIST OF SYMBOLS

Q = Expected Flow discharge

W = Width of spillway crest

q = Unit discharge at spillway crest

v = velocity of flow

y_1 = depth of approach water

Fr_1 = Froude number of conjugate depth

y_2 = sequent depth

H_j = Height of Basin wall

L_T = Length of stilling Basin

W or W_B = Width of stilling Basin

L_w = Distance between Base of Chute and Baffle Piers

h_1 = Height of chute blocks

W_1 = Width of chute blocks

S_1 = Spacing between chute blocks

N_c = Number of chute blocks

H_3 = Height of baffle piers

L_u = top thickness of baffle piers

L_L = bottom thickness of baffle piers

W_3 = Width of baffle piers

S_3 = Spacing between baffle piers

N_B = Number of baffle piers

H_4 = Height of end sill

L_5 = Length of end sill

ABSTRACT

Hydraulic structures such as dams require energy dissipation for their safe operation. Scouring and cavitation are challenges which may arise at the downstream toe of earth dams due to inadequate provision for proper energy dissipation leading to severe damages or total loss of the dam. This study aimed at designing the United States Bureau of Reclamation (USBR) type III basin for energy dissipation downstream of earth dam spillways in Nigeria using Microsoft Excel as computational tool. Microsoft Excel was used in developing the design code governed by a set of algorithms which conformed to USBR standard. The algorithm was used to compute flow data suitable for the formation of hydraulic jump within the USBR type III stilling basin. Various flow conditions with discharges ranging from 10 m³/s to 110 m³/s and inflow velocity ranging from 3 m/s to 18 m/s) were simulated at various basin widths ranging from 3 m to 12 m. Acceptable design flows were determined using the Froude numbers that ranged between 4.5 to 9 as the major criterion. The results obtained showed that an increase in velocity led to an increased Froude number for the various basin widths. At 3 m/s inflow velocity, the mean Fr values were 0.59, 0.85, 1.03 and 1.10 for stilling basins width of 3 m, 6 m, 9 m and 12 m respectively. At 6 m/s the mean Fr values were 1.69, 2.38, 2.93 and 3.38. At 9 m/s, mean Fr values were 3.10, 4.34, 5.37 and 6.21. At 12 m/s, the mean Fr values were 4.77, 6.76, 8.82 and 9.47. At 15 m/s, mean Fr values were 6.68, 9.89, 9.89 and 13.36. At 18 m/s mean Fr values were 8.68, 12.42, 15.22 and 17.57. These implied that at increased basin widths, the efficiency of the formation of hydraulic jump improved with higher inflow velocities resulting in shorter basins with more numbers of baffle piers and chute blocks. The results obtained will find relevant application in the preliminary design of the type III stilling basins for earth dams, reservoirs in Nigeria, in accordance with the United States Bureau of Reclamation standard. It will also aid Engineers in the proper control and evacuation of small earth dams while checking erosive effects from the velocity of the evacuated outflow by means of hydraulic jump formation. Furthermore, experimental researches involving physical models are recommended to ascertain more results and facilitate more efficient and economical USBR stilling basin designs.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy dissipation is the reduction in the amount of excess hydraulic energy due to high-velocity flow released through the conversion of potential energy upstream of a dam to kinetic energy at the base, downstream within the outlet structure of the spillway (Negm et al, 2015). A spillway is a structure used to provide the controlled release of flows from a dam or levee into a downstream area, usually the downstream riverbed. Energy dissipation downstream a spillway is a very critical problem which has been faced by design engineers. The overflow (discharge) collected at the spillway crest possesses great erosive forces which when released become detrimental to the downstream toe of hydraulic structures.

Many earth dams have encountered failures due to such unchecked erosion. Hence, it is pertinent and reasonable procedure to reduce the energy effects of the overflow discharge at the dam toe by providing at least minimum protection, through the use of an energy dissipating device. Various energy dissipating devices exist based on economy and complexity. Design and selection of the type of energy dissipator to be utilized is based on estimation of the extent of the likely damage that will be encountered at the earth dam toe. These estimations involve the evaluation of erosion, scour potential and resistance of the toe of the spillway channel to erosive forces under superimposed flow conditions, in the absence of these energy dissipating devices.

The stilling basin is a common type of energy dissipator for weirs and small dams. Stilling basins are generally reinforced concrete structures designed to contain the turbulent flow of a hydraulic structure (Wurbs et al, 2009). In a stilling basin, most of the energy is dissipated in a hydraulic jump assisted by appurtenances (e.g. step and baffle blocks) to increase the turbulence. The hydraulic jump induced takes place in the stilling basin. Other forms of

energy dissipators include the drop structure, impact type stilling basins, flip bucket, ski jumps (Chanson, 2002). According to Sunil and Deodhar (2004), and Ashraf (2013), a hydraulic jump type stilling basin, is the ideal type of energy dissipation device.

A hydraulic jump is the rapid transition from a supercritical to subcritical flow. It is an extremely turbulent process, characterised by large scale turbulence, surface waves and spray, energy dissipation and air entrainment (Chanson, 2002). It is an extremely useful phenomenon which can be forced to form at the foot of a spillway, canal structure, culvert outlet or transition structure to reduce the flow velocity with an associated reduction in the energy content of the flow (Bhowmik, 1971).

Improper design of hydraulic structures such as dams and their relative appurtenance structures such as spillway, stilling basins can lead to their failures. Generalized designs of hydraulic jump stilling basins have been developed, thus stilling basins may now be designed without the need for additional model studies (FEMA, 2010).

1.2 Statement of the Problem

The problem of poor dissipation of energy due to the approach velocity of the tail water at the downstream toe of the spillway structure has often resulted to the erosion of the entire dam structure. Many hydraulic structures such as earth dams, spillways, culverts, weirs have failed due to erosion from overtopping water or inadequate dissipation of energy from floods thereby undermining the main dam structure. In many cases, inadequate energy dissipation of hydraulic structures has resulted in ecological problems of great dimensions (such as gullies) around the adjoining areas where these structures are sited. Hence it is pertinent to design hydraulic structures together with its appurtenances, which can cater for proper energy dissipation within the stilling basin of earth dams. Therefore, in order to avert such failures it

is important to have knowledge of the amount of energy developed and the methods which could be effective in energy dissipation within such hydraulic structures.

Small earth dams are commonly designed and constructed in many developing countries including Nigeria for harnessing the water resources potentials of streams for water supply, irrigation, hydroelectricity, etc. Considering the expected flow regimes, such earth dams utilize stilling basins which are designed in accordance with the specifications of the United States Bureau for Reclamation (USBR) type III stilling basins for energy dissipation. The design could be cumbersome, iterative and requires a rigorous manual computation which is time consuming. Hence it is important to study this type of energy dissipator and develop a computerized simple to use method for its design for use by engineers. Earth dam is chosen for this study as they are the most predominantly designed and constructed dams in developing countries.

1.3 Aim and Objectives

The aim of this work was to carry out a study of the USBR type III stilling basin utilized for energy dissipation downstream of an earth dam spillway and develop a simple to use computer method for its design.

The objectives were:

- (i) to review literature of hydraulic jump stilling basins for energy dissipation in hydraulic structures and particularly the USBR type III basin in order to identify its peculiarities.
- (ii) to appraise the use of USBR type III stilling basins for energy dissipation below Earth dam spillways.
- (iii) to develop simple to use computer approach to be used in the design of the USBR type III stilling basin and its components.

1.4 Scope of Work

This study covered the following:

- (i) Review of literature on the use of Hydraulic jump stilling basins as a means of energy dissipation in hydraulic structures.
- (ii) Evaluation of the USBR type III stilling basin for energy dissipation below earth dam spillways.
- (iii) Obtain all the necessary data required for the hydraulic design of USBR type III stilling basin.
- (iv) Development of flow chart/procedures necessary for computer based design of USBR type III stilling basin.
- (v) Develop a program for the computation of design parameters of USBR type III stilling basin.
- (vi) Validation of program using the design parameters of small earth dams.

1.5 Relevance of Study

Failure of earth dams due to poorly designed or constructed energy dissipators can lead to loss of functionality of the structure. Damages resulting from the basin structure can lead to expensive repairs and maintenance which are uneconomical. Dam failures poses threats to communities downstream and lead to an out-of-service operation period, hence, the design of the USBR type III stilling basin. Generally, this study aided for the construction, maintenance, and safety of hydraulic structures, including small earth dams, weirs, and culverts. It also sought to facilitate the design procedures for the USBR type III stilling basin in terms of efficiency, timeliness, detail, accuracy and flexibility, which are usually time consuming, requiring rigorous manual step-by-step computations using a computer program. This study provided a means of designing energy dissipation devices, check against over-design of the

stilling basin and energy dissipators while ensuring minimal reduction in flow conditions substantially below the natural or normal channel conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy Dissipation

An overflow coming from some river or from some other body of water is known as flood. Apart from the overflow of rivers, the floods may be caused by the failure of some dam, with a sudden release of huge amounts of water, causing considerable damage to life and property downstream. For structures constructed within a channel reach, proper planning and design is of utmost importance while considering the susceptibility of such structure to damage and the extent of catastrophe such damages could result in, should any failure occur (Kramer, 2006).

Hence, predicting the likelihood of critical flooding conditions cannot be ruled out. This means that provisions must be put in place to cater for such unusual conditions. For example, flood control systems such as spillways with adequate capacity must be provided for dams, together with adequate protection at the toe to prevent scouring action. Other conditions which must be considered in flood control within a channel includes providing adequate height of wall for levees, weirs and dams to prevent overtopping, providing sufficient waterway openings for bridges, provision of outlet works for storage and water retaining structures, as well as energy dissipating structures (Meireles et al, 2014).

Energy dissipation may be realised by a wide range of design and construction techniques (Habib et al, 2013). Some methods which can be utilized to reduce the approach flow velocity include:

- (i) Creation of a hydraulic jump thereby increasing the depth of flow and decreasing the velocity.
- (ii) Allowing a free falling jet to strike a rock surface directly. The energy dissipation is through turbulence diffusion.

- (iii) Reversing the direction of free falling jet and allowing it to go into the air. The energy is dissipated through air entrapment and diffusion.

The main dissipative feature utilized in these methods is one in which energy is transformed from some initial form to some final form (for example, from potential to kinetic, to heat), then conversion of kinetic energy to turbulence. Energy transformed to turbulent flow field is ultimately lost as heat energy and part of the kinetic energy is also transformed to sound and pressure energy, the capacity of the final form to mechanical work being less than that of the initial form.

Energy dissipation is typically required for outlet works associated with embankment and concrete dams where flow emerges at a high velocity in a near horizontal direction. Outlet works and spillway energy dissipators often experience similar loading conditions. However, outlet works dissipation structures typically operate more frequently (often at or near their design discharge) and operate for longer durations, hence a more conservative design is necessary (Stephenson, 1991). When water at high velocity (supercritical) discharges into a zone of lower velocity (subcritical), a rather abrupt rise (a step or standing wave) occurs on the liquid surface. This abrupt rise is called a “hydraulic jump”. The phenomenon depends upon the initial velocity of the flow. If the initial velocity is below the critical velocity, no jump is possible. When a jump occurs, flow will change from supercritical ($Fr > 1$) to subcritical ($Fr < 1$). As the flow velocity increases, the transition grows more abrupt. Hydraulic jumps can be accompanied by violent turbulence, eddying, air entrainment, and surface undulations (USBR, 1958). In this study, the inducement, control and the type of hydraulic jump formed, as well as its characteristics is determined by the design of the various components within the stilling basin and its appurtenant structure (El Gawhary et al, 1986).

2.2 The Hydraulic Jump as a mode of dissipating energy

Within a channel flow, stream or river, an impediment such as a block, may be placed to obstruct the free flow downstream. The flow impediment induces a jump such as found within the downstream areas where earth dams are built thereby making the flow upstream to be supercritical. Hence, a hydraulic jump occurs when the upstream flow is supercritical (i.e. Froude number is greater than 1). As water depth increases during a hydraulic jump, turbulence occurs and consequently energy is dissipated. In order to induce the occurrence of a hydraulic jump, engineers usually install impediments within the channels, spillway, or culverts downstream. Such impediments may be in form of concrete blocks (Falvey, 1990).

2.3 Energy dissipators

Energy dissipators are structural elements which are designed to reduce the excess of kinetic energy possessed by the flow along the chute of the spillway, before it re-enters the natural stream. They protect downstream areas of hydraulic structures such as dams, culverts, spillways, etc from erosion damages by reducing the velocity of the flow to acceptable limits. In dams, energy dissipation can be achieved through the use of a plunging jet pool, stepped spillway chute, a stilling basin, drop structures, impact type or a flip bucket. However, due to the predominance of weirs and small earth dams, especially in developing countries, the stilling basin is the most utilized form of energy dissipator. Mason, (1982) reported that the energy dissipation in stepped chute is characterized by white waters (air entrainment).

2.3.1 Types of energy dissipators

There are many types of energy dissipation structures. Examples of dissipation structures include the hydraulic jump stilling basin designed to dissipate energy within the concrete structure itself and plunge basin, designed for energy dissipation in the natural channel

located downstream. Alternatives dissipators include the internal and external dissipators, drop structures, stilling basins and the natural scour holes.

2.3.2 Design Consideration/Criteria for the selection of energy dissipator type

During the design of the selected type of energy dissipator, the following are considered (Tiwari and Goel, 2014):

- (i) Ice Build-up: if ice build up is considered as a criteria for energy dissipator design, it can be mitigated by sizing the structure in order not to obstruct the winter low flow, and using energy dissipators.
- (ii) Debris Control: Debris control is considered and designed for using HEC 9. The criteria for design includes where clean-out access is limited, and if the dissipator type selected cannot cater for debris.
- (iii) Flood Frequency: The flood frequency used in the design of the energy dissipator device should be the same as that of the spillway design. Evaluation of the flood is of utmost importance. For example, for most external dissipators, the review flood check will indicate that the dissipator will have a higher outlet velocity than the design flood. If this higher velocity causes concern, it should be mitigated. Internal dissipators and some external dissipators (eg. Hook, USBR Type VI) may cause the culvert to flow full for the review flood. If this is likely and if the higher headwater causes concern, a different dissipator should be evaluated. Justification for the use of a design flood of less magnitude may be seen for:
 - (a) Substantial cost savings.
 - (b) Limited or no adverse effect on the downstream channel,
 - (c) Limited or no adverse effect on the downstream development, and
 - (d) Low risk of failure of the crossing.

- (iv) Cost: Comparison based on maintenance costs, traffic delay costs, difficulty of construction, replacement costs are usually considered in determining the selected energy dissipator type. The type selected for the dissipator should be based on a comparison of the total cost over the design life of alternative types and should not be made using first cost as the only criteria.
- (v) Tail-water relationship: The hydraulic conditions downstream should be evaluated to determine a tail-water depth and the maximum velocity for a range of discharges:
 - (a) Open channels: (See Bridge hydraulics)
 - (b) Lakes, ponds or large water bodies should be evaluated using the high-water elevation, which has the same frequency as the design flood for the culvert/spillway if events are known to occur concurrently (statistically dependent). If statistically independent, the joint probability of the flood magnitude is evaluated.
- (vi) Maximum spillway/culvert exit velocity: The spillway/culvert exit velocity should be consistent with the maximum velocity in the natural channel or should be mitigated using energy dissipation and channel stabilization.

2.4 Design of Energy Dissipators

HEC 14 contains design details for specific energy dissipators. Recent advances in technology have permitted the development of new design and construction techniques, particularly with the provision of adequate flood release facilities. Chutes and spillways are designed to spill large water discharges over a hydraulic structure (e.g. dam, weir) without major damage to the structure itself and to its environment. A number of modern

developments have demonstrated that such energy dissipation may be achieved along the spillway chute, in a downstream energy dissipator, or a combination of both.

Many engineers have never been exposed to the complexity of energy dissipator designs, to the physical processes taking place and to the structural challenges. Several energy dissipators, spillways and storm waterways failed because of poor engineering design. It is believed that a major issue affecting these failures was the lack of understanding of the basic turbulent dissipation processes and of the interactions between free-surface aeration and flow turbulence. Among the range of design techniques utilized includes the block ramps, stepped spillways, hydraulic jump stilling basins, ski jumps and impact dissipators (Rhone, 1977).

2.5 Selection of appropriate Energy dissipator

Selection of the appropriate energy dissipator is a critical design consideration. There are certain limitations for each energy dissipator, and each situation is unique. During the selection the following may be considered (Mason, 1982):

- (i) The required number of outlets involved.
- (ii) The topography and geology of the sited.
- (iii) The energy content and unit discharge of flow entering the dissipator.
- (iv) The duration and frequency of flow.
- (v) The tail-water conditions for the range of discharges.
- (vi) The water quality.
- (vii) Alignment and location with respect to the toe of the dam and other features.
- (viii) Icing and spray restrictions.
- (ix) The compatibility of the emerging flow with the conduit, tunnel, valve or gate.
- (x) Other environmental and economic conditions.

2.5.1 The essence of Energy dissipator design

It is essential for energy dissipator designers to give proper attention to the hydraulic, structural and mechanical design details as a poorly designed energy dissipator can result to excessive maintenance, work safety issues, structural damage to the downstream structures such as the stilling basin, erosion of the downstream channel due to excessive turbulence.

The various problems which arise from energy dissipation within a hydraulic structure can be eliminated or reduced by a carefully engineered design. Dam-building agencies have developed standard design methods for many energy dissipators based on previous physical and computational hydraulic model tests. Most times, energy dissipator designs are based on experience, hence the need may arise for further model testing beyond the limits of these designs or where new innovative concepts are required (Svoboda, 2012).

2.6 Hydraulic Jump Stilling Basins

The performance of the stilling basin is based primarily on the various shapes in which the stilling basin can be designed. Each of these shapes of the stilling basin is of various advantages (Hager, 1992). Stabilization of the hydraulic jump can be achieved with the aid of drops and backward-facing steps. Such drops or steps are usually placed close to the toe of the jump. Baffle blocks on the other hand are used to force the flow by means of obstruction above them. They may be placed in single or several rows. They are usually not suitable for basins with high expected inflow velocity (above 18m/s) as they may become very prone to cavitation damage. Another technique utilized in enhancing turbulent energy dissipation within the stilling basin is through the introduction of sudden expansions (FEMA, 2010). Another main technique for energy dissipation involves placement of the energy dissipaters

on the apron downstream of head structures in order to facilitate the formation of a hydraulic jump (Tarek *et al.*, 2014). Various researches have been carried out to investigate the efficiency in dissipating energy by inducing the hydraulic jump. These studies utilized different configurations of energy dissipators of various types and shapes (Ashour *et al.*, 2014). Such studies which included notable researches of Peterka (1958), Gawhary *et al.* (1986), Aziz *et al.* (1999), Alikhani *et al.* (2010), Tiwari *et al.* (2013), Bastawy (2013), and Habib and Nasser (2013) also noted that the hydraulic jump stilling basin is an efficient means of energy dissipation. Evaluations on smooth and stepped chutes were carried out by various researchers: Stephenson (1991), Chanson (1994, 2002), Matos (2000), Boes and Hager (2003), Meireles and Matos (2009); (Svboda, 2012). The results of numerous site-specific model studies (Houston, 1987; Hunt, 2008) have shown that smaller, i.e. shorter, stilling basin lengths are required for efficient energy dissipation. Cardoso, *et al.* (2007) and Meireles (2011) also studied in particular the performance of the type III basins below stepped chutes. Their results showed a 20% decrease in the pressure developed at the base of the structure after the point of occurrence of a hydraulic jump in comparison with that of a type I stilling basin without appurtenances. Results also showed that the length of the hydraulic jump for a type III basin was reduced by 80% in comparison with that of a type I basin under the same flow conditions.

2.7 Model Application

Stilling basin designs are based primarily on experience, analytical background, laboratory investigations, and model studies. Although model studies may be made for large structures, a detailed model study to establish guidelines for a small structure may not be economical. In such an instance, the designer must depend on experience and rely on other experimental and prototype performances of stilling basins under similar circumstances (Bhowmik, 1971).

Gulliver and Wetzel (1984) expressed the view that a hydraulic model study can be performed to verify that the proposed design functions properly. The model may also be a tool to improve structure performance or to reduce anticipated construction costs (Olatunji, 2005).

According to Jose Carlos (1998), with the recent development of computational resources, the numerical models for hydraulic jump predictions have motivated various researchers. Numerical models are valuable tools that can easily be used in the adjustment of various design details in the geometry modification, even if the model is not to be used in final determination of the best geometry, differently of the physical models. They are considered to be versatile for this very reason.

Generalized designs of hydraulic jump stilling basins have been developed, so future stilling basins can be designed without the need for additional model studies (FEMA, 2010). Rectangular stilling basins are preferred over trapezoidal basins. Model tests have shown that the hydraulic jump action in a trapezoidal basin is much less complete and less stable than in a rectangular basin. Where trapezoidal basins are contemplated, a model study is strongly recommended.

A numerical and experimental study of the turbulent flow in a hydraulic jump stilling basin was performed by Jose *et al* (1998) to determine, through comparison of a physical and a numerical (Computational Fluid dynamics) model, the efficiency of CFD modelling techniques in predicting flow characteristics within the stilling basin.

According to Jose (1998), the time and budget required for the construction of computational models, modification of structural geometries, limits the optimization of such projects to analysis by physical models. However with recent development of computational resources, the numerical models for hydraulic jump predictions have motivated various researches.

Valero et al (2014) employed a Reynolds-averaged Navier-Stokes (RANS) model coupled with a calibrated turbulent air entrainment model, a Volume of Fluid (VOF) method and the RNG k-epsilon ($k-\epsilon$) turbulence model to analyse the complex multiphase flows taking place within an United States Bureau of Reclamation type II stilling basin with varying chute blocks height.

Jose (1998) used the Flow-3D software which uses the finite-volume method to solve the Reynolds-averaged Navier-Stokes equation over the computational domain for numerical modelling. A major limitation of this computational resource is its inability to effectively treat turbulent flows numerically.

2.8 Hydraulic Jump Characteristics

2.8.1 The Froude Number

The Froude number is factor or parameter that signifies the effects of gravitational force on an open channel flow. It plays a very vital role in open channel flow analysis. The characteristics pertaining to a particular flow regime can be ascertained if the magnitude of its Froude number is known. Laboratory tests show that if the range of Froude number is limited to between 4.5 to 9, steady jump may be observed. However, sometimes higher values up to 12 are also used in design of stilling basins (Elmoustafa, 2010). Experimental observations conducted by (Peyras et al, 1991) show that stepped weirs are particularly convenient for specific flows less than 3 m³/s (FAO, 2001). Studies by Pillai (1966; 1969) showed good results in developing stilling basins for Froude numbers between 5 and 9. The study utilized a wedge-shaped baffle pier of vertex angle 120 degrees cut back at an angle of 90 degrees. Low inflow Froude number were also catered for in further studies by Pillai *et al* (1989) through increased vertex angle of the baffle pier to 150 degrees.

2.8.2 Initial Depth, Sequent Depth, and Tail water Depth

Generally, the industrial standard for the design of stilling basins, Reclamation's Engineering Monograph No. 25, titled Hydraulic Design of Stilling Basins and Energy Dissipators, published originally in September 1958 by A.J. Peterka, with the fourth and last revised printing occurring in January 1978 recommends tail water elevations equivalent to the conjugate flow depth or higher (Svoboda, 2012). A wider basin would provide a shallower basin, which would allow the ideal jump depth to more closely match the tail-water depths for all discharges. The importance of accurate tail-water for the full range of stilling basin operations cannot be overemphasized for hydraulic jump stilling basins (FEMA, 2010).

2.8.3 Length of a Hydraulic Jump Stilling Basin

For any hydraulic jump stilling basin, the optimal length varies for each outlet works discharge. So, the selected length should be designed for when the basin is operated at maximum design flow (FEMA, 2010). The length of the hydraulic jump is measured from the toe of the jump to the point where the water surface profile becomes horizontal. For a stilling basin with a horizontal floor, the toe of the jump is assumed to occur at the intersection of the chute and the horizontal stilling basin floor. The end of the hydraulic jump is more difficult to define and could be chosen as either the point downstream where the high velocity jet begins to lift from the floor, or a point immediately downstream from the roller where the water surface becomes horizontal, whichever occurs farthest downstream. The length of the basin is measured from the intersection of the chute and the horizontal stilling basin floor to a point downstream that will confine the entire length of the jump to the concrete floor and side walls of a conventional stilling basin. Increasing the length of the jump has been related to the Froude number of the incoming flow (Frizell, 1990a; Frizell, 1990b; Frizell, 1992).

2.8.4 The Spillway/Chute Shape and Dimension

Basically, the baffled apron or chute consists of a sloping apron with multiple rows of blocks or baffle piers equally spaced across the chute. The extent of acceleration and ultimate

velocity at the base of the chute depends on the discharge and height, width, and spacing of the baffle piers (Rhone, 1977). Bombac (2011) performed a physical model research of the spillway shape and the dimensions of the stilling basin elements of the Hydro power plants (HPP) Brezice. The research utilized different spillway shapes with steeper spillway face since by applying this measure a longer and more efficient stilling basin, with the same dimensions of the spillway, dissipating a larger part of the kinetic energy of the water flow can be achieved (.

2.9 Stilling Basin Appurtenances

Compared to a simple hydraulic jump basin in which the approach flow momentum is balanced by an adequate tail water level, stilling basins have in addition chute and baffles elements. Those elements are located on the basin bottom and involve steps, sills and blocks. The effect of dissipation can be increased with a diverging basin (Thandaveswara, 2012). Elmoustafa (2010) also states the importance of the installation of certain components such as baffle blocks, end sills and chute blocks along the basin floor to control and stabilize the jump (which in turn helps in the dissipation of excess energy and reduces the cost of the project). The use of these devices permitted the shortening of the basin and acts as a safety factor against sweep out of the jump.

2.9.1 Chute blocks

Chute blocks at the upstream end of a basin tend to corrugate the jet, lifting a portion of it from the floor to create a greater number of energy dissipating eddies, resulting in a shorter length of jump than would be possible without them. Chute blocks at the upstream end of a basin tend to corrugate the jet, lifting a portion of it from the floor to create a greater number of energy dissipating eddies, resulting 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

tail water elevations below conjugate depth (Peterka, 1984). Thus, they help stabilising the hydraulic jump. Despite the amount of studies carried out, only a reduced range of chute blocks heights have been analysed (Valero, 2014). Flow patterns within the stilling basin were analysed for chute block heights ranging from 1.0 to 10.7 H_w , and evaluating its role as a hydraulic jump stabiliser.

Therefore, in the case of a stilling basin, the intensity of turbulence can be expected to be a maximum in the vicinity of the roughness elements such as chute blocks (Bhowmik, 1971). Valero (2014) made it possible to identify two different mechanisms involving chute blocks effects upon flow: turbulent wall jet mechanism which takes place for lower values of chute block height, subsequently aiding in the stabilization of hydraulic jump, and flow deflector which is relatively undesirable.

2.9.2 Baffle Blocks/Piers

Baffle blocks are devices placed in a reach of a channel known as a stilling basin to stabilize the location of a hydraulic jump and to aid in the dissipation of the flow energy. They contribute towards the stability of the basin, reduce the wave activity, and prevent sweep out of the jump at an early stage of flow when the tail-water depth is not sufficient for the full development of the jump (Aziz et al, 1999). With an increase in the value of the Froude number, Fr_1 , some danger exists in possible cavitation damages to the baffle blocks or chute blocks (Bhowmik, 1971). Typically, for a type III stilling basin, they are used for Fr_1 greater than 4.5. Basically, design standards have been established based on observations of existing basins and laboratory model studies (ISI, 1968). Baffle elements are prone to cavitation damage and in case of stilling basins with high velocity leading to the possibilities of abrasion, baffles should be fitted with steel-armouring (Thandaveswara, 2012). Study of various shapes and positions of baffle piers was performed in a physical model. It was established that the most optimal baffle piers in the stilling basin of the HPP Brezice were

3.0m high and 1.5m wide. Two widths of baffle piers were examined for the final shape of spillway: it could be seen that the differences between the curves for the baffle piers with the widths of 1.5 and 2.0 were insignificant. Change of the spillway shape has significantly enhanced the efficiency of the spillway behaviour in the light of the hydraulic jump stability in the stilling basin (Bombac *et. al*, 2011).

2.9.3 End Sills

The end sill, either dentated or solid is usually located at the downstream end of the stilling basin. The purpose of the end sill is to reduce the length of the stilling basin by creating additional tail-water depth and to provide for scour control. For large basins that are designed for high incoming velocities, the end sill is usually dentated to perform the additional function of diffusing the residual portion of the high velocity jet that may reach the end of the basin (Bhowmik, 1971).

2.9.4 Other Stilling Basin Appurtenances

Hydraulic jump stilling basins contain other features, such as side walls or training walls, which contain the hydraulic jump. Splitter walls assist in keeping the flow uniform (Bejestan, 2009). Wing walls and cut-off walls at the downstream end of the basin provide erosion protection. Stoplog slots at the downstream end allow for unwatering of the basin. Structural under drains beneath the basin floor relieve uplift pressures. Flow deflectors help to prevent abrasive material from being drawn into the basin (FEMA, 2010).

CHAPTER THREE

METHODOLOGY

3.1 Design Concept

The methodology for the design of the USBR type III stilling basin and its required appurtenances in this study for adequate energy dissipation were adopted based primarily on the recommendations/guidelines of Monograph 25 provided by Bradley and Peterka (1978). This provided ranges of flow data for the optimum operation and performance of the various USBR stilling basin types, from amongst which the USBR type III stilling basin design was considered.

A 3-D diagrammatic representation for the geometry of a typical USBR type III stilling basin and its components (chute blocks, baffle piers, end sill and basin wall) is as shown below in Figure 3.1.

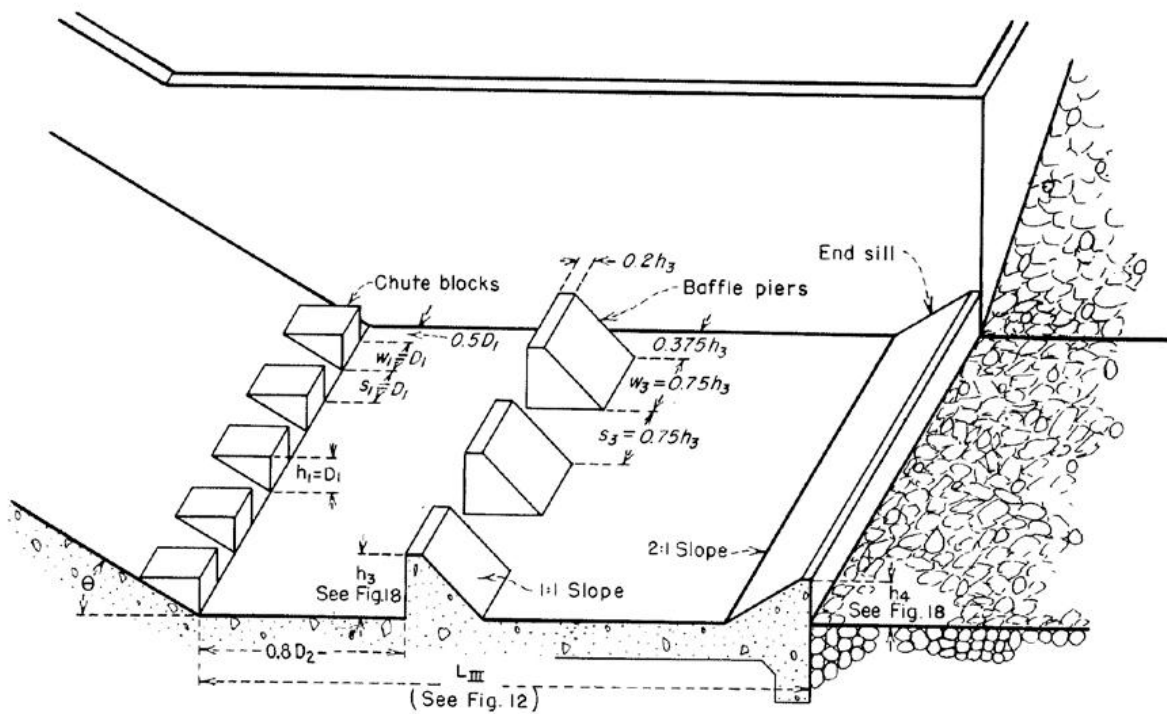


Figure 3.1. Layout of Reclamation Type III stilling basin (Peterka, 1978).

Optimal and suitable sizing approach for the components of the stilling basin of rectangular cross section, and its appurtenances were achieved by means of a selected computer program. The computer program comprised of a numerical computational system which was developed using its basic compiler tool for the computation, simulation and analysis of expected flow data (with discharge ranging from $10\text{m}^3/\text{s}$ to $110\text{m}^3/\text{s}$) entering the USBR type III stilling basin.

3.2 Design Tool Description

The computational tool that was selected and used for this study is Microsoft Excel. Microsoft Excel is an interactive system for matrix computations which can also be used interactively as a calculator and programmable command language (Fosdick et al, 1996). It is not only a programming language but a programming environment which can be made to perform repetitive tasks. It comprises of spreadsheet, command line, statistics tool box (<https://www.yorku.ca/jdc/Excel/Lesson1.htm>). It was chosen because of its simplicity in operation, quick processing speed, interactive graphical output and user-friendly outlook/interface both in data entry and presentation (<https://guides.libraries.uc.edu/M.ExcelForEngineers>, 2019).

Figure 3.1 above also provides the optimal and suitable sizing approach which was used by the Excel program in determining the dimensions of the stilling basin appurtenances. All equations required for the computation of flow magnitudes and sizing of the stilling basin were collected in form of algorithms. Excel command write up (basic compiler tool) was used in developing design codes generated from these algorithms (See Appendix D). The Excel spread sheet was used to key in input data, from which output data were displayed on spreadsheet after being automatically generated.

3.3 Data Collection

The data utilized in this study were selected within the ranges of flow conditions for the optimal performance of USBR type III stilling basin as adopted previously by Hubert *Chanson 2006*. The following parameters were used:

- (i) Overflow (spillway) discharge (Q),
- (ii) the unit discharge (q),
- (iii) the incoming flow velocity (v_1),
- (iv) the depth of approach tail water (y_1),
- (v) and the width of basin (W).

3.3.1 Stilling Basin Flow Conditions

The spillway flow conditions established the inflow conditions for the stilling basin. However, these parameters required closer analysis for energy dissipator design. The flow conditions are as stated below:

- (i) Application to small earth dams
- (ii) General flow conditions with Froude number, $Fr > 4.5$ and < 9 ; unit discharge, $q < 18.6 \text{ m}^3/\text{s}/\text{m}$; approach velocity, $v < 15 - 18.3 \text{ m/s}$; basin length = $2.82d_{\text{conj}}$ (*Chanson, 2006*).

The above parameters correlate with the conditions for the optimal performance of the USBR Type III hydraulic jump stilling basin, while ensuring safe operation within a wide range of these flow conditions. Other data which may influence the behaviour of hydraulic jump within the stilling basin and consequently the stilling basin design are:

- i. Spillway Discharge, Q between $10 \text{ m}^3/\text{s}$ and $100 \text{ m}^3/\text{s}$ and tested at a uniform interval of $10 \text{ m}^3/\text{s}$ was adopted for this study.

ii. The width across spillway crest, W was considered consistent with that of the maximum stilling basin width with minimum of 3m and an acceptable maximum value of 12m (limited to the scope of this design).

iii. Spillway cross sectional Area, A : The cross sectional area, A (m^2) of flow at the spillway outlet which can be calculated using equation 3.1.

$$A = Q/v \quad (3.1)$$

Where Q = discharge, m^3/s .

v = velocity of flow, m/s

3.3.2 Check for possible outliers

Considering that the type III basin functioned effectively between Froude numbers of 4.5 to 9, this design study was based on the relationship between approach water depth and Froude number while aiming at checking the velocity of approach tail water to prevent/control its erosive effects. Hence, the following deductions were made to facilitate the accuracy of data entry and subsequently, aid further computations on Excel while eliminating outliers:

$$Fr_1 = v_1/\sqrt{gy_1} \quad (3.2)$$

Where v_1 = velocity of flow entering the basin in m/s ,

Fr_1 = Froude number

g = gravitational constant in m^2/s

y_1 = depth of incoming flow in m

Q = discharge in m^3/s

Consider a condition of maximum flow velocity, where $v_1 = 18$ m/s

$Fr_1 = 4.5$; $g = 9.81$

$$Fr_1 = v_1/\sqrt{gy_1}$$

$$4.5 = 18/\sqrt{9.81 \times y_1}$$

$$y_1 = 1.63 \text{ m}$$

Again, when $v_1 = 18 \text{ m/s}$

$$Fr_1 = 9; g = 9.81$$

$$Fr_1 = v_1/\sqrt{gy_1}$$

$$9 = 18/\sqrt{9.81 \times y_1}$$

$$y_1 = 0.40 \text{ m}$$

Therefore,

At $v_1 = 18 \text{ m/s}$, $g = 9.81 \text{ m/s}^2$, $4.5 < Fr_1 < 9$ we have:

$$1.63 > y_1 > 0.40$$

$$\text{But } Q = vA \tag{3.3}$$

$$\text{and } A = y_1W \tag{3.4}$$

Taking $v_{\max} = 18 \text{ m/s}$

$$Q = vy_1W \tag{3.5}$$

$$\text{With } y_1 = 1.63 \text{ m, } Q = 18 \times 1.63 \times W$$

$$Q = 29.34W$$

$$q = Q/W = 29.34 \text{ m}^3/\text{s/m} > 18.6 \text{ m}^3/\text{s/m}$$

Again, with $y_1 = 0.40 \text{ m}$,

$$Q = vy_1W$$

$$Q = 18 \times 0.40 \times W$$

$$Q = 7.2W$$

$$q = Q/W = 7.2 \text{ m}^3/\text{s/m} < 18.6 \text{ m}^3/\text{s/m}$$

where q = unit discharge or discharge per unit width across spillway/basin crest in $\text{m}^3/\text{s/m}$.

So if we limit Q/W to $18.6 \text{ m}^3/\text{s/m}$, we have:

$$18.6 = 18 \times y_1$$

$$y_1 = 18.6/18$$

$$y_1 = 1.03$$

At $y_1 = 1.03$, $v_{\max} = 18$ m/s

$$\begin{aligned} Fr_1 &= v_1/\sqrt{(gy_1)} \\ &= 18/\sqrt{(9.81 \times 1.03)} \end{aligned}$$

$$Fr_1 = 5.66$$

Given the conditions for optimal performance of the USBR Type III hydraulic jump stilling basin:

$$\text{At } Fr_1 = 4.5; y_1 = 1.63; v = 18\text{m/s}; q = 29.34 \text{ m}^3/\text{s/m}$$

$$\text{At } Fr_1 = 5.66; y_1 = 1.03; v = 18\text{m/s}; q = 18.6 \text{ m}^3/\text{s/m}$$

$$\text{At } Fr_1 = 9.0; y_1 = 0.40; v = 18\text{m/s}; q = 7.2 \text{ m}^3/\text{s/m}$$

$$V = Q/(y_1 W) < 18 \text{ m/s}$$

$$\text{Therefore, } y_1 W > Q/18$$

This implied that the average discharge Q influences the average velocity, v and hence determined the average water depth generated; the greater the Froude number Fr_1 the lesser the water depth y_1 . It is recommended that where y_1 is less than 0.2 m, the height of chute blocks, h_1 equal to 0.2 m also be adopted.

To test for velocities at $y_1 = 0.2$ m, for Froude number between 4.5 and 9:

$$Fr = v/\sqrt{(gy_1)}$$

$$Fr^2 = v^2/(gy_1)$$

$$v^2 = Fr^2 \times gy_1 \text{ [where } g = 9.81 \text{ m}^2/\text{s}]$$

When $Fr = 4.5$

$$v^2 = 4.5^2 \times 9.81 \times 0.2$$

$$v = 6.31 \text{ m/s}$$

When $Fr = 9.0$

$$v^2 = 9.0^2 \times 9.81 \times 0.2$$

$$v = 12.6 \text{ m/s}$$

The above implied that flow velocities above 12.6 m/s would require y_1 to be greater than 0.2 m for the proper formation of a stable hydraulic jump.

3.4 USBR Type III Stilling Basin Design Procedure

The design involved the following major procedures:

1. Determining the stilling basin inflow conditions such as the incoming flow depth, y_1 , the incoming Froude number, Fr_1 and the tail water depth, y_2 . These parameters are as analysed in detail as below:

- (i) Calculation of the incoming flow depth, y_1

For any given design discharge, Q the expected flow depth were computed using equation 3.2 below:

$$y_1 = Q / (v_1 W_B) \quad (3.6)$$

Where W_B = width of stilling basin in m

v_1 = velocity of incoming flow in m/s

Q = Design discharge in m^3/s

- (ii) Calculation of the associated incoming Froude number, Fr_1

The Froude number is a flow parameter that has traditionally being used to design energy dissipators. The associated Froude number for any given flow with inflow conditions of known conjugate depth, y_1 and incoming velocity, v_1 were determined using equation 3.3:

$$Fr_1 = v_1 / [(gy_1)^{1/2}] \quad (3.7)$$

Where g = gravitational acceleration in m/s^2

- (iii) Calculation of the tail water depth (sequent depth), y_2

The sequent depth was determined using the following equation:

$$y_2 = y_1 / 2 ((1 + 8Fr_1^2)^{1/2} - 1) \quad (3.8)$$

Where y_2 = sequent depth in m

y_1 = incoming flow depth in m

Fr_1 = incoming Froude number

2. Determining the size of the stilling basin such as the length of the basin, the height of the basin entraining walls, the width of the basin. Below is a detail of how these parameters were determined:

- (i) Calculation of the height of the basin wall

The height of the basin wall was determined using the value attained from the height of jump. The height of jump was determined using equation 3.5:

$$H_j = (y_2 - y_1)^3 / 4y_1y_2 \quad (3.9)$$

Where y_2 = sequent depth in m

y_1 = incoming flow depth in m

- (ii) Calculation of the length of basin, L_B

The length of the basin was determined using the value attained from the length of hydraulic jump. The length of the hydraulic jump was calculated using equation 3.6:

$$L_B = 5y_2 \quad (3.10)$$

Where, y_2 = sequent depth in m

L_B = incoming flow depth in m

- (iii) Calculation of Basin width, W_B

The width of the stilling basin was chosen between the ranges of values 3 to 12m. The value chosen were kept constant in sizing the width of the appurtenant structures for every given set of design trial.

3. Determining the sizes of the appurtenant structures such as the baffle piers, chute blocks and end sills.

- (i) Calculation of the length between chute blocks and the baffle piers, L_w

The length between the base of the chute block and the baffle blocks of the basin was determined using equation 3.7.

$$L_w = 0.8y_2 \quad (3.11)$$

Where, y_2 = sequent depth in m

L_w = Length between chute blocks and baffle piers in m

(ii) Calculation of Chute number, N_c

The number of chute blocks, N_c was determined from equation 3.8 below:

$$N_c = W_B / 2y_1 \text{ rounded to a whole number.} \quad (3.12)$$

(iii) Calculation of Chute block spacing, S_1

The spaces between chute blocks, S_1 were determined from equation 3.9 below:

$$S_1 = y_1 \quad (3.13)$$

Where y_1 = incoming flow depth in m

(iv) Calculation of Chute block width, W_1

The width of the chute blocks, W_1 was determined using equation 3.10 below:

$$W_1 = y_1 \quad (3.14)$$

Where y_1 = incoming flow depth in m

$$\text{The Adjusted } W_1 = W_B / 2N_c \quad (3.15)$$

(v) Calculation of the height of the chute blocks, H_1

The height of the chute blocks was determined using equation 3.12

$$H_1 / y_1 = 1.0 \quad (3.16)$$

Where y_1 = incoming flow depth in m

(vi) Calculation of the height of the baffle piers, H_3

The height of the baffle piers was determined using equation 3.13

$$H_3 = y_1 (0.60 + Fr_1/6) \quad (3.17)$$

Where y_1 = incoming flow depth in m

Fr_1 = incoming Froude number

- (vii) Calculation of the width of the baffle piers, W_3

The width of the baffle piers were determined using equation 3.14

$$W_3 = 0.75H_3 \quad (3.18)$$

Where H_3 = height of the baffle piers in m

- (viii) Calculation of the base length (thickness) of the baffle piers, L_L

The base length of the baffle piers were determined using equation 3.15

$$L_L = 1.20 H_3 \quad (3.19)$$

Where y_1 = incoming flow depth in m

Fr_1 = incoming Froude number

- (ix) Calculation of the top length (thickness) of the baffle piers, L_U

The top length of the baffle piers were determined using equation 3.16

$$L_U = 0.20 H_3 \quad (3.20)$$

Where y_1 = incoming flow depth in m

Fr_1 = incoming Froude number

- (x) Calculation of the baffle piers spacing, S_3

The spacing of the baffle piers were determined using equation 3.17

$$S_3 = 0.75 H_3 \quad (3.21)$$

Where H_3 = height of the baffle piers in m

The Additional spacing on baffle $W_4=0.375H_3$ (3.22)

- (xi) Calculation of the height of end sill, H_4

The spacing of the baffle piers were determined using equation 3.19

$$H_4 = y_1 (1.00 + Fr_1/18) \quad (3.23)$$

Where y_1 = incoming flow depth in m

Fr_1 = incoming Froude number

- (xii) Calculation of the slope of end sill, H_4

The slope of the end sill was determined using equation 3.21

$$H_4 = 1V \quad (3.24)$$

$$2H: 1V \quad (3.25)$$

Where H and V represent the horizontal and vertical sides respectively.

3.5. Using EXCEL (Application and Data Testing)

Various models exist for the numerical modelling of flows. The commercial software Flow-3D, developed by Flow Science (Svoboda, 2012) being one of such. Having pre-defined the parameters, all the required equations above necessary for the computation of flow magnitudes, sizing of the stilling basin and its appurtenances were assembled in form of algorithms. Excel command write up was then used in writing the design codes (See Appendix D) in order to further develop them into a spreadsheet prior to testing. Computations were done by applying the required operator, and the sizes of appurtenances were selected and displayed as output. Testing was carried out by varying the input parameters which included the discharge, basin width and velocity. Accuracy of results was attempted by reducing the uniform interval difference for the various governing input parameters. This can be likened to the mesh system where finer meshes are obtained by reducing the spacing between one node and another.

3.5.1 Boundary conditions and Interval of input Data

The range of values of discharge tested were between 10 m³/s and 100 m³/s at an interval of 10 m³/s. The range of values for width of the spillway crest was between 3 m and 12 m at a uniform interval of 3m, while the velocity of flow was between 3m/s and 18m/s at a uniform interval of 3 m/s. Simulation for all the possible values obtainable within the ranges of the

above conditions was carried out. This was to ascertain the most suitable results for the optimal performance of the USBR type III stilling basin under the various flow conditions.

3.5.2 Simulation procedure

Simulation involved performing a series of iterations using the 3 given input parameters (discharge Q , basin width W , and flow velocity v). This was achieved by entering the range of discharge, the width and velocity of flow, after which one parameter (velocity) was made to vary increasingly at a uniform interval, while the other parameters were kept constant and vice versa. For example, a first set of trial test involved increasing the velocity uniformly, while keeping the width of the spillway crest constant. Once this was completed for all ranges of data from the minimum velocity (3 m/s) to the maximum velocity (18 m/s) at a uniform increasing interval of 3 m/s, a second trial test was carried out but this time around, while the velocity remained constant the width of the spillway crest was increased from minimum value of 3 m to the maximum design value of 12 m at a constant uniform interval of 3 m for all values of discharge between 10 m³/s and 100 m³/s and at uniform interval of 10 m³/s.

The results of the simulation are presented in chapter four.

The basic framework for the computation and analysis using Microsoft Excel is shown in Table 3.1 below.

Table 3.1: Frame work for data analysis

Subroutine	Data type	Data
Optimum Design Discharge and width of spillway crest	Input	Discharge over the spillway crest, Width across the spillway crest, Unit Design discharge
	Output	Nil
Depth of incoming flow parameters	Input	Unit design discharge, width of spillway crest, velocity of incoming flow
	Output	Depth of incoming flow, Froude number, sequent/tail water depth
Stilling basin design	Input	Sequent depth and conjugate depths
	Output	Length of stilling basin Height of basin walls Width of basin
Basin appurtenances	Input	Depth of incoming flow Tail water depth
	Output	Width of baffle and chute blocks Height of baffle and chute blocks Thickness of baffle blocks Slope of the end sill Height of the end sill Distance between chute blocks and baffle piers

Figure 3.2 shows the schematic diagram which backs up the basic framework of this design:

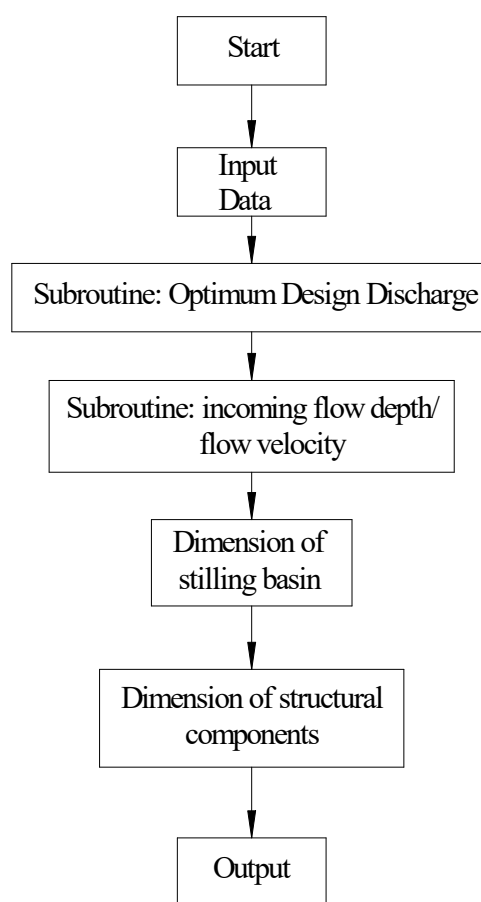


Figure 3.2. Design flow chart

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Presentation of Results

The results obtained from the simulation carried out in this study using expected inflow data for optimal performance of the United States Bureau of Reclamation type III stilling basin for discharges between 10 m³/s and 100 m³/s are presented in this section.

4.1.1 Effect of varying inflow velocity at constant spillway width of 3 m

The results obtained from varying the inflow velocity at 3 m/s to 18 m/s for a 3 m wide spillway crest are shown in Table 4.1. The values for Froude number, Fr, depth of incoming flow, y_1 , and sequent depth, y_2 are as presented.

Tables 4.1 showed that a 3 m wide basin was suitable for discharges up to 50 m³/s (i.e. $q < 18$ m³/s/m) beyond which the force of the released discharge (i.e. $Q > 50$ m³/s) upstream may become detrimental to the baffle piers due to excess pressure.

For all ranges of discharge, Q between 10 m³/s and 110 m³/s, the observed corresponding decrease in Froude number at various flow velocities were 3 m/s (Fr values between 0.908 to 0.273), 6 m/s (Fr values between 2.57 and 0.812), 9 m/s (Fr values between 4.72 and 1.49), 12 m/s (Fr values between 7.26 to 2.29), 15 m/s (Fr values between 10.15 and 3.21) and 18 m/s (Fr values 13.15 and 4.22) respectively.

Generally, acceptable Fr values were formed from flow velocities within the range of 15 m/s to 18 m/s. The Fr values for flow conditions developed from velocities, $v < 15$ m/s implied subcritical flow (thereby limiting proper hydraulic jump formation), which could result in a sweep out. At 12 m/s it was observed that a stable hydraulic jump could also be attained but only for Q values lesser than 30 m³/s ($Q < 30$ m³/s).

Table 4.1: Simulated discharges for 3 m width basin with velocity varying from (3 to 18) m/s

Discharge, Q (m ³ /s)	Basin width, W (m)	Unit discharge, q (m ³ /s/m)	Simulated Froude number (Fr), sequent depth (y ₁) and tail water (y ₂) values from discharges (Q) at various velocities (v)																	
			Velocity (m/s)																	
			3m/s			6m/s			9m/s			12m/s			15m/s			18m/s		
			y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂
10	3	3.33	1.11	0.91	1.63	0.56	2.57	1.53	0.37	4.72	1.44	0.28	7.27	1.37	0.22	10.16	1.31	0.19	13.35	1.26
20	3	6.67	2.22	0.64	2.62	1.11	1.82	2.49	0.74	3.34	2.36	0.56	5.14	2.26	0.44	7.18	2.17	0.37	9.44	2.10
30	3	10.00	3.33	0.52	3.44	1.67	1.48	3.31	1.11	2.73	3.16	0.83	4.20	3.02	0.67	5.87	2.91	0.56	7.71	2.82
40	3	13.33	4.44	0.45	4.17	2.22	1.29	4.05	1.48	2.36	3.87	1.11	3.63	3.72	0.89	5.08	3.59	0.74	6.67	3.48
50	3	16.67	5.56	0.41	4.83	2.78	1.15	4.73	1.85	2.11	4.54	1.39	3.25	4.36	1.11	4.54	4.21	0.93	5.97	4.09
60	3	20.00	6.67	0.37	5.45	3.33	1.05	5.36	2.22	1.93	5.16	1.67	2.97	4.97	1.33	4.15	4.80	1.11	5.45	4.66
70	3	23.33	7.78	0.34	6.02	3.89	0.97	5.96	2.59	1.78	5.75	1.94	2.75	5.55	1.56	3.84	5.37	1.30	5.05	5.21
80	3	26.67	8.89	0.32	6.57	4.44	0.91	6.54	2.96	1.67	6.32	2.22	2.57	6.10	1.78	3.60	5.91	1.48	4.72	5.74
90	3	30.00	10.00	0.30	7.09	5.00	0.86	7.09	3.33	1.57	6.86	2.50	2.42	6.63	2.00	3.39	6.43	1.67	4.45	6.25
100	3	33.33	11.11	0.29	7.59	5.56	0.81	7.62	3.70	1.49	7.39	2.78	2.30	7.15	2.22	3.21	6.93	1.85	4.22	6.74
110	3	36.67	12.22	0.27	8.07	6.11	0.77	8.13	4.07	1.42	7.90	3.06	2.19	7.65	2.44	3.06	7.42	2.04	4.03	7.22

The above stated results implied that the 3 m wide stilling basin performed optimally with varying velocities of 12 m/s, 15 m/s and 18 m/s and at discharges between (10 and 30) m³/s, (10 and 50) m³/s and between (20 and 50) m³/s respectively. This width of basin is best operable at 15 m/s with discharges between (10 and 50) m³/s (say an average of 30 m³/s).

4.1.2 Effect of varying inflow velocity at constant spillway width of 6 m

The inflow velocities of a 6 m wide spillway crest were varied at 3 m/s to 18 m/s with the resulting values for Froude number, Fr, depth of incoming flow, y_1 , and sequent depth, y_2 as presented in Table 4.2.

The results from Tables 4.2 showed that a 6m wide basin produced flows of suitable unit discharges, q for all discharges ranging from 10 m³/s to 100 m³/s.

At the various velocities for all ranges of discharge between 10 m³/s and 100 m³/s, the decreasing Froude ranges number were 3 m/s (1.29 and 0.406), 6 m/s (3.63 and 1.14), 9 m/s (6.67 to 2.01), 12 m/s (10.28 to 3.25), 15 m/s (14.36 to 5.43) and 18 m/s (18.88 to 5.97) respectively. This implied that a stable hydraulic jump may not be formed at 3 m/s and 6 m/s. It was observed that at 9 m/s discharges lesser than or equal to 20 m³/s resulted in flows with Froude numbers adequate for the formation of stable hydraulic jump. At 12 m/s the acceptable Fr values were obtained from discharges between 10 m³/s to 50 m³/s.

At 15 m/s discharges between 20 m³/s to 100 m³/s satisfied the Froude number range of between 4.5 to 9 for the formation of a stable hydraulic jump, while at 18m/s discharges between 40 m³/s to 100 m³/s fell between Froude numbers of 4.5 to 9.

These implied that flows from discharges emanating from a spillway crest with a width of 6 m had adequate discharges at velocities of 9 m/s, 12 m/s, 15 m/s and 18 m/s between Q values of (6 to 24) m³/s, (12 to 68) m³/s, (25 to 100) m³/s and (43 to 110) m³/s respectively. The basin of 6m width is also best operable at 15 m/s with discharges between (25 to 100) m³/s (say an average of 63 m³/s).

Table 4.2: Simulated discharges for 6 m width basin with velocity varying from (3 to 18) m/s

Discharge, Q (m ³ /s)	Basin width, W (m)	Unit discharge, q (m ³ /s/m)	Simulated Froude number (Fr), sequent depth (y ₁) and tail water (y ₂) values from discharges (Q) at various velocities (v)																	
			Velocity (m/s)																	
			3m/s			6m/s			9m/s			12m/s			15m/s			18m/s		
			y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂
10	6	1.67	0.56	1.29	1.01	0.28	3.63	0.93	0.19	6.68	0.87	0.14	10.28	0.82	0.11	14.37	0.79	0.09	18.89	0.76
20	6	3.33	1.11	0.91	1.63	0.56	2.57	1.53	0.37	4.72	1.44	0.28	7.27	1.37	0.22	10.16	1.31	0.19	13.35	1.26
30	6	5.00	1.67	0.74	2.16	0.83	2.10	2.03	0.56	3.86	1.92	0.42	5.93	1.83	0.33	8.30	1.76	0.28	10.90	1.70
40	6	6.67	2.22	0.64	2.62	1.11	1.82	2.49	0.74	3.34	2.36	0.56	5.14	2.26	0.44	7.18	2.17	0.37	9.44	2.10
50	6	8.33	2.78	0.57	3.05	1.39	1.63	2.91	0.93	2.99	2.77	0.69	4.60	2.65	0.56	6.43	2.55	0.46	8.45	2.47
60	6	10.00	3.33	0.52	3.44	1.67	1.48	3.31	1.11	2.73	3.16	0.83	4.20	3.02	0.67	5.87	2.91	0.56	7.71	2.82
70	6	11.67	3.89	0.49	3.81	1.94	1.37	3.69	1.30	2.52	3.52	0.97	3.89	3.38	0.78	5.43	3.26	0.65	7.14	3.15
80	6	13.33	4.44	0.45	4.17	2.22	1.29	4.05	1.48	2.36	3.87	1.11	3.63	3.72	0.89	5.08	3.59	0.74	6.67	3.48
90	6	15.00	5.00	0.43	4.51	2.50	1.21	4.39	1.67	2.23	4.21	1.25	3.43	4.04	1.00	4.79	3.91	0.83	6.30	3.79
100	6	16.67	5.56	0.41	4.83	2.78	1.15	4.73	1.85	2.11	4.54	1.39	3.25	4.36	1.11	4.54	4.21	0.93	5.97	4.09
110	6	18.33	6.11	0.39	5.14	3.06	1.10	5.05	2.04	2.01	4.85	1.53	3.10	4.67	1.22	4.33	4.51	1.02	5.69	4.38

4.1.3 Effect of varying inflow velocity at constant spillway width of 9 m

The results obtained from varying the inflow velocity at 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s for a 9 m wide spillway crest are shown in Table 4.3.

Results showed that a 9 m width basin developed flow discharges, $q < 18 \text{ m}^3/\text{s/m}$ which were suitable for all flows of discharge ranging from $10 \text{ m}^3/\text{s}$ to $110 \text{ m}^3/\text{s}$.

Between $10 \text{ m}^3/\text{s}$ and $110 \text{ m}^3/\text{s}$ the observed corresponding decrease in Froude number at various flow velocities were: 3 m/s (Fr values between 1.57 to 0.49), 6 m/s (Fr values between 4.45 and 1.40), 9 m/s (Fr values between 8.17 and 2.58), 12 m/s (Fr values between 7.26 to 2.29), 15 m/s (Fr values between 12.59 and 3.98) and 18 m/s (Fr values 14.36 and 5.43) respectively. From the results, stable hydraulic jump may not be formed at 3 m/s. At 6 m/s the decreasing Froude number were also lower than the expected range of values (4.5 to 9) for the proper formation of a stable hydraulic jump. At 9 m/s it was observed that only discharges between $10 \text{ m}^3/\text{s}$ and $40 \text{ m}^3/\text{s}$ resulted to flows with Froude numbers adequate for the formation of stable hydraulic jump. Also, at 12 m/s flow discharges between $10 \text{ m}^3/\text{s}$ to $60 \text{ m}^3/\text{s}$ were observed to satisfy the Froude number condition (between 4.5 to 9) for the formation of a hydraulic jump and for optimal performance of the USBR Type III stilling basin. At 15 m/s only flows of discharges between $10 \text{ m}^3/\text{s}$ to $80 \text{ m}^3/\text{s}$ satisfied the Froude number conditions (between 4.5 to 9) for the formation of stable hydraulic jump. At 18 m/s discharges between $40 \text{ m}^3/\text{s}$ to $100 \text{ m}^3/\text{s}$ had Froude number between 4.5 and 9 thereby satisfying the conditions for the formation of stable hydraulic jump.

These implied that flows from discharges emanating from a spillway crest with a width of 9 m had adequate discharges at velocities of 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s between $(0.3 \text{ to } 1.2) \text{ m}^3/\text{s}$, $(2 \text{ to } 10) \text{ m}^3/\text{s}$, $(8 \text{ to } 33) \text{ m}^3/\text{s}$, $(18 \text{ to } 83) \text{ m}^3/\text{s}$, $(35 \text{ to } 110) \text{ m}^3/\text{s}$ and $(62 \text{ to } 110) \text{ m}^3/\text{s}$ respectively. The basin of 9 m width is also best operable at 12 m/s with discharges between $(17 \text{ to } 78) \text{ m}^3/\text{s}$ (say an average of $48 \text{ m}^3/\text{s}$).

Table 4.3: Simulated discharges for 9 m width basin with velocity varying from (3 to 18) m/s

Discharge, Q (m ³ /s)	Basin width, W (m)	Unit discharge, q (m ³ /s/m)	Simulated Froude number (Fr), sequent depth (y ₁) and tail water (y ₂) values from discharges (Q) at various velocities (v)																	
			Velocity (m/s)																	
			3m/s			6m/s			9m/s			12m/s			15m/s			18m/s		
			y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂
10	9	1.11	0.37	1.57	0.76	0.19	4.45	0.69	0.12	8.18	0.65	0.09	12.59	0.61	0.07	17.60	0.59	0.06	23.13	0.56
20	9	2.22	0.74	1.11	1.24	0.37	3.15	1.14	0.25	5.78	1.07	0.19	8.90	1.02	0.15	12.44	0.97	0.12	16.36	0.94
30	9	3.33	1.11	0.91	1.63	0.56	2.57	1.53	0.37	4.72	1.44	0.28	7.27	1.37	0.22	10.16	1.31	0.19	13.35	1.26
40	9	4.44	1.48	0.79	1.99	0.74	2.23	1.87	0.49	4.09	1.77	0.37	6.30	1.68	0.30	8.80	1.62	0.25	11.57	1.56
50	9	5.55	1.85	0.70	2.32	0.93	1.99	2.19	0.62	3.66	2.07	0.46	5.63	1.98	0.37	7.87	1.90	0.31	10.34	1.84
60	9	6.67	2.22	0.64	2.62	1.11	1.82	2.49	0.74	3.34	2.36	0.56	5.14	2.26	0.44	7.18	2.17	0.37	9.44	2.10
70	9	7.78	2.59	0.59	2.91	1.30	1.68	2.78	0.86	3.09	2.64	0.65	4.76	2.52	0.52	6.65	2.43	0.43	8.74	2.35
80	9	8.89	2.96	0.56	3.18	1.48	1.57	3.05	0.99	2.89	2.90	0.74	4.45	2.78	0.59	6.22	2.67	0.49	8.18	2.59
90	9	10.00	3.33	0.52	3.44	1.67	1.48	3.31	1.11	2.73	3.16	0.83	4.20	3.02	0.67	5.87	2.91	0.56	7.71	2.82
100	9	11.11	3.70	0.50	3.69	1.85	1.41	3.56	1.23	2.59	3.40	0.93	3.98	3.26	0.74	5.56	3.14	0.62	7.31	3.04
110	9	12.22	4.07	0.47	3.93	2.04	1.34	3.81	1.36	2.47	3.64	1.02	3.80	3.49	0.81	5.31	3.37	0.68	6.97	3.26

4.1.4 Effect of varying inflow velocity at constant spillway width of 12 m

The results obtained from varying the inflow velocity at 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s for a 12 m wide spillway crest are shown in Table 4.3.

Table 4.4 showed that a 12 m width basin resulted in unit flow discharges, $q < 18 \text{ m}^3/\text{s/m}$ which were suitable for all flow discharges ranging from $10 \text{ m}^3/\text{s}$ to $100 \text{ m}^3/\text{s}$. At a velocity of 3 m/s the decreasing Froude number fell between 1.81 and 0.57 for all ranges of discharge between $10 \text{ m}^3/\text{s}$ and $100 \text{ m}^3/\text{s}$ respectively. This implied that an ideal hydraulic jump may not be formed. At an increased velocity of 6m/s the decreasing Froude number fell between 5.14 and 1.62 for all ranges of discharge between $10 \text{ m}^3/\text{s}$ and $100 \text{ m}^3/\text{s}$ respectively. Only discharge of $10\text{m}^3/\text{s}$ resulted in Froude number adequate for the formation of a stable hydraulic jump, whereas discharges above $10\text{m}^3/\text{s}$ resulted in flows with Froude number lesser than 4.5. At 9 m/s, the decreasing Froude number ranged from 9.44 to 2.98 for all ranges of discharge between $10 \text{ m}^3/\text{s}$ and $110 \text{ m}^3/\text{s}$ respectively. It was observed that only discharges between $10\text{m}^3/\text{s}$ and $50 \text{ m}^3/\text{s}$ resulted in flows with acceptable Froude numbers (i.e. between 4.5 to 9) adequate for the formation of a hydraulic jump, whereas Q values above $50 \text{ m}^3/\text{s}$ resulted in flows of Fr values lesser than 4.5.

At 12 m/s, the decreasing Froude number fell between 14.53 to 4.59 for all ranges of discharge between $10\text{m}^3/\text{s}$ and $110\text{m}^3/\text{s}$ respectively. Flow discharges between $20\text{m}^3/\text{s}$ to $100\text{m}^3/\text{s}$ were observed to satisfy the Froude number condition for the formation of a hydraulic jump and for optimal performance of the USBR Type III stilling basin. At a velocity of 15m/s, the decreasing Froude number fell between 20.31 to 6.42 for all discharges between $10 \text{ m}^3/\text{s}$ and $100 \text{ m}^3/\text{s}$ respectively. Only flows of discharges between $50 \text{ m}^3/\text{s}$ to $100\text{m}^3/\text{s}$ satisfied the Froude number conditions for the formation of hydraulic jump in this stilling basin, whereas below $50 \text{ m}^3/\text{s}$ discharge the Froude numbers were greater than 9.

Table 4.4: Simulated discharges for 12 m width basin with velocity varying from (3 to 18) m/s

Discharge, Q (m ³ /s)	Basin width, W (m)	Unit discharge, q (m ³ /s/m)	Simulated Froude number (Fr), sequent depth (y ₁) and tail water (y ₂) values from discharges (Q) at various velocities (v)																	
			Velocity (m/s)																	
			3m/s			6m/s			9m/s			12m/s			15m/s			18m/s		
			y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂	y ₁	Fr ₁	y ₂
10	12	0.83	0.28	1.82	0.62	0.14	5.14	0.5	0.09	9.44	0.52	0.07	14.54	0.50	0.06	20.32	0.47	0.05	26.71	0.46
20	12	1.67	0.56	1.29	1.01	0.28	3.63	0.93	0.19	6.68	0.87	0.14	10.28	0.82	0.11	14.37	0.79	0.09	18.89	0.76
30	12	2.50	0.83	1.05	1.34	0.42	2.97	1.24	0.28	5.45	1.17	0.21	8.39	1.11	0.17	11.73	1.06	0.14	15.42	1.02
40	12	3.33	1.11	0.91	1.63	0.56	2.57	1.53	0.37	4.72	1.44	0.28	7.27	1.37	0.22	10.16	1.31	0.19	13.35	1.26
50	12	4.17	1.39	0.81	1.90	0.69	2.30	1.79	0.46	4.22	1.69	0.35	6.50	1.61	0.28	9.09	1.54	0.23	11.94	1.49
60	12	5.00	1.67	0.74	2.16	0.83	2.10	2.03	0.56	3.86	1.92	0.42	5.94	1.83	0.33	8.30	1.76	0.28	10.90	1.70
70	12	5.83	1.94	0.69	2.39	0.97	1.94	2.27	0.65	3.57	2.15	0.49	5.50	2.05	0.39	7.68	1.97	0.32	10.10	1.90
80	12	6.67	2.22	0.64	2.62	1.11	1.82	2.49	0.74	3.34	2.36	0.56	5.14	2.26	0.44	7.18	2.17	0.37	9.44	2.10
90	12	7.50	2.50	0.61	2.84	1.25	1.71	2.71	0.83	3.15	2.57	0.63	4.84	2.46	0.50	6.77	2.36	0.42	8.90	2.29
100	12	8.33	2.78	0.57	3.05	1.39	1.63	2.91	0.93	2.99	2.77	0.69	4.60	2.65	0.56	6.434	2.55	0.46	8.45	2.47
110	12	9.17	3.06	0.55	3.25	1.53	1.55	3.12	1.02	2.85	2.97	0.76	4.38	2.84	0.61	6.13	2.73	0.51	8.05	2.65

At a velocity of 18 m/s, the decreasing Froude number ranged from 26.70 to 8.44 for all discharges between 10 m³/s and 110 m³/s respectively. Only discharges above 80 m³/s to 100 m³/s satisfied the Froude number conditions for the formation of hydraulic jump in the stilling basin.

These implied that flows emanating from a spillway crest with a width of 12 m had adequate discharges at velocities of 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s between (1 to 10) m³/s, (10 to 50) m³/s, (20 to 100) m³/s, (50 to 100) m³/s and (80 to 110) m³/s respectively. However, at 3m/s, the required range of Froude number couldn't be obtained. The 9 m wide basin, the basin of 12 m width is best operable at 12 m/s with discharges between 25 m³/s to 100 m³/s, and estimated average of 62 m³/s.

4.2 Optimum Release discharge for all Widths of Basin with Fr values between 4.5 and 9 at the various velocities

The suitable values of discharges, for the various basin widths, flow velocities and their corresponding Fr values which enable the formation of a stable hydraulic jump were calculated as shown in Table 4.5 below:

Table 4.5: Optimal discharge and optimal velocity at various basin widths

Velocity, v (m/s)	Basin Width							
	3m		6m		9m		12m	
	Discharge, Q (m ³ /s)		Discharge, Q (m ³ /s)		Discharge, Q (m ³ /s)		Discharge, Q (m ³ /s)	
	Q (Fr _{9.0})	Q (Fr _{4.5})	Q (Fr _{9.0})	Q (Fr _{4.5})	Q (Fr _{9.0})	Q (Fr _{4.5})	Q (Fr _{9.0})	Q (Fr _{4.5})
0	0	0	0	0	0	0	0	0
3	0.1	0.4	0.2	0.82	0.3	1.2	0.4	1.7
6	0.8	3.2	1.6	6.5	2.5	9.5	3.2	13
9	2.7	10.8	5.4	21.6	8.2	33	11	44
12	6.5	25.5	13	53	19	78	26.5	103
15	12.5	50	25	100	37.5	159	50	203
18	22	85	43	172	65	260	89	350

Results from tables 4.4 shows that the flow regimes for the various basin widths of 3 m to 12 m. The 3 m, 6 m, 9 m and 12 m width basins permitted a flow of maximum velocity 18 m/s at a maximum discharge of 85 m³/s, 172 m³/s, 260 m³/s and 350 m³/s respectively. Since this study simulated flows for all ranges of discharge between 10 m³/s and 110 m³/s, it was observed that the 6 m and 12 m wide basins developed maximum discharges of 100 m³/s and 103 m³/s at 15 m/s and 12 m/s respectively, at Fr number of 4.5. Fig. 4.1 to 4.4 show the flow regimes of possible release discharges for the various widths of basin and at various velocities.

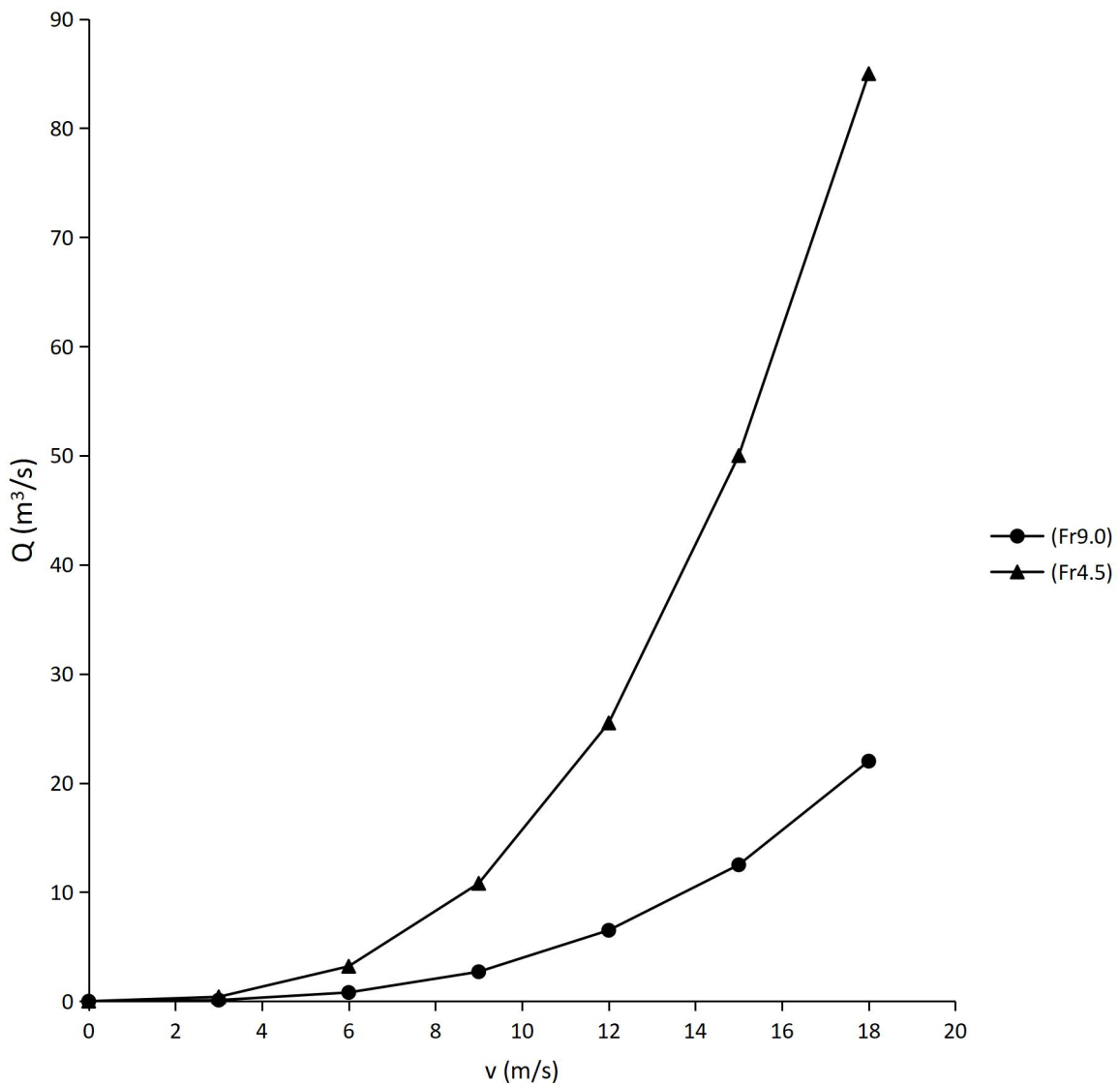


Figure 4.1: Flow regime developed from 3 m Basin at Optimal performance

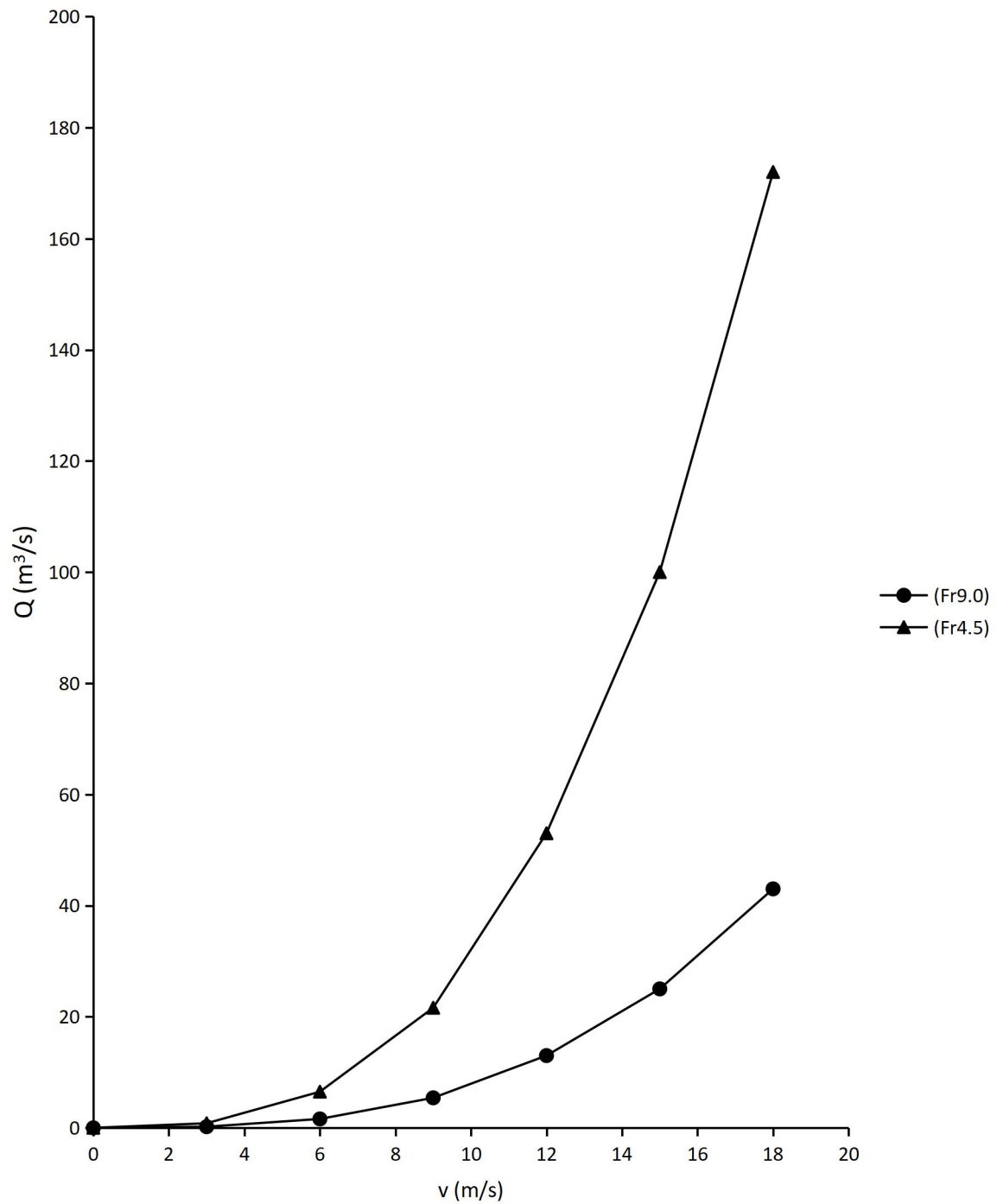


Figure 4.2: Flow regime developed from 6 m Basin at Optimal performance

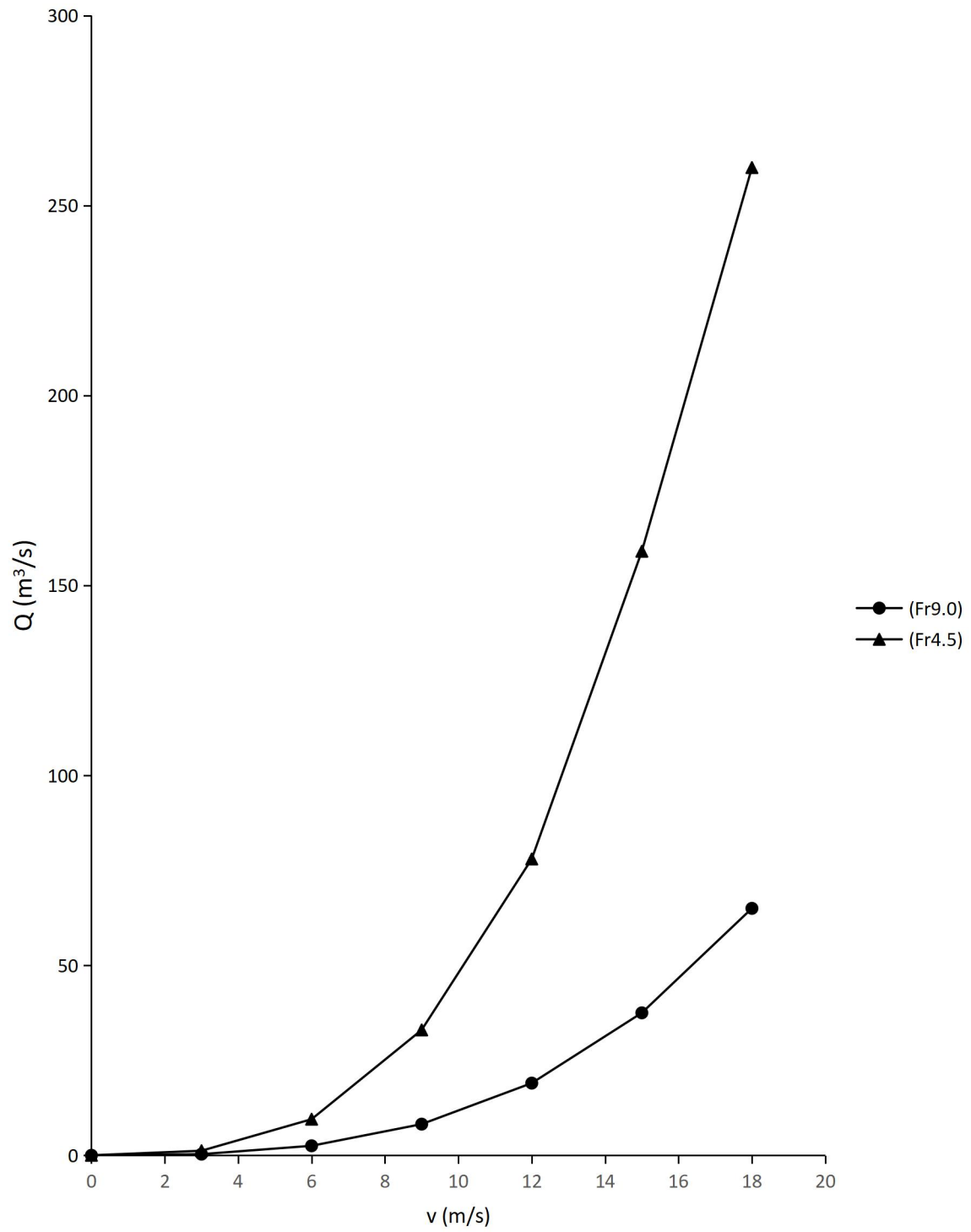


Figure 4.3: Flow regime developed from 9 m Basin at Optimal performance

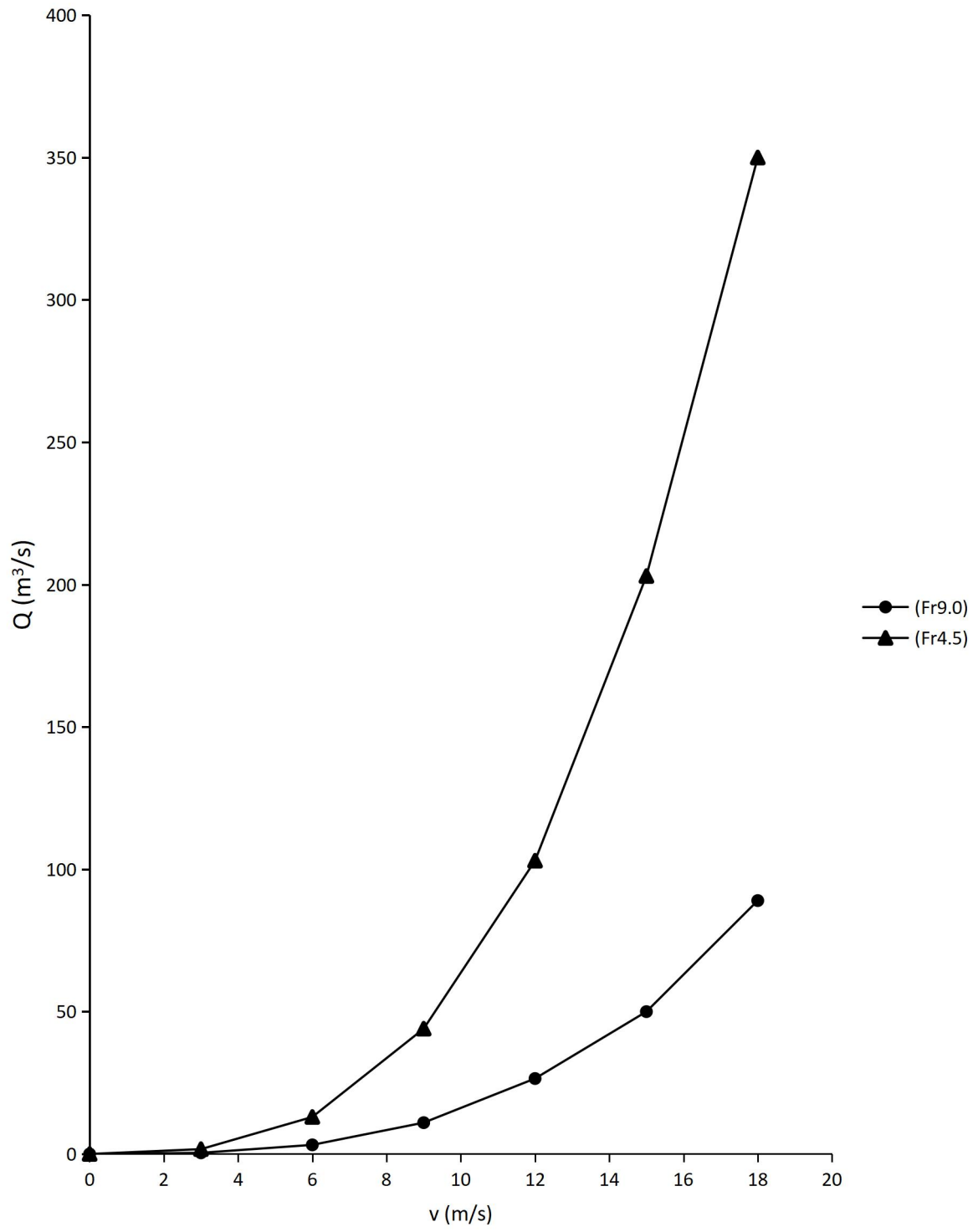
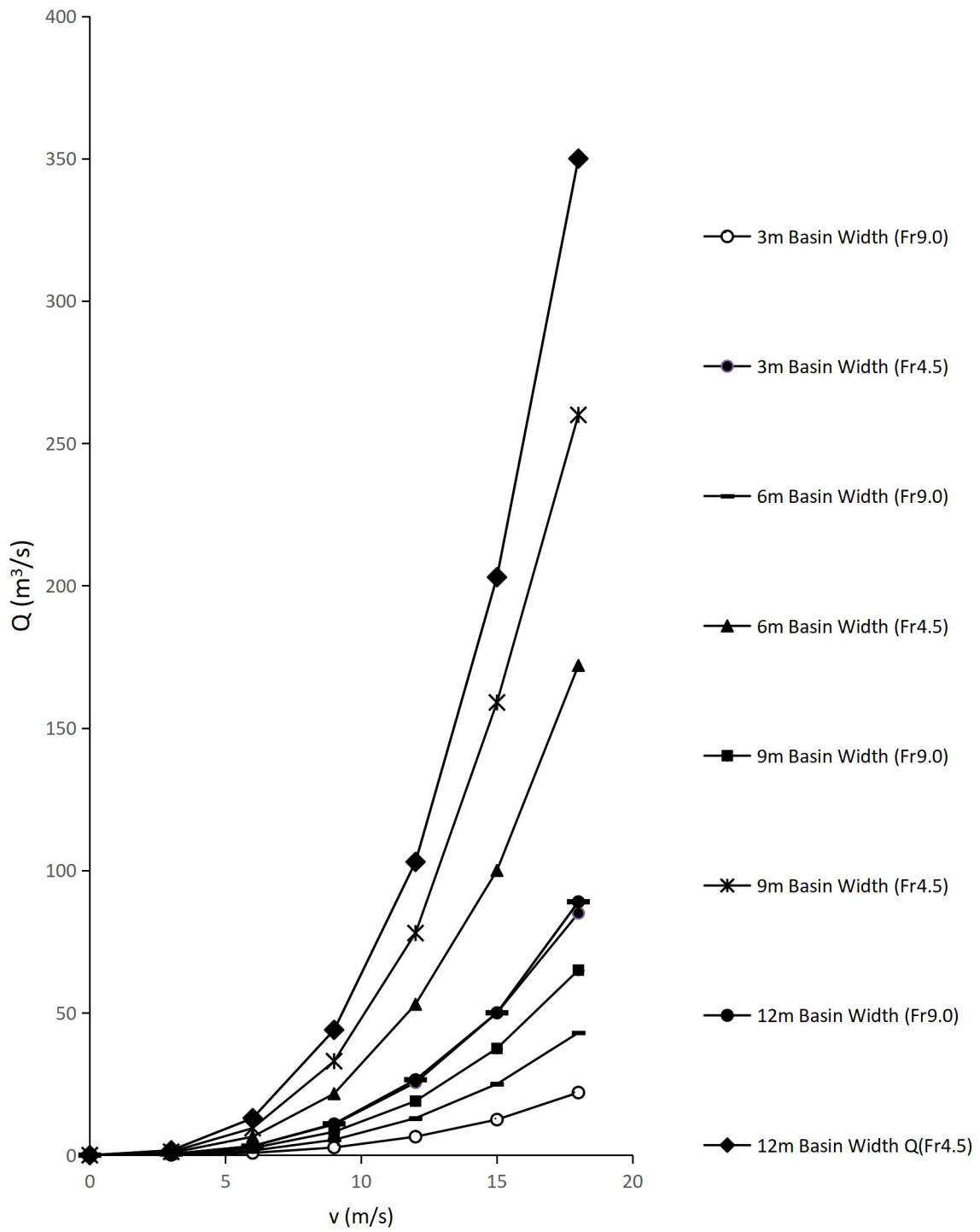


Figure 4.4: Flow regime developed from 12 m Basin at Optimal performance

The flow regimes of discharge developed for both 3m and 12m width basins at Fr values of 4.5 and 9.0 respectively were approximately the same for all ranges of velocity. Fig. 4.5 shows the optimal discharge for all ranges of basin width, velocity and Froude numbers



simulated.

Figure 4.5: Comparative flow regime developed by all Basin widths at optimal performance

Figure 4.5 shows a comparison between the flow regimes for acceptable Froude number of the various basin width. At a peak velocity of 18m/s, the 12 m basin width performed optimally at discharges up to 350 m³/s with Froude number of 4.5, while that of the 3 m basin width was at discharge as low as 20 m³/s with Froude number of 9.0. This peak value exceeds 100 m³/s which is considered as the most critical operating case for the HPP Brezice of width 15m in a study carried out by Bombac, 2012.

4.3 Effects of Increased Velocity on the Basin Size

The results obtained in this section shows the influence various flow velocities on the size of the external stilling basin structure which included its entire length, height of the entraining wall and the distance between the base of chute blocks and baffle piers. The results for varying the velocity at a constant width and resulting sizes of the basin are shown in Tables A1 to A24 (Appendix A).

4.3.1 Effects of Increased Velocity on the Entire Basin Length

The resulting effects for a 3m wide basin are as shown in Fig. 4.6 (See Appendix A, Tables A1 to A6). For a 3m width stilling basin, as discharge increased from 10 m³/s to 100 m³/s at velocities of 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s the length of the basin fell between 4.44 m to 20.64 m, 4.14 m to 21.71 m, 3.90 m to 20.09 m, 3.71 m to 19.44 m, 3.56 m to 18.85 m and 3.43 m to 18.33 m respectively.

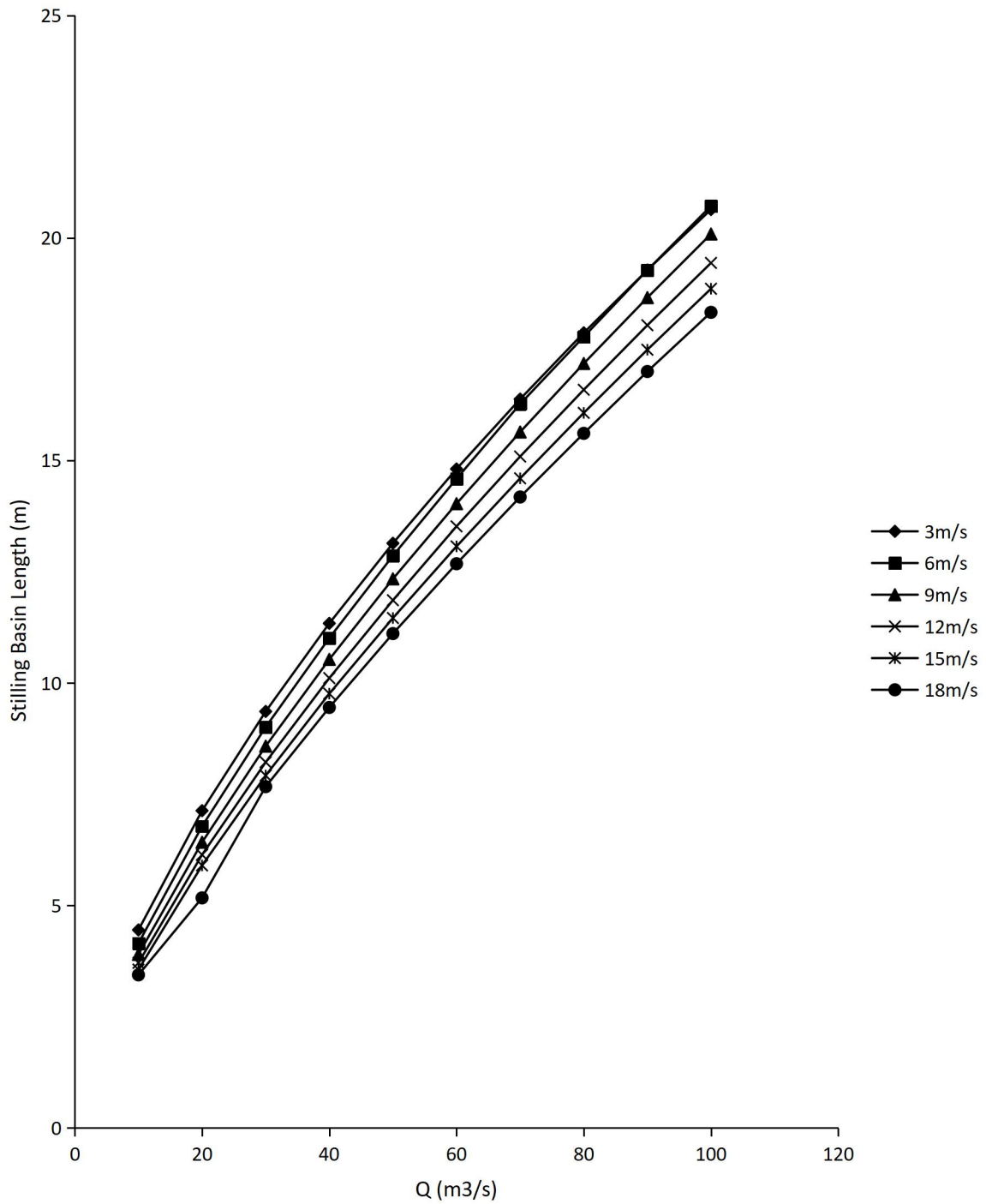


Figure 4.6: The effects of velocity on the stilling basin length with 3 m width

For a 6 m wide basin and for the range of discharge from 10 to 100 m³/s, as velocities increased at 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s, the length of the basin fell between 2.75 m to 13.13 m, 2.52 m to 12.85 m, 2.36 m to 12.33 m, 2.24 m to 11.86 m, 2.14

m to 11.46 m and 2.06 m to 11.11 m respectively (See Tables A7 to A12). Fig. 4.7 shows the effect of various velocities obtainable.

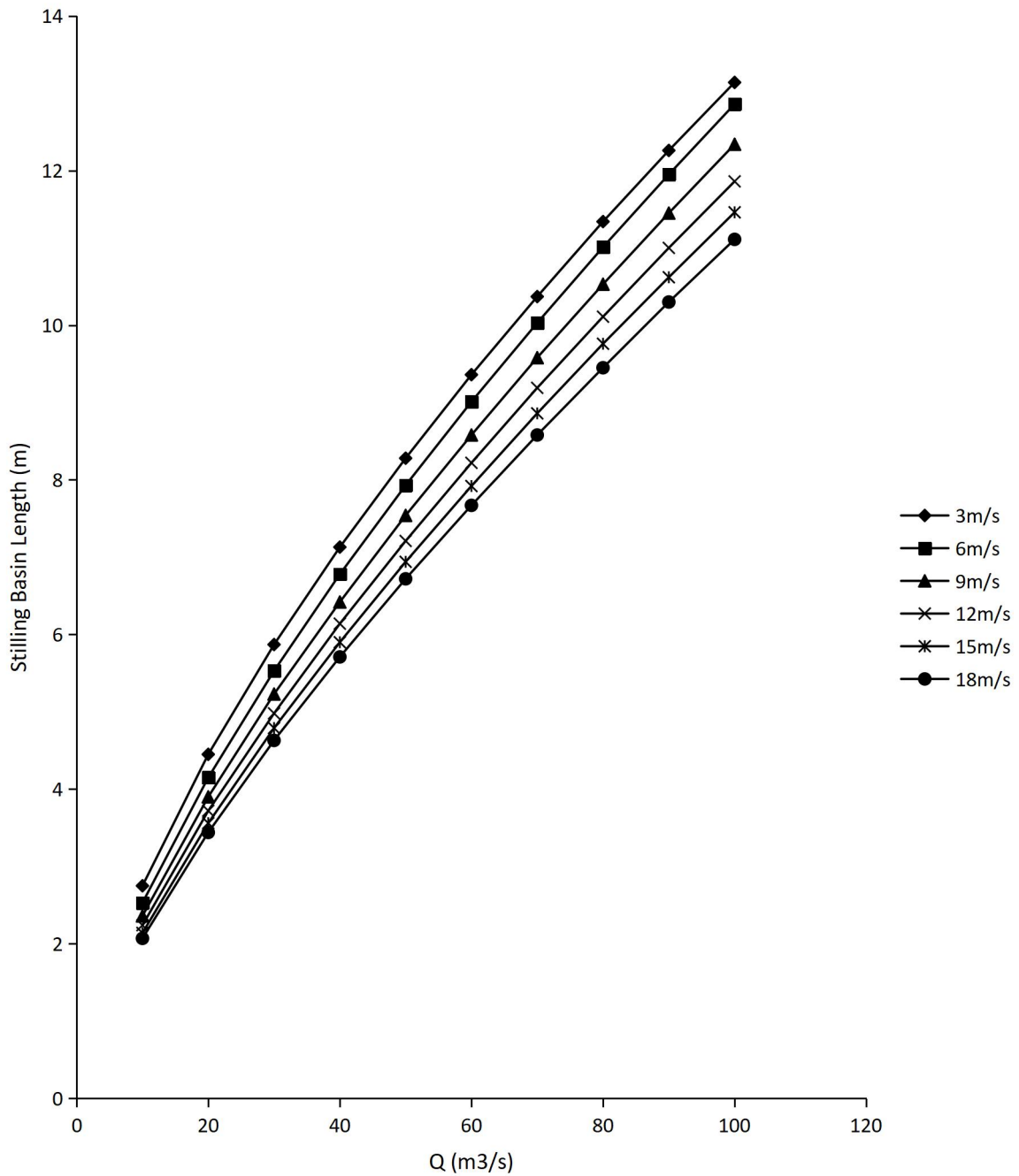


Figure 4.7: The effects of velocity on stilling basin length with 6 m width

At a basin width of 9 m, at discharge ranging from 10 to 100 m³/s and for increasing velocities of 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s the length of basin fell between

2.07 m to 10.04 m, 1.88 m to 9.69 m, 1.76 m to 9.25 m, 1.66 m to 8.87 m, 1.59 m to 8.55 m and 1.53 m to 8.28 m respectively (See Figure 4.8, Tables A13 to A18).

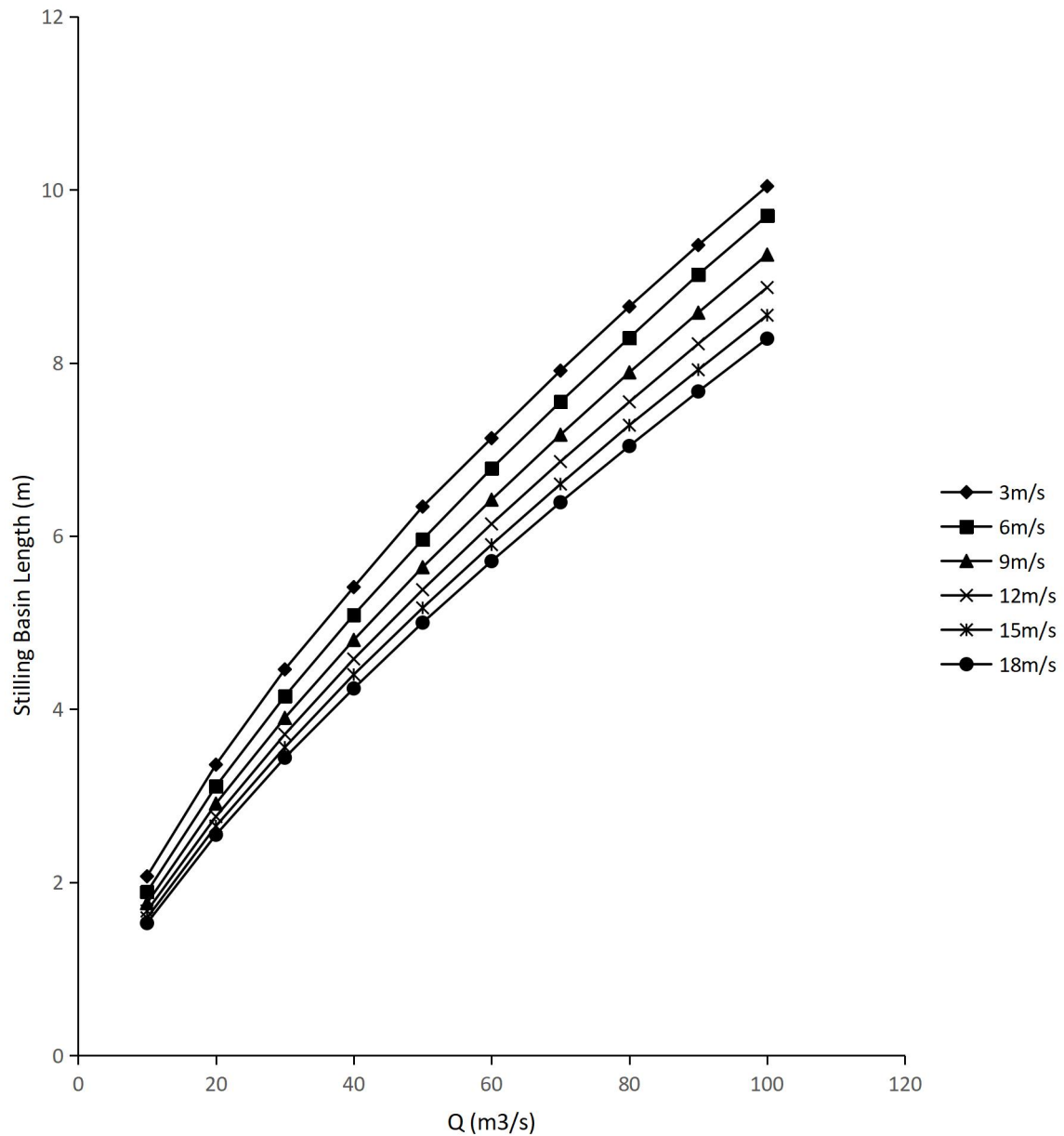


Figure 4.8: The effects of velocity on stilling basin length with 9 m width

At 12 m, with discharges ranging from 10 m³/s to 110 m³/s and velocity increasing at 3m/s, 6m/s, 9m/s, 12m/s, 15m/s and 18m/s (Tables A19 to A24), the length of the stilling basin fell between 1.69 m to 8.28 m, 1.53 m to 7.92 m, 1.42 m to 7.53 m, 1.34 m to 7.21 m, 1.28 m to 6.94 m and 1.24 m to 6.72 m.

The resulting effects of the flow parameters on the length of a 12 m basin is shown in Figure 4.9 below.

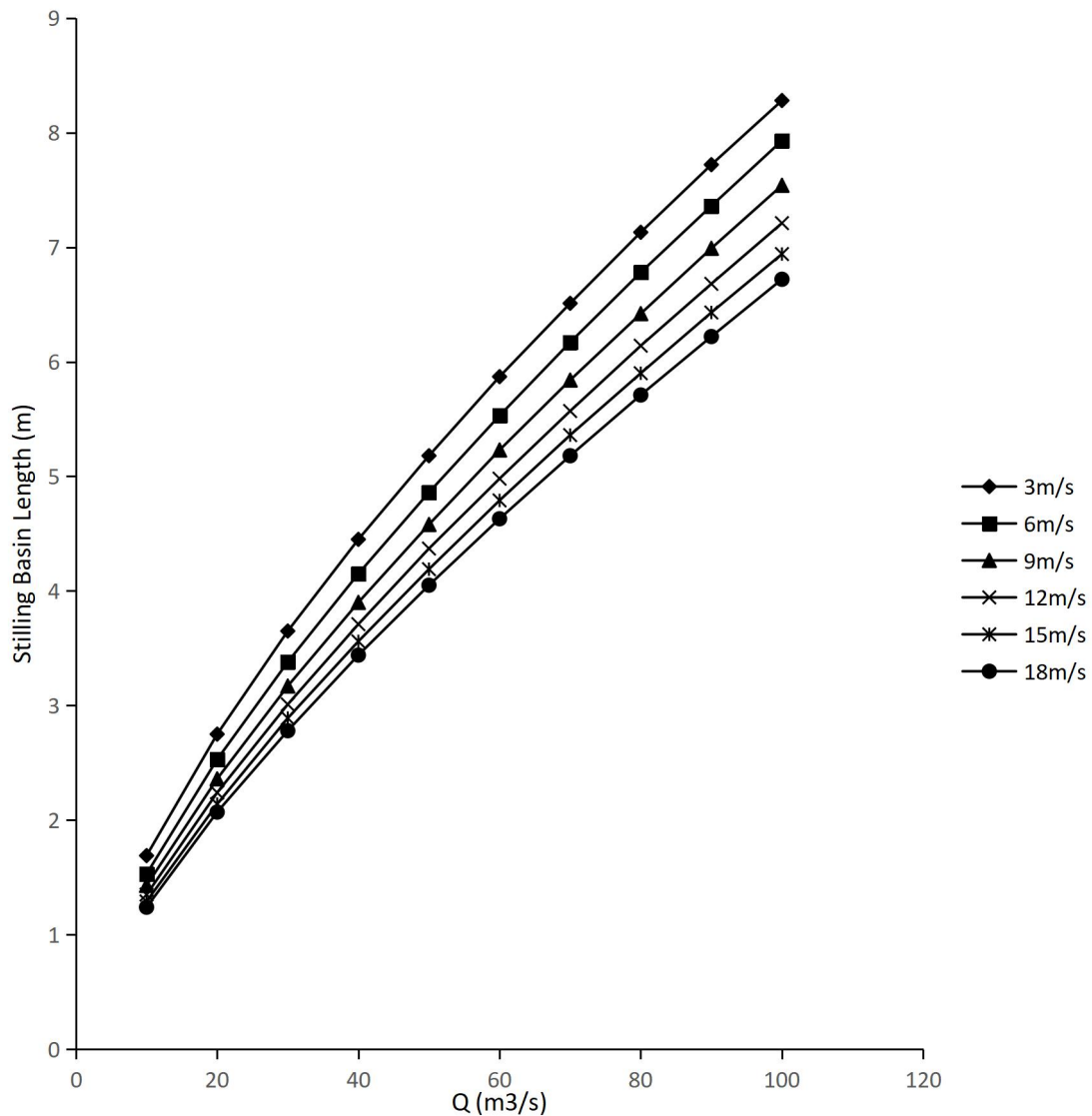


Figure 4.9: The effects of velocity on stilling basin length with 12 m width

It was observed that for the various basin widths, as the velocity of the basin increased, flows which fell within the Froude number range of between 4.5 and 9 resulted in basins of smaller lengths. The 3 m width basin (Figure 4.6) required shorter lengths at 3 m/s compared to flows of 6 m/s and at higher discharges. From Figures 4.6 and Fig 4.9, at minimum discharges of 10m³/s the lengths of basins (L_T) were 4.44 and 1.67, while at maximum discharges of 100m³/s, the resulting basin length (L_T) were 21.71 m and 6.72 m respectively. This implied

that basin lengths reduced with increase in width. These smaller basins are considered more effective and economical.

4.3.2 Effects of increased velocity on the stilling basin height

The resulting effects of flow parameters on the height of basin for a 3m wide basin are as shown in Figure 4.10 below (Also see Appendix A, Tables A1 to A6). As discharge increased from 10 m³/s to 100 m³/s at velocities of 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s the length of the basin fell between 1.91 m to 8.85 m, 1.78 m to 8.89 m, 1.67 m to 8.62 m, 1.59 m to 8.34 m, 1.53 m to 8.09 m and 1.47 m to 7.86 m respectively.

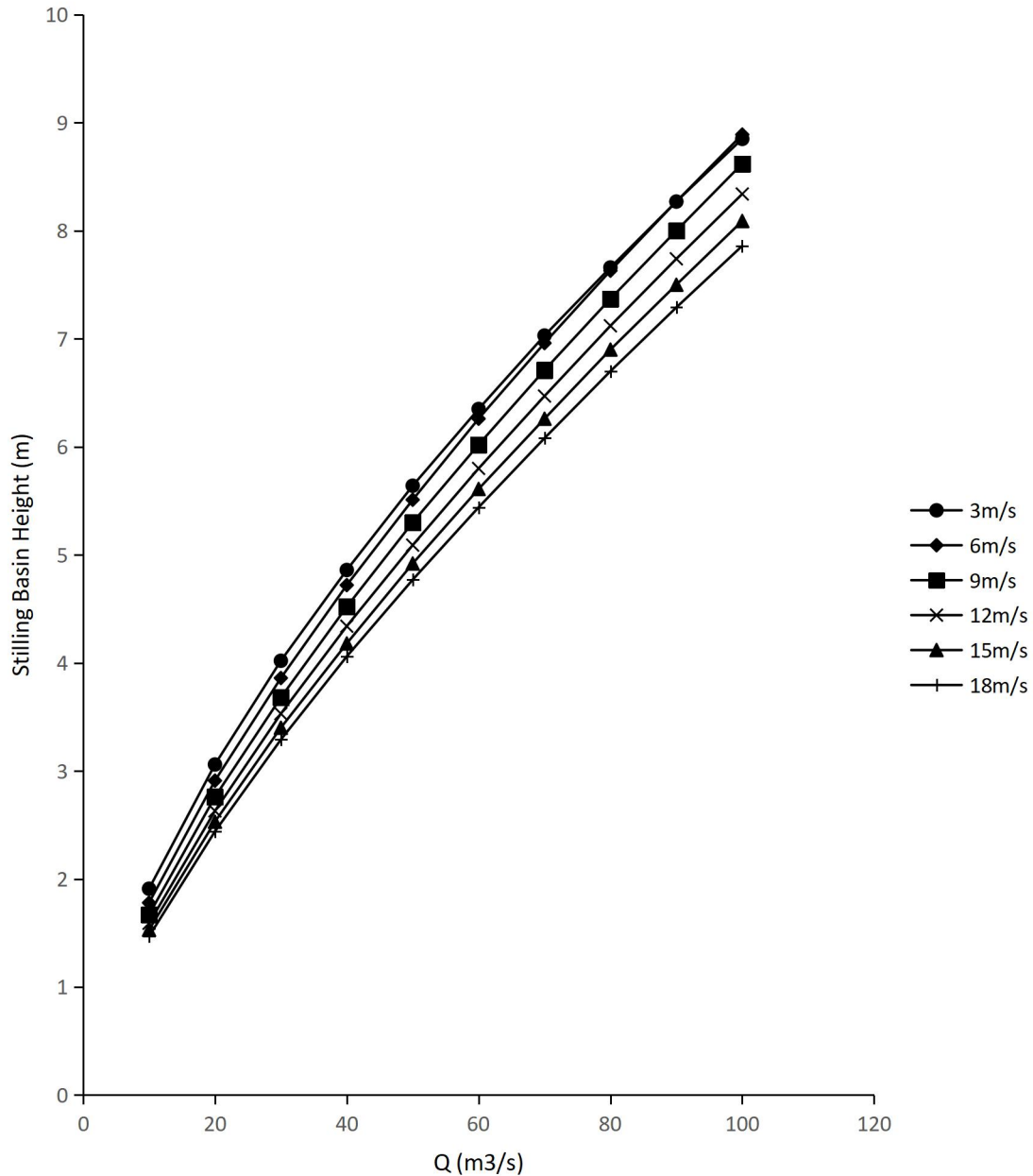


Figure 4.10: The effects of velocity on the stilling basin height with 3 m width

For a 6 m wide basin and for the range of discharge from 10 to 100 m³/s, as velocities increased at 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s, the length of the basin fell between 1.18 m to 5.64 m, 1.08 m to 5.51 m, 1.01 m to 5.29 m, 0.96 m to 5.09 m, 0.92 m to 4.92 m and 0.89 m to 4.77 m respectively (See Appendix A, Tables A7 to A12). Figure 4.11 shows the effect of various velocities obtainable.

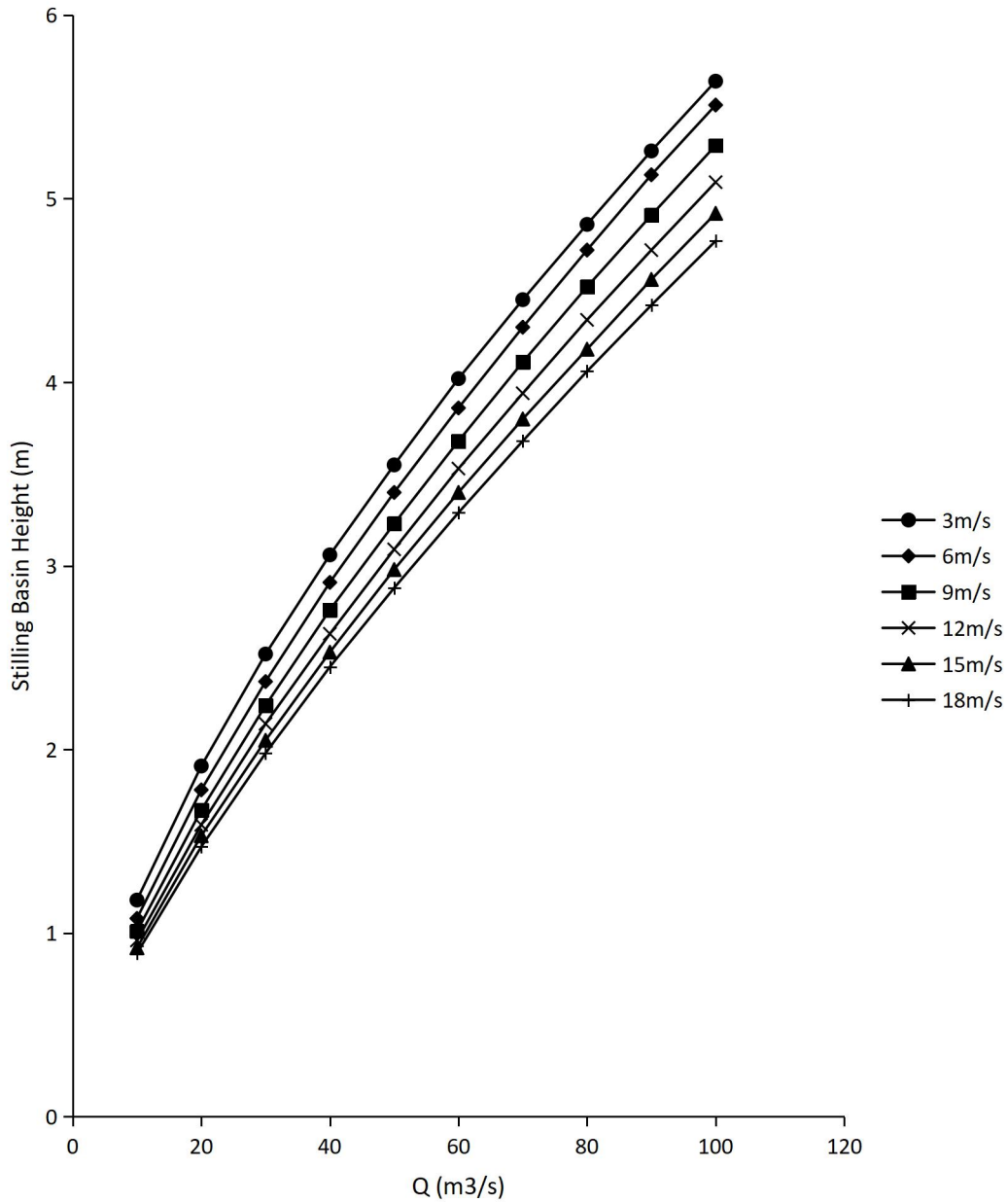


Figure 4.11: The effects of velocity on the stilling basin height with 6 m width

At a basin width of 9 m, at discharge ranging from 10 to 100 m³/s and for increasing velocities of 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s and 18 m/s the length of basin fell between 0.89 m to 4.31 m, 0.81 m to 4.16 m, 0.75 m to 3.97 m, 0.71 m to 3.80 m, 0.68 m to 3.67 m and 0.66 m to 3.55 m respectively (Tables A13 to A18). The resulting effect is as shown in Figure 4.12 below.

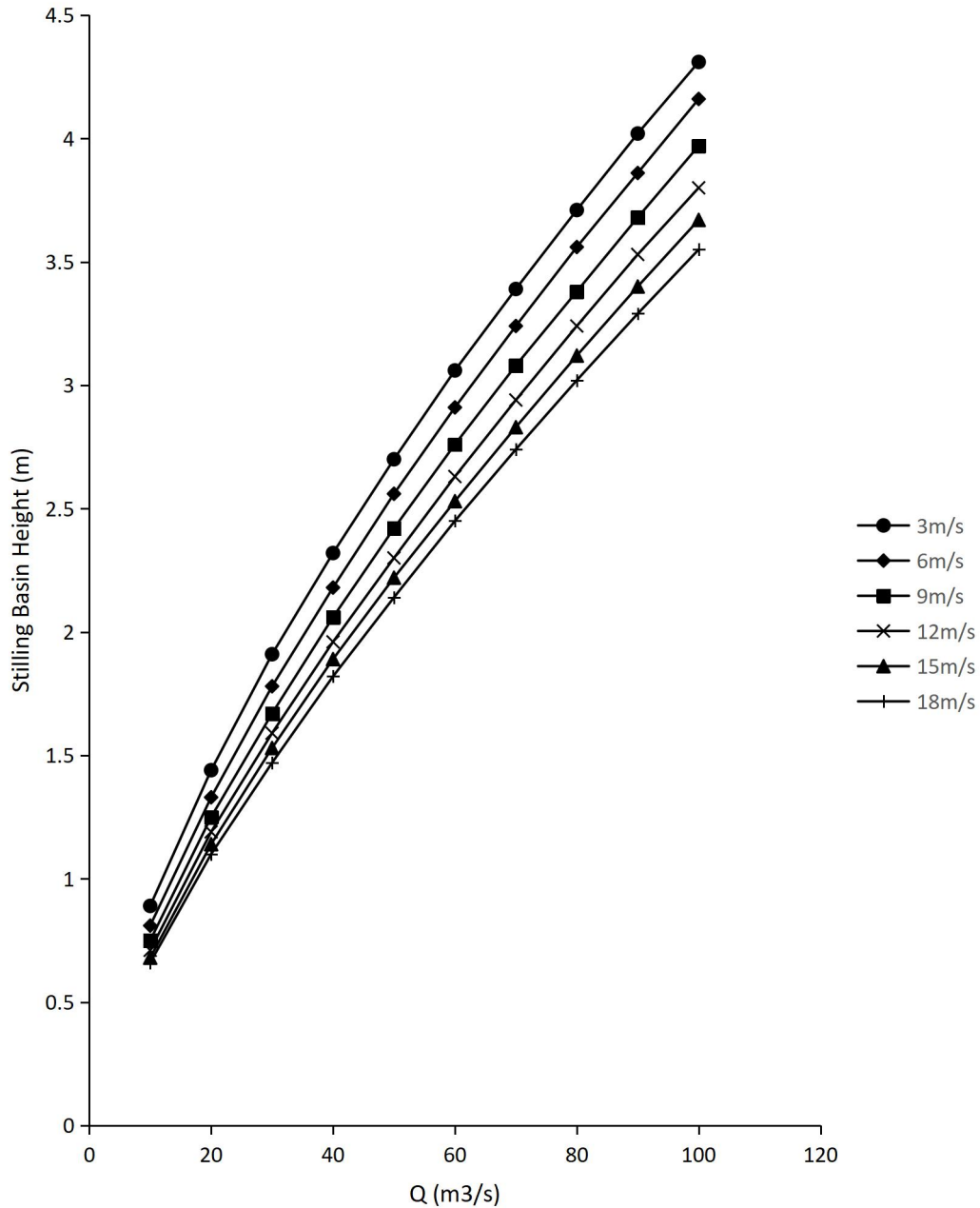


Figure 4.12: The effects of velocity on the stilling basin height with 9 m width

At 12 m, with discharges ranging from 10 m³/s to 110 m³/s and velocity increasing at 3m/s, 6m/s, 9m/s, 12m/s, 15m/s and 18m/s (Tables A19 to A24), the length of the stilling basin fell between 0.73 m to 3.55 m, 0.66 m to 3.40 m, 0.61 m to 3.23 m, 0.58 m to 3.09 m, 0.55 m to 2.98 m and 0.53 m to 2.88 m. The resulting effects of the flow parameters on the length of a 12 m basin is shown in Figure 4.13 below.

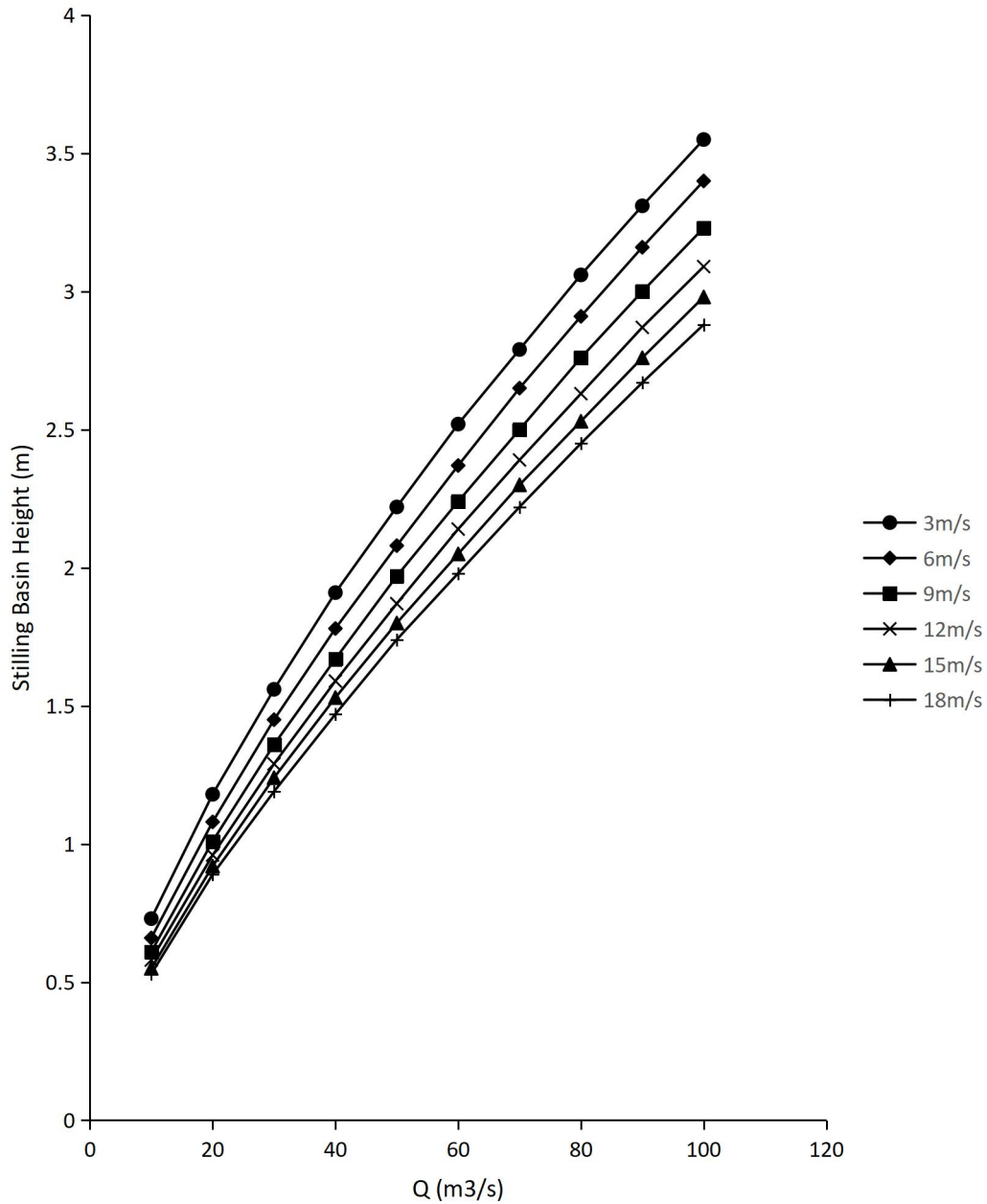


Figure 4.13: The effects of velocity on the stilling basin height at 12 m width

The results obtained from all the flow parameters for the length of stilling basin (L_T), the height of basin wall (H_j) and the distance between the base of chute and baffle piers (L_w) at the various basin widths are shown in Figure C1 to Figure C24 (See Appendix C).

It was observed that for the various basin width, as the velocity of the basin increased, smaller heights of the entraining basin walls were required.

4.3.3 Effects of Increased Velocity on the Stilling Basin Appurtenances

Results from Tables B1 to B24 (See Appendix B) showed that wider basins required an increased numbers of basin appurtenances (chute blocks and baffle piers) of relatively smaller sizes. It was also observed from Figure 4.6 to Figure 4.9 that increase in velocity resulted to more stable hydraulic jumps within the acceptable range of Froude numbers between 4.5 and 9.0, with lesser velocities resulting in longer basins. Studies by Svoboda, 2012 stated that while the onset of sweep out may pose less of a danger, they may result in higher velocities within the basin with the possibility of excess splashing and jetting occurring thus leading to damage. With the length of the basin shortened from this same velocity effect, the height of the jump also decreased. Invariably, this implied that the basin will perform optimally at higher incoming velocities than at relatively lower ones.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

In order to achieve optimal performance of the USBR Type III stilling basin for energy dissipation through the use of forced hydraulic jump, series of iterations (either experimental, theoretical or both) are required. This study involved the analysis of simulation (of a set of algorithms) governed by the design procedure for the Type III stilling basin in accordance with the United States Bureau of Reclamation (USBR) standard. The simulation was used to ascertain flows which fell between Froude numbers of 4.5 to 9, and to assess the effect of such corresponding flow on the USBR Type III stilling basin and its appurtenances in order to facilitate its design. The conclusions from this study and recommendations for further studies are presented in subsequent sections.

5.1 Conclusion

The conclusion from this study are as summarised below:

This study has shown that optimal performance of the stilling basin for energy dissipation through the formation of stable hydraulic jump can be achieved at basin widths between 3 m to 12 m but is dependent mainly on the incoming velocity. Although initial studies by Peterka (1978) observed that measurements of the incoming depth of flow, y_1 and incoming flow velocity, v_1 were probably the most important factors in achieving a stable hydraulic jump, further studies by Svoboda (2012) measuring the flow depths in smooth chute and their impact on the type III stilling basin design procedure produced irregular results.

Forces of great magnitude are developed from overflow discharge of the spillway crest. Such forces may be distributed evenly or unevenly across the base of the stilling basin floor, with its magnitude dependent on the depth of the incoming flow.

Although the effects of the incoming flow depth do not pose a direct impact on the hydraulic jump formation, sequent depths of up to but not exceeding 1.63 m is considered critical, and should only be used in cases of emergency where timely evacuation of a dam/reservoir is required.

Increasing the stilling basin width can be non-conservative leading to longer basin length. Shorter basins become more efficient with higher tail water depths of induced higher but controlled velocities thereby aiding the formation of a stable hydraulic jump. Hence maintaining an overflow between 0.4 m and 1.0 m at the spillway crest is safest practice in achieving optimal energy dissipation since increasing the water depth of overflow discharge beyond 1 m resulted in Froude numbers below 5.66 with increased impact load potentials on the baffle pier.

5.2 Recommendations

The recommendations from this study are as follows:

1. Further experimental research is required for more accurate assessment of flow characteristics in the USBR Type III stilling basin as results from this study are strictly hypothetical. This could be achieved by using physical model to ascertain the effects of various ranges of discharge and velocity of flows on the design and sizing of the USBR Type III stilling basin and its appurtenances.
2. Effect of spillway angle of slope on the velocity of the incoming water should also be studied.

5.3 Contribution to Knowledge

1. Results from this study has shown that hypothetical theoretical computer models can be used to predict the sizes of stilling basin and its appurtenances using its inflow

parameters such discharge and vice versa for the operation and maintenance of small and medium earth dams in Nigeria.

2. The results obtained will find relevant application in the preliminary design of the type III stilling basins for earth dams, reservoirs in Nigeria, in accordance with the United States Bureau of Reclamation standard. It will also aid Engineers and other stakeholders in the proper control and evaluation of small earth dams while checking erosive effects from the velocity of the evaluated outflow by means of hydraulic jump formation.

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APPENDICES

**APPENDIX A – DESIGN FOR THE SIZE OF THE USBR TYPE III STILLING BASIN
STRUCTURE**

Table A1: Stilling Basin Size with basin width 3m and velocity 3m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.91	4.45	3	1.31
20	3.06	7.13	3	2.10
30	4.02	9.36	3	2.75
40	4.86	11.34	3	3.33
50	5.64	13.14	3	3.86
60	6.35	14.81	3	4.36
70	7.03	16.38	3	4.82
80	7.66	17.87	3	5.25
90	8.27	19.28	3	5.67
100	8.85	20.64	3	6.07

Table A2: Stilling Basin Size with basin width 3m and velocity 6m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.78	4.15	3	1.22
20	2.91	6.78	3	1.99
30	3.86	9.01	3	2.65
40	4.72	11.01	3	3.24
50	5.51	12.86	3	3.78
60	6.26	14.59	3	4.29
70	6.96	16.22	3	4.77
80	7.63	17.78	3	5.23
90	8.27	19.28	3	5.67
100	8.89	20.72	3	6.09

Table A3: Stilling Basin Size with basin width 3m and velocity 9m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.67	3.90	3	1.15
20	2.76	6.42	3	1.89
30	3.68	8.58	3	2.52
40	4.52	10.53	3	3.10
50	5.30	12.34	3	3.63
60	6.02	14.03	3	4.13
70	6.71	15.64	3	4.60
80	7.37	17.18	3	5.05
90	8.00	18.66	3	5.49
100	8.62	20.09	3	5.91

Table A4: Stilling Basin Size basin with width 3m and velocity 12m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.59	3.71	3	1.09
20	2.63	6.14	3	1.81
30	3.53	8.22	3	2.42
40	4.34	10.11	3	2.97
50	5.09	11.86	3	3.49
60	5.80	13.52	3	3.98
70	6.47	15.09	3	4.44
80	7.12	16.59	3	4.88
90	7.74	18.04	3	5.31
100	8.34	19.44	3	5.72

Table A5: Stilling Basin Size with width 3m and velocity 15m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.53	3.56	3	1.05
20	2.53	5.90	3	1.74
30	3.40	7.92	3	2.33
40	4.18	9.76	3	2.87
50	4.92	11.46	3	3.37
60	5.61	13.07	3	3.84
70	6.26	14.60	3	4.29
80	6.90	16.07	3	4.73
90	7.50	17.49	3	5.14
100	8.09	18.86	3	5.55

Table A6: Stilling Basin Size with width 3m and velocity 18m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.47	3.44	3	1.01
20	2.44	5.71	3	1.68
30	3.29	7.67	3	2.26
40	4.06	9.45	3	2.78
50	4.77	11.11	3	3.27
60	5.44	12.68	3	3.73
70	6.08	14.18	3	4.17
80	6.70	15.61	3	4.59
90	7.29	17.00	3	5.00
100	7.86	18.33	3	5.39

Table A7: Stilling Basin Size with width 6m and velocity 3m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.18	2.75	6	0.81
20	1.91	4.45	6	1.31
30	2.52	5.87	6	1.73
40	3.06	7.13	6	2.10
50	3.55	8.28	6	2.44
60	4.02	9.36	6	2.75
70	4.45	10.37	6	3.05
80	4.86	11.34	6	3.33
90	5.26	12.26	6	3.60
100	5.64	13.14	6	3.86

Table A8: Stilling Basin Size with width 6m and velocity 6m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y_2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.08	2.53	6	0.74
20	1.78	4.15	6	1.22
30	2.37	5.53	6	1.63
40	2.91	6.78	6	1.99
50	3.40	7.93	6	2.33
60	3.86	9.01	6	2.65
70	4.30	10.03	6	2.95
80	4.72	11.01	6	3.24
90	5.13	11.95	6	3.51
100	5.51	12.86	6	3.78

Table A9: Stilling Basin Size with width 6m and velocity 9m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	1.01	2.36	6	0.70
20	1.67	3.90	6	1.15
30	2.24	5.23	6	1.54
40	2.76	6.42	6	1.89
50	3.23	7.54	6	2.22
60	3.68	8.58	6	2.52
70	4.11	9.58	6	2.82
80	4.52	10.53	6	3.10
90	4.91	11.45	6	3.37
100	5.29	12.34	6	3.63

Table A10: Stilling Basin Size with width 6m and velocity 12m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.96	2.24	6	0.66
20	1.59	3.72	6	1.09
30	2.14	4.98	6	1.47
40	2.63	6.14	6	1.81
50	3.09	7.21	6	2.12
60	3.53	8.22	6	2.42
70	3.94	9.19	6	2.70
80	4.34	10.11	6	2.97
90	4.72	11.00	6	3.24
100	5.09	11.86	6	3.49

Table A11: Stilling Basin Size with width 6m and velocity 15m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.92	2.14	6	0.63
20	1.53	3.56	6	1.05
30	2.05	4.79	6	1.41
40	2.53	5.90	6	1.74
50	2.98	6.94	6	2.04
60	3.40	7.92	6	2.33
70	3.80	8.86	6	2.61
80	4.18	9.76	6	2.87
90	4.56	10.62	6	3.12
100	4.92	11.46	6	3.37

Table A12: Stilling Basin Size with width 6m and velocity 18m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.89	2.07	6	0.61
20	1.47	3.44	6	1.01
30	1.98	4.63	6	1.36
40	2.45	5.71	6	1.68
50	2.88	6.72	6	1.98
60	3.29	7.67	6	2.26
70	3.68	8.58	6	2.52
80	4.06	9.45	6	2.78
90	4.42	10.30	6	3.03
100	4.77	11.11	6	3.27

Table A13: Stilling Basin Size with width 9m and velocity 3m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H_j (m)	LT (m)	WB (m)	LW (m)
10	0.89	2.07	9	0.61
20	1.44	3.36	9	0.99
30	1.91	4.46	9	1.31
40	2.32	5.41	9	1.59
50	2.70	6.30	9	1.85
60	3.06	7.13	9	2.10
70	3.39	7.91	9	2.33
80	3.71	8.65	9	2.54
90	4.02	9.36	9	2.75
100	4.31	10.04	9	2.95

Table A14: Stilling Basin Size with width 9m and velocity 6m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H_j (m)	LT (m)	WB (m)	LW (m)
10	0.81	1.89	9	0.56
20	1.33	3.11	9	0.91
30	1.78	4.15	9	1.22
40	2.18	5.09	9	1.50
50	2.56	5.96	9	1.75
60	2.91	6.78	9	1.99
70	3.24	7.55	9	2.22
80	3.56	8.29	9	2.44
90	3.86	9.01	9	2.65
100	4.16	9.70	9	2.85

Table A15: Stilling Basin Size with width 9m and velocity 9m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.75	1.76	9	0.52
20	1.25	2.91	9	0.86
30	1.67	3.90	9	1.15
40	2.06	4.80	9	1.41
50	2.42	5.64	9	1.66
60	2.76	6.42	9	1.89
70	3.08	7.17	9	2.11
80	3.38	7.89	9	2.32
90	3.68	8.58	9	2.52
100	3.97	9.25	9	2.72

Table A16: Stilling Basin Size with width 9m and velocity 12m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use $2.72 Y^2$]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.71	1.67	9	0.49
20	1.19	2.76	9	0.81
30	1.59	3.71	9	1.09
40	1.96	4.58	9	1.35
50	2.30	5.38	9	1.58
60	2.63	6.14	9	1.81
70	2.94	6.86	9	2.02
80	3.24	7.55	9	2.22
90	3.53	8.22	9	2.42
100	3.80	8.87	9	2.61

Table A17: Stilling Basin Size with width 9m and velocity 15m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.68	1.59	9	0.47
20	1.14	2.65	9	0.78
30	1.53	3.56	9	1.05
40	1.89	4.40	9	1.29
50	2.22	5.17	9	1.52
60	2.53	5.90	9	1.74
70	2.83	6.60	9	1.94
80	3.12	7.28	9	2.14
90	3.40	7.92	9	2.33
100	3.67	8.55	9	2.52

Table A18: Stilling Basin Size with width 9m and velocity 18m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y_2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.66	1.53	9	0.45
20	1.10	2.55	9	0.75
30	1.47	3.44	9	1.01
40	1.82	4.24	9	1.25
50	2.14	5.00	9	1.47
60	2.45	5.71	9	1.68
70	2.74	6.39	9	1.88
80	3.02	7.04	9	2.07
90	3.29	7.67	9	2.26
100	3.55	8.28	9	2.44

Table A19: Stilling Basin Size with width 12m and velocity 3m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use 0.84Y2]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.73	1.69	12	0.50
20	1.18	2.75	12	0.81
30	1.56	3.65	12	1.08
40	1.91	4.45	12	1.31
50	2.22	5.18	12	1.53
60	2.52	5.87	12	1.73
70	2.79	6.51	12	1.92
80	3.06	7.13	12	2.10
90	3.31	7.72	12	2.27
100	3.55	8.28	12	2.44

Table A20: Stilling Basin Size with width 12m and velocity 6m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use 0.84Y2]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.66	1.53	12	0.45
20	1.08	2.53	12	0.74
30	1.45	3.38	12	0.99
40	1.78	4.15	12	1.22
50	2.08	4.86	12	1.43
60	2.37	5.53	12	1.63
70	2.65	6.17	12	1.81
80	2.91	6.78	12	1.99
90	3.16	7.36	12	2.17
100	3.40	7.93	12	2.33

Table A21: Stilling Basin Size with width 12m and velocity 9m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use 0.84Y2]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.61	1.43	12	0.42
20	1.01	2.36	12	0.70
30	1.36	3.17	12	0.93
40	1.67	3.90	12	1.15
50	1.97	4.58	12	1.35
60	2.24	5.23	12	1.54
70	2.50	5.84	12	1.72
80	2.76	6.42	12	1.89
90	3.00	6.99	12	2.06
100	3.23	7.54	12	2.22

Table A22: Stilling Basin Size with width 12m and velocity 12m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use 0.84Y2]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.58	1.35	12	0.40
20	0.96	2.24	12	0.66
30	1.29	3.01	12	0.89
40	1.59	3.71	12	1.09
50	1.87	4.37	12	1.28
60	2.14	4.98	12	1.47
70	2.39	5.57	12	1.64
80	2.63	6.14	12	1.81
90	2.87	6.68	12	1.97
100	3.09	7.21	12	2.12

Table A23: Stilling Basin Size with width 12m and velocity 15m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.55	1.29	12	0.38
20	0.92	2.14	12	0.63
30	1.24	2.89	12	0.85
40	1.53	3.56	12	1.05
50	1.80	4.19	12	1.23
60	2.05	4.79	12	1.41
70	2.30	5.36	12	1.58
80	2.53	5.90	12	1.74
90	2.76	6.43	12	1.89
100	2.98	6.94	12	2.04

Table A24: Stilling Basin Size with width 12m and velocity 18m/s

Overflow Discharge	Height of Basin wall [$7/6 H_j$]	Length of Basin [Use 2.72 Y2]	Width of Basin [Use W]	Distance between Base of Chute and Baffle Piers [use $0.84Y^2$]
Q (m ³ /s)	H _j (m)	LT (m)	WB (m)	LW (m)
10	0.53	1.24	12	0.36
20	0.89	2.07	12	0.61
30	1.19	2.78	12	0.82
40	1.47	3.44	12	1.01
50	1.74	4.05	12	1.19
60	1.98	4.63	12	1.36
70	2.22	5.18	12	1.52
80	2.45	5.71	12	1.68
90	2.67	6.22	12	1.83
100	2.88	6.72	12	1.98

**APPENDIX B – DESIGN FOR THE SIZE OF APPURTENANCES OF THE STILLING
BASIN**

Table B 1: Appurtenances sizes for basin width 3m and velocity 3m/s

Appurtenance Section Discharge, Q (m ³ /s)	Chute Blocks				Baffle Piers						End Still	
	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
10	1.11	1.11	1.1	0	0.84	0.17	1.00	0.63	0.63	2	1.17	2.38
20	2.22	2.22	2.2	0	1.57	0.31	1.89	1.18	1.18	1	2.30	4.65
30	3.33	3.33	3.3	0	2.29	0.46	2.75	1.72	1.72	1	3.43	6.91
40	4.44	4.44	4.4	0	3.00	0.60	3.60	2.25	2.25	1	4.56	9.16
50	5.56	5.56	5.6	0	3.71	0.74	4.45	2.78	2.78	1	5.68	11.40
60	6.67	6.67	6.7	0	4.41	0.88	5.29	3.31	3.31	0	6.80	13.70
70	7.78	7.78	7.8	0	5.11	1.02	6.13	3.83	3.83	0	7.93	15.90
80	8.89	8.89	8.9	0	5.81	1.16	6.97	4.36	4.36	0	9.05	18.10
90	10.00	10.00	10.0	0	6.51	1.30	7.81	4.88	4.88	0	10.20	20.40
100	11.10	11.10	11.0	0	7.20	1.44	8.64	5.40	5.40	0	11.30	22.60

Table B 3: Appurtenances sizes for basin width 3m and velocity 9m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.37	0.37	0.4	4	0.51	0.10	0.62	0.39	0.39	4	0.47	0.99
20	0.74	0.74	0.7	2	0.86	0.17	1.03	0.64	0.64	2	0.88	1.81
30	1.11	1.11	1.1	1	1.17	0.23	1.41	0.88	0.88	2	1.28	2.61
40	1.48	1.48	1.5	1	1.47	0.29	1.77	1.10	1.10	1	1.68	3.40
50	1.85	1.85	1.9	1	1.76	0.35	2.12	1.32	1.32	1	2.07	4.19
60	2.22	2.22	2.2	1	2.05	0.41	2.46	1.54	1.54	1	2.46	4.97
70	2.59	2.59	2.6	1	2.33	0.47	2.79	1.75	1.75	1	2.85	5.75
80	2.96	2.96	3.0	1	2.60	0.52	3.12	1.95	1.95	1	3.24	6.53
90	3.33	3.33	3.3	0	2.87	0.57	3.45	2.16	2.16	1	3.62	7.30
100	3.70	3.70	3.7	0	3.14	0.63	3.77	2.36	2.36	1	4.01	8.07

Table B 2: Appurtenances sizes for basin width 3m and velocity 6m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.56	0.56	0.6	3	0.57	0.11	0.69	0.43	0.43	4	0.63	1.32
20	1.11	1.11	1.1	1	1.00	0.20	1.20	0.75	0.75	2	1.22	2.50
30	1.67	1.67	1.7	1	1.41	0.28	1.69	1.06	1.06	1	1.80	3.66
40	2.22	2.22	2.2	1	1.81	0.36	2.17	1.36	1.36	1	2.38	4.81
50	2.78	2.78	2.8	1	2.20	0.44	2.64	1.65	1.65	1	2.96	5.96
60	3.33	3.33	3.3	0	2.58	0.52	3.10	1.94	1.94	1	3.53	7.11
70	3.89	3.89	3.9	0	2.96	0.59	3.56	2.22	2.22	1	4.10	8.25
80	4.44	4.44	4.4	0	3.34	0.67	4.01	2.50	2.50	1	4.67	9.39
90	5.00	5.00	5.0	0	3.71	0.74	4.46	2.79	2.79	1	5.24	10.50
100	5.56	5.56	5.6	0	4.09	0.82	4.90	3.06	3.06	0	5.81	11.70

Table B 4: Appurtenances sizes for basin width 3m and velocity 12m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.28	0.28	0.3	5	0.50	0.10	0.60	0.38	0.38	4	0.39	0.83
20	0.56	0.56	0.6	3	0.81	0.16	0.97	0.61	0.61	2	0.71	1.48
30	0.83	0.83	0.8	2	1.08	0.22	1.30	0.81	0.81	2	1.03	2.11
40	1.11	1.11	1.1	1	1.34	0.27	1.61	1.00	1.00	1	1.34	2.72
50	1.39	1.39	1.4	1	1.59	0.32	1.90	1.19	1.19	1	1.64	3.33
60	1.67	1.67	1.7	1	1.82	0.36	2.19	1.37	1.37	1	1.94	3.93
70	1.94	1.94	1.9	1	2.06	0.41	2.47	1.54	1.54	1	2.24	4.53
80	2.22	2.22	2.2	1	2.29	0.46	2.74	1.71	1.71	1	2.54	5.13
90	2.50	2.50	2.5	1	2.51	0.50	3.01	1.88	1.88	1	2.84	5.72
100	2.78	2.78	2.8	1	2.73	0.55	3.28	2.05	2.05	1	3.13	6.32

Table B 5: Appurtenances sizes for basin width 3m and velocity 15m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.22	0.22	0.2	7	0.51	0.10	0.61	0.38	0.38	4	0.35	0.75
20	0.44	0.44	0.4	3	0.80	0.16	0.96	0.60	0.60	3	0.62	1.29
30	0.67	0.67	0.7	2	1.05	0.21	1.26	0.79	0.79	2	0.88	1.82
40	0.89	0.89	0.9	2	1.29	0.26	1.54	0.96	0.96	2	1.14	2.33
50	1.11	1.11	1.1	1	1.51	0.30	1.81	1.13	1.13	1	1.39	2.83
60	1.33	1.33	1.3	1	1.72	0.34	2.07	1.29	1.29	1	1.64	3.33
70	1.56	1.56	1.6	1	1.93	0.39	2.31	1.45	1.45	1	1.89	3.82
80	1.78	1.78	1.8	1	2.13	0.43	2.56	1.60	1.60	1	2.13	4.32
90	2.00	2.00	2.0	1	2.33	0.47	2.79	1.75	1.75	1	2.38	4.80
100	2.22	2.22	2.2	1	2.52	0.50	3.03	1.89	1.89	1	2.62	5.29

Table B 6: Appurtenances sizes for basin width 3m and velocity 18m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m³/s)												
10	0.19	0.19	0.2	8	0.52	0.10	0.63	0.39	0.39	4	0.32	0.70
20	0.37	0.37	0.4	4	0.81	0.16	0.97	0.60	0.60	2	0.56	1.18
30	0.56	0.56	0.6	3	1.05	0.21	1.26	0.79	0.79	2	0.79	1.64
40	0.74	0.74	0.7	2	1.27	0.25	1.52	0.95	0.95	2	1.02	2.08
50	0.93	0.93	0.9	2	1.48	0.30	1.77	1.11	1.11	1	1.23	2.52
60	1.11	1.11	1.1	1	1.68	0.34	2.01	1.26	1.26	1	1.45	2.95
70	1.30	1.30	1.3	1	1.87	0.37	2.24	1.40	1.40	1	1.66	3.37
80	1.48	1.48	1.5	1	2.06	0.41	2.47	1.54	1.54	1	1.87	3.79
90	1.67	1.67	1.7	1	2.24	0.45	2.68	1.68	1.68	1	2.08	4.21
100	1.85	1.85	1.9	1	2.42	0.48	2.90	1.81	1.81	1	2.29	4.62

Table B 7: Appurtenances sizes for basin width 6m and velocity 3m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.56	0.56	0.6	5	0.45	0.09	0.54	0.34	0.34	9	0.60	1.24
20	1.11	1.11	1.1	3	0.84	0.17	1.00	0.63	0.63	5	1.17	2.38
30	1.67	1.67	1.7	2	1.21	0.24	1.45	0.90	0.90	3	1.74	3.52
40	2.22	2.22	2.2	1	1.57	0.31	1.89	1.18	1.18	3	2.30	4.65
50	2.78	2.78	2.8	1	1.93	0.39	2.32	1.45	1.45	2	2.87	5.78
60	3.33	3.33	3.3	1	2.29	0.46	2.75	1.72	1.72	2	3.43	6.91
70	3.89	3.89	3.9	1	2.65	0.53	3.18	1.99	1.99	2	3.99	8.04
80	4.44	4.44	4.4	1	3.00	0.6	3.60	2.25	2.25	1	4.56	9.16
90	5.00	5.00	5.0	1	3.36	0.67	4.03	2.52	2.52	1	5.12	10.30
100	5.56	5.56	5.6	1	3.71	0.74	4.45	2.78	2.78	1	5.68	11.40

Table B 8: Appurtenances sizes for basin width 6 m and velocity 6 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.28	0.28	0.3	11	0.34	0.07	0.40	0.25	0.25	12	0.33	0.72
20	0.56	0.56	0.6	5	0.57	0.11	0.69	0.43	0.43	7	0.63	1.32
30	0.83	0.83	0.8	4	0.79	0.16	0.95	0.59	0.59	5	0.93	1.91
40	1.11	1.11	1.1	3	1.00	0.20	1.20	0.75	0.75	4	1.22	2.50
50	1.39	1.39	1.4	2	1.21	0.24	1.45	0.91	0.91	3	1.51	3.08
60	1.67	1.67	1.7	2	1.41	0.28	1.69	1.06	1.06	3	1.80	3.66
70	1.94	1.94	1.9	2	1.61	0.32	1.93	1.21	1.21	2	2.09	4.24
80	2.22	2.22	2.2	1	1.81	0.36	2.17	1.36	1.36	2	2.38	4.81
90	2.50	2.50	2.5	1	2.01	0.40	2.41	1.50	1.50	2	2.67	5.39
100	2.78	2.78	2.8	1	2.20	0.44	2.64	1.65	1.65	2	2.96	5.96

Table B 9: Appurtenances sizes for basin width 6 m and velocity 9 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still		
	Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)													
10	0.19	0.19	0.2	16	0.32	0.06	0.38	0.24	0.24	13	0.25	0.56	
20	0.37	0.37	0.4	8	0.51	0.10	0.62	0.39	0.39	8	0.47	0.99	
30	0.56	0.56	0.6	5	0.69	0.14	0.83	0.52	0.52	6	0.67	1.40	
40	0.74	0.74	0.7	4	0.86	0.17	1.03	0.64	0.64	5	0.88	1.81	
50	0.93	0.93	0.9	3	1.02	0.20	1.22	0.76	0.76	4	1.08	2.21	
60	1.11	1.11	1.1	3	1.17	0.23	1.41	0.88	0.88	3	1.28	2.61	
70	1.30	1.30	1.3	2	1.32	0.26	1.59	0.99	0.99	3	1.48	3.01	
80	1.48	1.48	1.5	2	1.47	0.29	1.77	1.10	1.10	3	1.68	3.40	
90	1.67	1.67	1.7	2	1.62	0.32	1.94	1.21	1.21	2	1.87	3.80	
100	1.85	1.85	1.9	2	1.76	0.35	2.12	1.32	1.32	2	2.07	4.19	

Table B 10: Appurtenances sizes for basin width 6 m and velocity 12 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still		
	Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)													
10	0.14	0.14	0.1	22	0.32	0.06	0.39	0.24	0.24	12	0.22	0.49	
20	0.28	0.28	0.3	11	0.50	0.1	0.60	0.38	0.38	8	0.39	0.83	
30	0.42	0.42	0.4	7	0.66	0.13	0.79	0.50	0.50	6	0.55	1.16	
40	0.56	0.56	0.6	5	0.81	0.16	0.97	0.61	0.61	5	0.71	1.48	
50	0.69	0.69	0.7	4	0.95	0.19	1.14	0.71	0.71	4	0.87	1.79	
60	0.83	0.83	0.8	4	1.08	0.22	1.30	0.81	0.81	4	1.03	2.11	
70	0.97	0.97	1.0	3	1.21	0.24	1.46	0.91	0.91	3	1.18	2.41	
80	1.11	1.11	1.1	3	1.34	0.27	1.61	1.00	1.00	3	1.34	2.72	
90	1.25	1.25	1.3	2	1.46	0.29	1.76	1.10	1.10	3	1.49	3.03	
100	1.39	1.39	1.4	2	1.59	0.32	1.90	1.19	1.19	3	1.64	3.33	

Table B 11: Appurtenances sizes for basin width 6 m and velocity 15 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.11	0.11	0.1	27	0.33	0.07	0.40	0.25	0.25	12	0.20	0.45
20	0.22	0.22	0.2	14	0.51	0.10	0.61	0.38	0.38	8	0.35	0.75
30	0.33	0.33	0.3	9	0.66	0.13	0.79	0.50	0.50	6	0.49	1.02
40	0.44	0.44	0.4	7	0.80	0.16	0.96	0.60	0.60	5	0.62	1.29
50	0.56	0.56	0.6	5	0.93	0.19	1.11	0.70	0.70	4	0.75	1.56
60	0.67	0.67	0.7	5	1.05	0.21	1.26	0.79	0.79	4	0.88	1.82
70	0.78	0.78	0.8	4	1.17	0.23	1.40	0.88	0.88	3	1.01	2.07
80	0.89	0.89	0.9	3	1.29	0.26	1.54	0.96	0.96	3	1.14	2.33
90	1.00	1.00	1.0	3	1.40	0.28	1.68	1.05	1.05	3	1.27	2.58
100	1.11	1.11	1.1	3	1.51	0.30	1.81	1.13	1.13	3	1.39	2.83

Table B 12: Appurtenances sizes for basin width 6 m and velocity 18 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.09	0.09	0.1	32	0.35	0.07	0.42	0.26	0.26	11	0.19	0.43
20	0.19	0.19	0.2	16	0.52	0.10	0.63	0.39	0.39	8	0.32	0.70
30	0.28	0.28	0.3	11	0.67	0.13	0.81	0.50	0.50	6	0.45	0.94
40	0.37	0.37	0.4	8	0.81	0.16	0.97	0.60	0.60	5	0.56	1.18
50	0.46	0.46	0.5	6	0.93	0.19	1.12	0.70	0.70	4	0.68	1.41
60	0.56	0.56	0.6	5	1.05	0.21	1.26	0.79	0.79	4	0.79	1.64
70	0.65	0.65	0.6	5	1.16	0.23	1.39	0.87	0.87	3	0.91	1.86
80	0.74	0.74	0.7	4	1.27	0.25	1.52	0.95	0.95	3	1.02	2.08
90	0.83	0.83	0.8	4	1.37	0.27	1.65	1.03	1.03	3	1.12	2.30
100	0.93	0.93	0.9	3	1.48	0.30	1.77	1.11	1.11	3	1.23	2.52

Table B 13: Appurtenances sizes for basin width 9 m and velocity 3 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.37	0.37	0.4	12	0.32	0.06	0.38	0.24	0.24	19	0.40	0.86
20	0.74	0.74	0.7	6	0.58	0.12	0.70	0.44	0.44	10	0.79	1.62
30	1.11	1.11	1.1	4	0.84	0.17	1.00	0.63	0.63	7	1.17	2.38
40	1.48	1.48	1.5	3	1.08	0.22	1.30	0.81	0.81	6	1.55	3.14
50	1.85	1.85	1.9	2	1.33	0.27	1.59	1.00	1.00	5	1.92	3.90
60	2.22	2.22	2.2	2	1.57	0.31	1.89	1.18	1.18	4	2.30	4.65
70	2.59	2.59	2.6	2	1.81	0.36	2.18	1.36	1.36	3	2.68	5.41
80	2.96	2.96	3.0	2	2.05	0.41	2.46	1.54	1.54	3	3.05	6.16
90	3.33	3.33	3.3	1	2.29	0.46	2.75	1.72	1.72	3	3.43	6.91
100	3.70	3.70	3.7	1	2.53	0.51	3.04	1.90	1.90	2	3.81	7.66

Table B 14: Appurtenances sizes for basin width 9 m and velocity 6 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.19	0.19	0.2	24	0.25	0.05	0.30	0.19	0.19	24	0.23	0.51
20	0.37	0.37	0.4	12	0.42	0.08	0.50	0.31	0.31	14	0.44	0.92
30	0.56	0.56	0.6	8	0.57	0.11	0.69	0.43	0.43	10	0.63	1.32
40	0.74	0.74	0.7	6	0.72	0.14	0.86	0.54	0.54	8	0.83	1.71
50	0.93	0.93	0.9	5	0.86	0.17	1.04	0.65	0.65	7	1.03	2.11
60	1.11	1.11	1.1	4	1.00	0.20	1.20	0.75	0.75	6	1.22	2.50
70	1.30	1.30	1.3	3	1.14	0.23	1.37	0.86	0.86	5	1.42	2.88
80	1.48	1.48	1.5	3	1.28	0.26	1.53	0.96	0.96	5	1.61	3.27
90	1.67	1.67	1.7	3	1.41	0.28	1.69	1.06	1.06	4	1.80	3.66
100	1.85	1.85	1.9	2	1.55	0.31	1.85	1.16	1.16	4	2.00	4.04

Table B 15: Appurtenances sizes for basin width 9 m and velocity 9 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.12	0.12	0.1	36	0.24	0.05	0.29	0.18	0.18	25	0.18	0.41
20	0.25	0.25	0.2	18	0.39	0.08	0.46	0.29	0.29	16	0.33	0.70
30	0.37	0.37	0.4	12	0.51	0.10	0.62	0.39	0.39	12	0.47	0.99
40	0.49	0.49	0.5	9	0.63	0.13	0.76	0.47	0.47	9	0.61	1.26
50	0.62	0.62	0.6	7	0.75	0.15	0.90	0.56	0.56	8	0.74	1.54
60	0.74	0.74	0.7	6	0.86	0.17	1.03	0.64	0.64	7	0.88	1.81
70	0.86	0.86	0.9	5	0.96	0.19	1.16	0.72	0.72	6	1.01	2.08
80	0.99	0.99	1.0	5	1.07	0.21	1.28	0.80	0.80	6	1.15	2.34
90	1.11	1.11	1.1	4	1.17	0.23	1.41	0.88	0.88	5	1.28	2.61
100	1.23	1.23	1.2	4	1.27	0.25	1.53	0.95	0.95	5	1.41	2.87

Table B 16: Appurtenances sizes for basin width 9 m and velocity 12 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.09	0.09	0.1	49	0.25	0.05	0.30	0.19	0.19	24	0.16	0.36
20	0.19	0.19	0.2	24	0.37	0.08	0.46	0.29	0.29	16	0.28	0.60
30	0.28	0.28	0.3	16	0.50	0.10	0.60	0.38	0.38	12	0.39	0.83
40	0.37	0.37	0.4	12	0.61	0.12	0.73	0.46	0.46	10	0.50	1.05
50	0.46	0.46	0.5	10	0.71	0.14	0.85	0.53	0.53	8	0.61	1.27
60	0.56	0.56	0.6	8	0.81	0.16	0.97	0.61	0.61	7	0.71	1.48
70	0.65	0.65	0.6	7	0.90	0.18	1.08	0.68	0.68	7	0.82	1.69
80	0.74	0.74	0.7	6	0.99	0.20	1.19	0.75	0.75	6	0.92	1.90
90	0.83	0.83	0.8	5	1.08	0.22	1.30	0.81	0.81	6	1.03	2.11
100	0.93	0.93	0.9	5	1.17	0.23	1.40	0.88	0.88	5	1.13	2.31

Table B 17: Appurtenances sizes for basin width 9 m and velocity 15 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.07	0.07	0.1	61	0.26	0.05	0.31	0.20	0.20	23	0.15	0.34
20	0.15	0.15	0.1	30	0.40	0.08	0.48	0.30	0.30	15	0.25	0.55
30	0.22	0.22	0.2	20	0.51	0.10	0.61	0.38	0.38	12	0.35	0.75
40	0.30	0.30	0.3	15	0.61	0.12	0.73	0.46	0.46	10	0.44	0.93
50	0.37	0.37	0.4	12	0.71	0.14	0.85	0.53	0.53	8	0.53	1.11
60	0.44	0.44	0.4	10	0.80	0.16	0.96	0.60	0.60	8	0.62	1.29
70	0.52	0.52	0.5	9	0.89	0.18	1.06	0.66	0.66	7	0.71	1.47
80	0.59	0.59	0.6	8	0.97	0.19	1.16	0.73	0.73	6	0.80	1.64
90	0.67	0.67	0.7	7	1.05	0.21	1.26	0.79	0.79	6	0.88	1.82
100	0.74	0.74	0.7	6	1.13	0.23	1.36	0.85	0.85	5	0.97	1.99

Table B 18: Appurtenances sizes for basin width 9 m and velocity 18 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.06	0.06	0.1	73	0.28	0.06	0.33	0.21	0.21	22	0.14	0.33
20	0.12	0.12	0.1	36	0.41	0.08	0.49	0.31	0.31	15	0.24	0.52
30	0.19	0.19	0.2	24	0.52	0.10	0.63	0.39	0.39	11	0.32	0.70
40	0.25	0.25	0.2	18	0.62	0.12	0.75	0.47	0.47	10	0.41	0.86
50	0.31	0.31	0.3	15	0.72	0.14	0.86	0.54	0.54	8	0.49	1.02
60	0.37	0.37	0.4	1	0.81	0.16	0.97	0.60	0.60	7	0.56	1.18
70	0.43	0.43	0.4	10	0.89	0.18	1.07	0.67	0.67	7	0.64	1.33
80	0.49	0.49	0.5	9	0.97	0.19	1.16	0.73	0.73	6	0.72	1.49
90	0.56	0.56	0.6	8	1.05	0.21	1.26	0.79	0.79	6	0.79	1.64
100	0.62	0.62	0.6	7	1.12	0.22	1.35	0.84	0.84	5	0.87	1.79

Table B 19: Appurtenances sizes for basin width 12 m and velocity 3 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.28	0.28	0.3	22	0.25	0.05	0.3	0.19	0.19	32	0.31	0.66
20	0.56	0.56	0.6	11	0.45	0.09	0.54	0.34	0.34	18	0.60	1.24
30	0.83	0.83	0.8	7	0.65	0.13	0.77	0.48	0.48	12	0.88	1.81
40	1.11	1.11	1.1	5	0.84	0.17	1.00	0.63	0.63	10	1.17	2.38
50	1.39	1.39	1.4	4	1.02	0.20	1.23	0.77	0.77	8	1.45	2.95
60	1.67	1.67	1.7	4	1.21	0.24	1.45	0.90	0.90	7	1.74	3.52
70	1.94	1.94	1.9	3	1.39	0.28	1.67	1.04	1.04	6	2.02	4.09
80	2.22	2.22	2.2	3	1.57	0.31	1.89	1.18	1.18	5	2.30	4.65
90	2.50	2.5	2.5	2	1.75	0.35	2.10	1.31	1.31	5	2.58	5.22
100	2.78	2.78	2.8	2	1.93	0.39	2.32	1.45	1.45	4	2.87	5.78

Table B 20: Appurtenances sizes for basin width 12 m and velocity 6 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.14	0.14	0.1	43	0.20	0.04	0.24	0.15	0.15	39	0.18	0.41
20	0.28	0.28	0.3	22	0.34	0.07	0.40	0.25	0.25	24	0.33	0.72
30	0.42	0.42	0.4	14	0.46	0.09	0.55	0.34	0.34	18	0.49	1.02
40	0.56	0.56	0.6	11	0.57	0.11	0.69	0.43	0.43	14	0.63	1.32
50	0.69	0.69	0.7	9	0.68	0.14	0.82	0.51	0.51	12	0.78	1.62
60	0.83	0.83	0.8	7	0.79	0.16	0.95	0.59	0.59	10	0.93	1.91
70	0.97	0.97	1.0	6	0.90	0.18	1.08	0.67	0.67	9	1.08	2.20
80	1.11	1.11	1.1	5	1.00	0.20	1.20	0.75	0.75	8	1.22	2.50
90	1.25	1.25	1.3	5	1.11	0.22	1.33	0.83	0.83	7	1.37	2.79
100	1.39	1.39	1.4	4	1.21	0.24	1.45	0.91	0.91	7	1.51	3.08

Table B 21: Appurtenances sizes for basin width 12 m and velocity 9 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.09	0.09	0.1	65	0.20	0.04	0.24	0.15	0.15	40	0.14	0.33
20	0.19	0.19	0.2	32	0.32	0.06	0.38	0.24	0.24	25	0.25	0.56
30	0.28	0.28	0.3	22	0.42	0.08	0.50	0.31	0.31	19	0.36	0.77
40	0.37	0.37	0.4	16	0.51	0.10	0.62	0.39	0.39	16	0.47	0.99
50	0.46	0.46	0.5	13	0.60	0.12	0.72	0.45	0.45	13	0.57	1.19
60	0.56	0.56	0.6	11	0.69	0.14	0.83	0.52	0.52	12	0.67	1.40
70	0.65	0.65	0.6	9	0.77	0.15	0.93	0.58	0.58	10	0.78	1.60
80	0.74	0.74	0.7	8	0.86	0.17	1.03	0.64	0.64	9	0.88	1.81
90	0.83	0.83	0.8	7	0.94	0.19	1.12	0.70	0.70	9	0.98	2.01
100	0.93	0.93	0.9	6	1.02	0.20	1.22	0.76	0.76	8	1.08	2.21

Table B 22: Appurtenances sizes for basin width 12 m and velocity 12 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.07	0.07	0.1	86	0.21	0.04	0.25	0.16	0.16	38	0.13	0.30
20	0.14	0.14	0.1	43	0.32	0.06	0.39	0.24	0.24	25	0.22	0.49
30	0.21	0.21	0.2	29	0.42	0.08	0.50	0.31	0.31	19	0.31	0.66
40	0.28	0.28	0.3	22	0.50	0.10	0.60	0.38	0.38	16	0.39	0.83
50	0.35	0.35	0.3	17	0.59	0.12	0.70	0.44	0.44	14	0.47	1.00
60	0.42	0.42	0.4	14	0.66	0.13	0.79	0.50	0.50	12	0.55	1.16
70	0.49	0.49	0.5	12	0.74	0.15	0.88	0.55	0.55	11	0.63	1.32
80	0.56	0.56	0.6	11	0.81	0.16	0.97	0.61	0.61	10	0.71	1.48
90	0.63	0.63	0.6	10	0.88	0.18	1.06	0.66	0.66	9	0.79	1.64
100	0.69	0.69	0.7	9	0.95	0.19	1.14	0.71	0.71	8	0.87	1.79

Table B 23: Appurtenances sizes for basin width 12 m and velocity 15 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.06	0.06	0.1	108	0.22	0.04	0.27	0.17	0.17	36	0.12	0.29
20	0.11	0.11	0.1	54	0.33	0.07	0.40	0.25	0.25	24	0.20	0.45
30	0.17	0.17	0.2	36	0.43	0.09	0.51	0.32	0.32	19	0.28	0.60
40	0.22	0.22	0.2	27	0.51	0.10	0.61	0.38	0.38	16	0.35	0.75
50	0.28	0.28	0.3	22	0.59	0.12	0.70	0.44	0.44	14	0.42	0.89
60	0.33	0.33	0.3	18	0.66	0.13	0.79	0.50	0.50	12	0.49	1.02
70	0.39	0.39	0.4	15	0.73	0.15	0.88	0.55	0.55	11	0.55	1.16
80	0.44	0.44	0.4	14	0.80	0.16	0.96	0.60	0.60	10	0.62	1.29
90	0.50	0.50	0.5	12	0.86	0.17	1.04	0.65	0.65	9	0.69	1.43
100	0.56	0.56	0.6	11	0.93	0.19	1.11	0.70	0.70	9	0.75	1.56

Table B 24: Appurtenances sizes for basin width 12 m and velocity 18 m/s

Appurtenance	Chute Blocks				Baffle Piers						End Still	
Section	h1 (m)	W1 (m)	S1 (m)	Nc	H3 (m)	Lu (m)	LL (m)	W3 (m)	S3 (m)	NB	H4 (m)	L5 (m)
Discharge, Q (m ³ /s)												
10	0.05	0.05	0.0	130	0.23	0.05	0.28	0.18	0.18	34	0.11	0.28
20	0.09	0.09	0.1	65	0.35	0.07	0.42	0.26	0.26	23	0.19	0.43
30	0.14	0.14	0.1	43	0.44	0.09	0.53	0.33	0.33	18	0.26	0.57
40	0.19	0.19	0.2	32	0.52	0.10	0.63	0.39	0.39	15	0.32	0.70
50	0.23	0.23	0.2	26	0.60	0.12	0.72	0.45	0.45	13	0.39	0.82
60	0.28	0.28	0.3	22	0.67	0.13	0.81	0.50	0.50	12	0.45	0.94
70	0.32	0.32	0.3	19	0.74	0.15	0.89	0.55	0.55	11	0.51	1.06
80	0.37	0.37	0.4	16	0.81	0.16	0.97	0.60	0.60	10	0.56	1.18
90	0.42	0.42	0.4	14	0.87	0.17	1.04	0.65	0.65	9	0.62	1.30
100	0.46	0.46	0.5	13	0.93	0.19	1.12	0.70	0.70	9	0.68	1.41

**APPENDIX C – BASIN SIZING RESULTS FOR LENGTHS AND HEIGHTS OF
BASIN WALL**

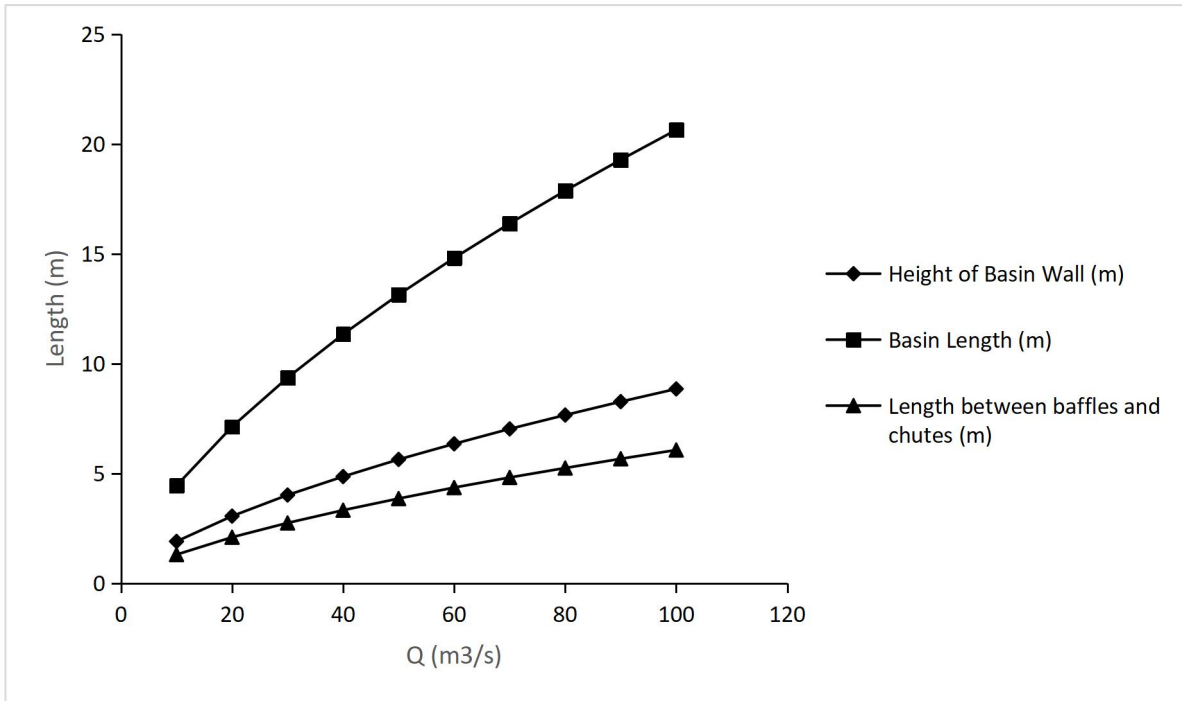


Fig. C1: The effects of velocity on the size of stilling basin 3 m width at 3 m/s

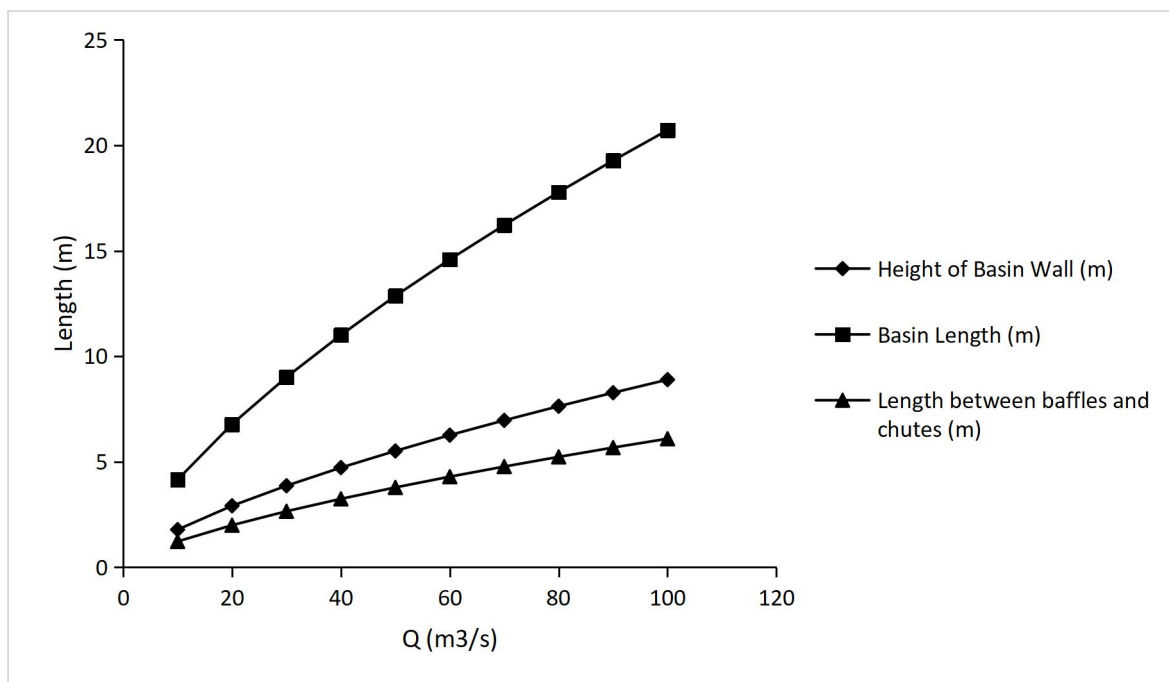


Fig. C2: The effects of velocity on the size of stilling basin 3 m width at 6 m/s

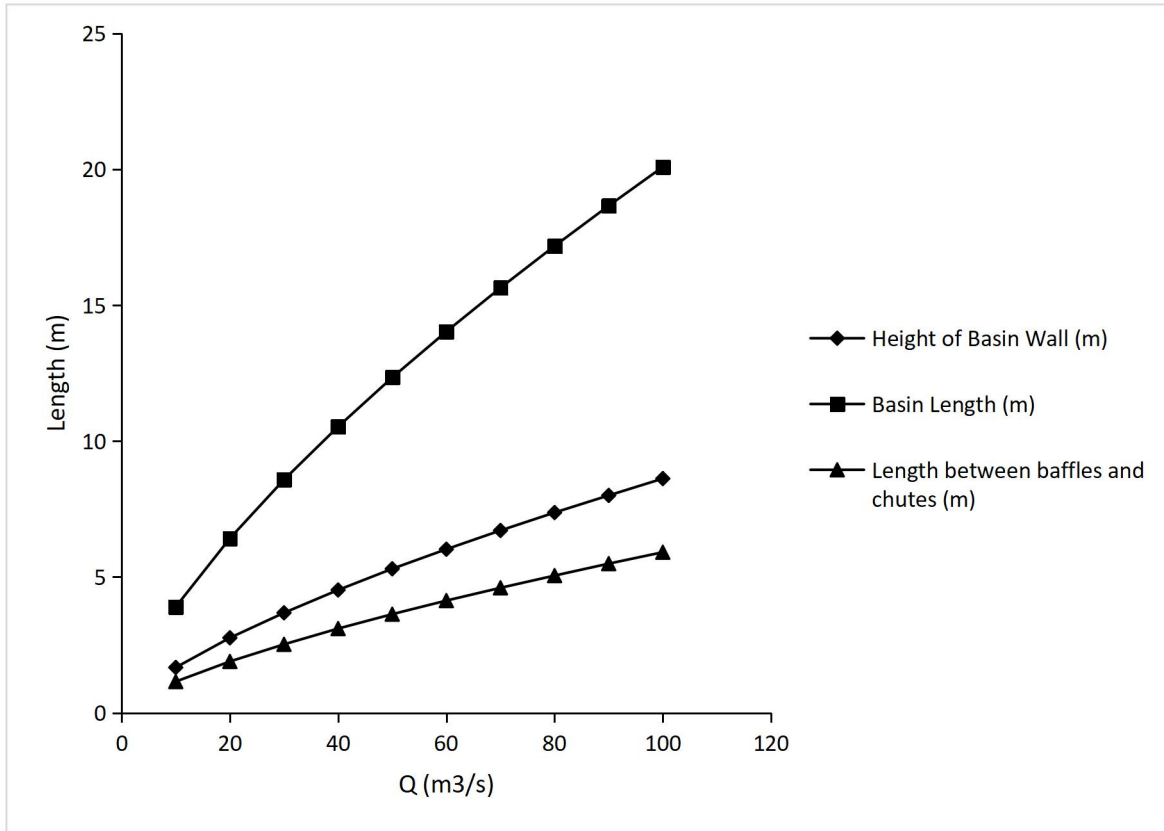


Fig. C3: The effects of velocity on the size of stilling basin 3 m width at 9 m/s

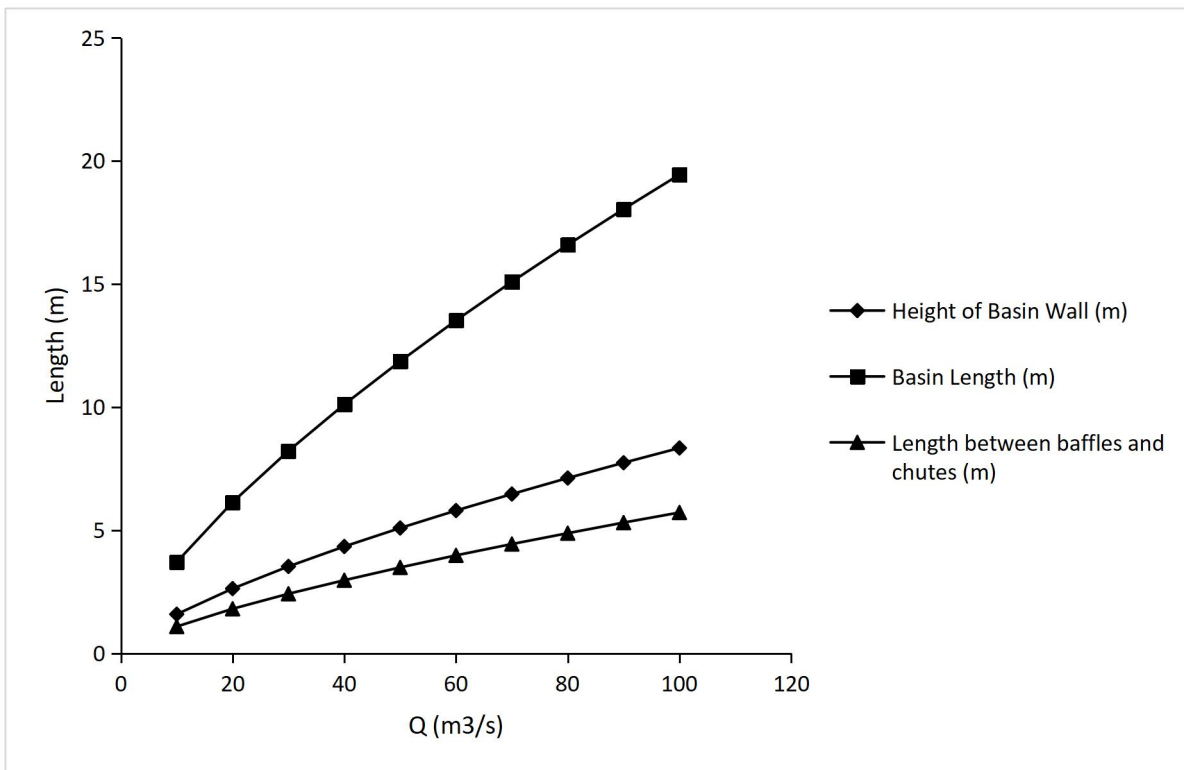


Fig. C4: The effects of velocity on the size of stilling basin 3 m width at 12 m/s

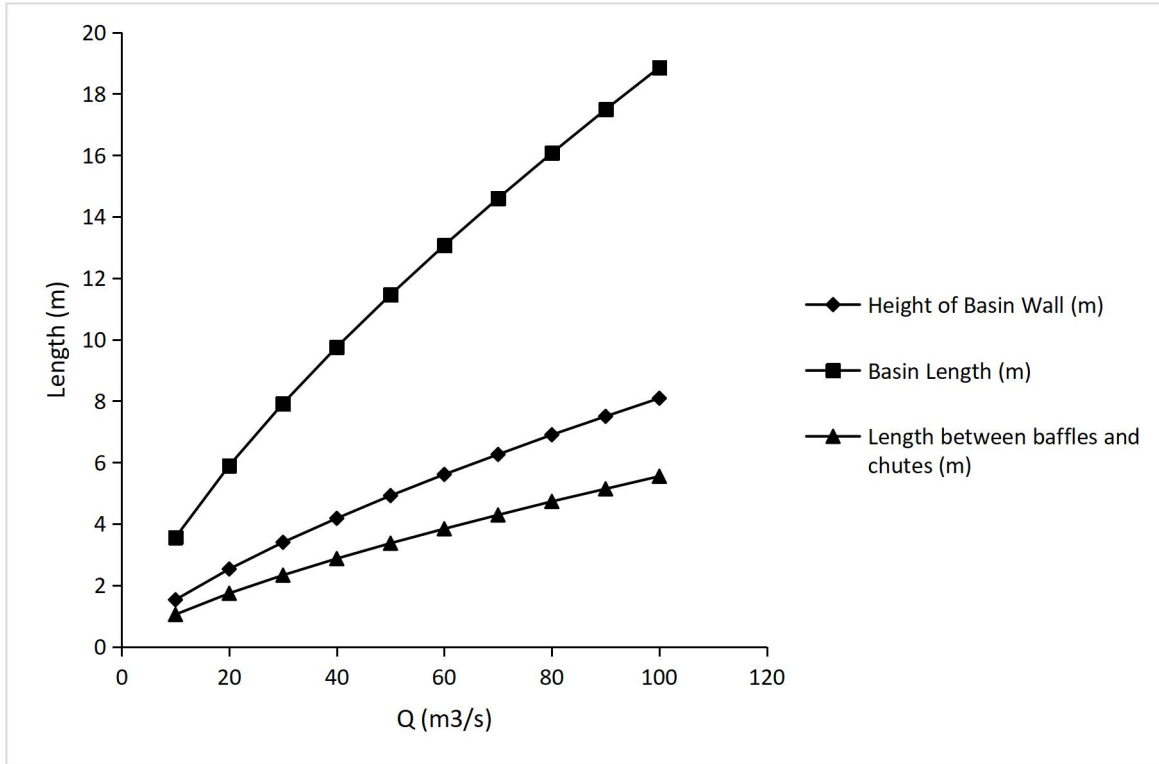


Fig. C5: The effects of velocity on the size of stilling basin 3 m width at 15 m/s

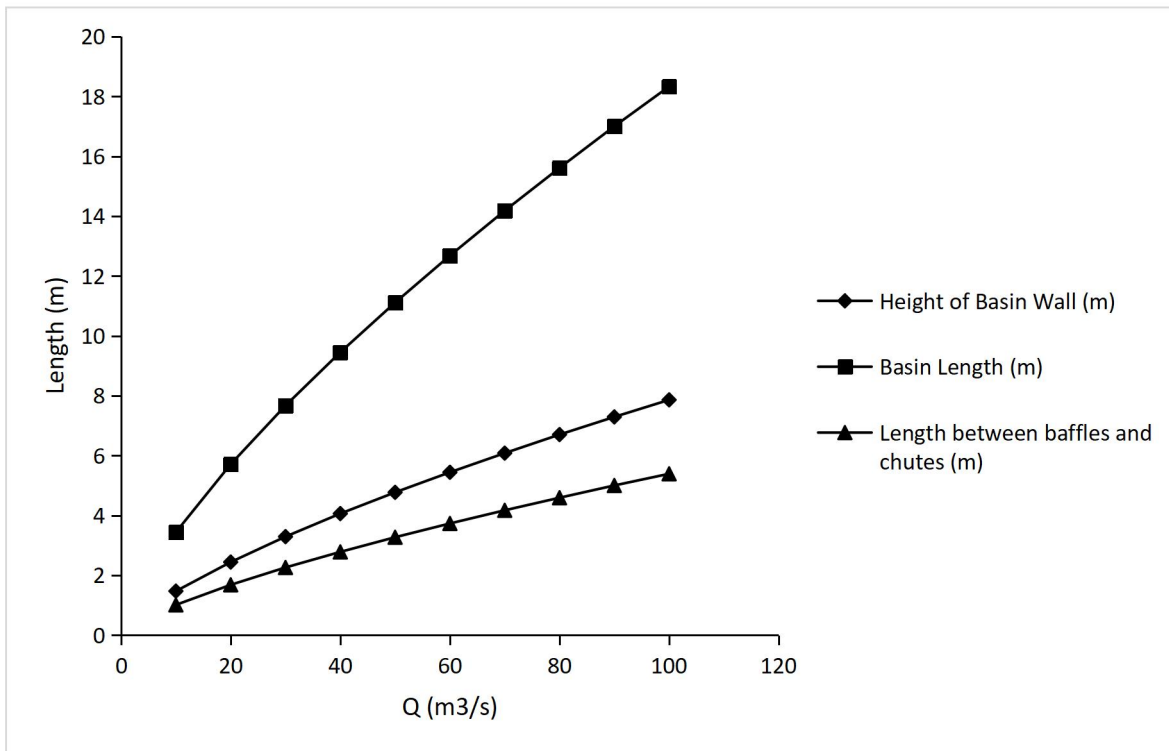


Fig. C6: The effects of velocity on the size of stilling basin 3 m width at 18 m/s

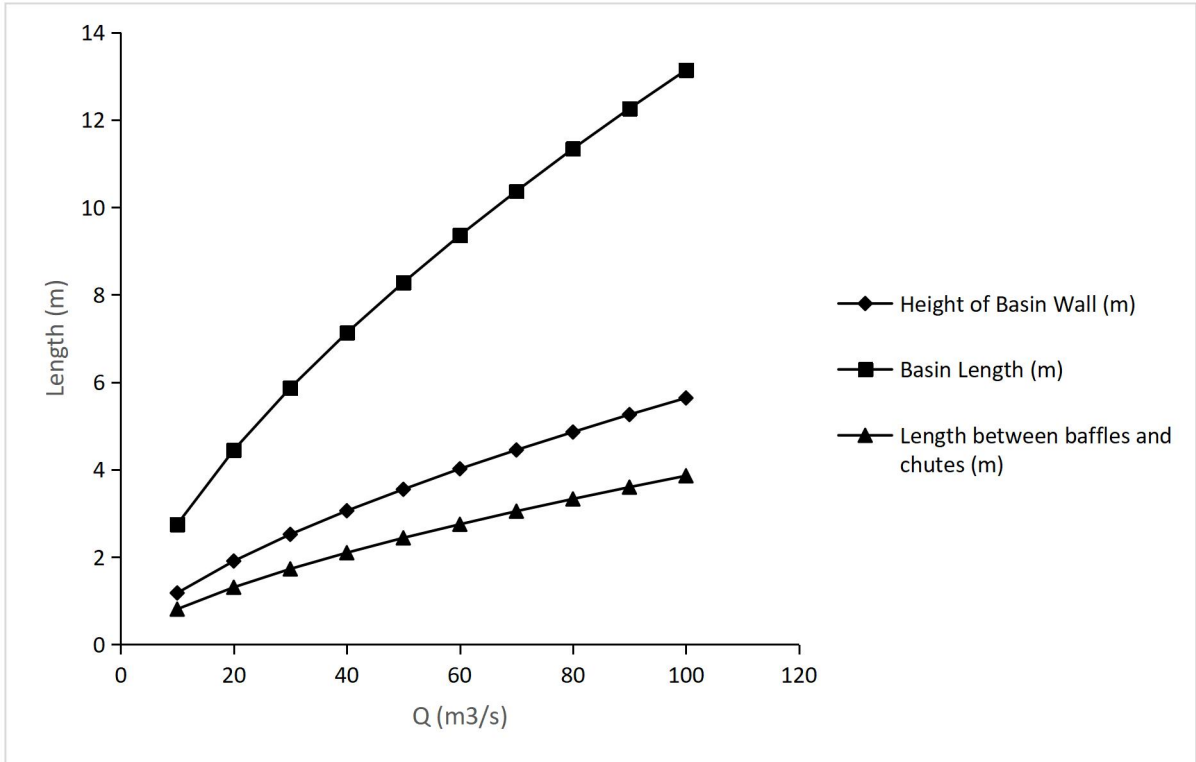


Fig. C7: The effects of velocity on the size of stilling basin 6 m width at 3 m/s

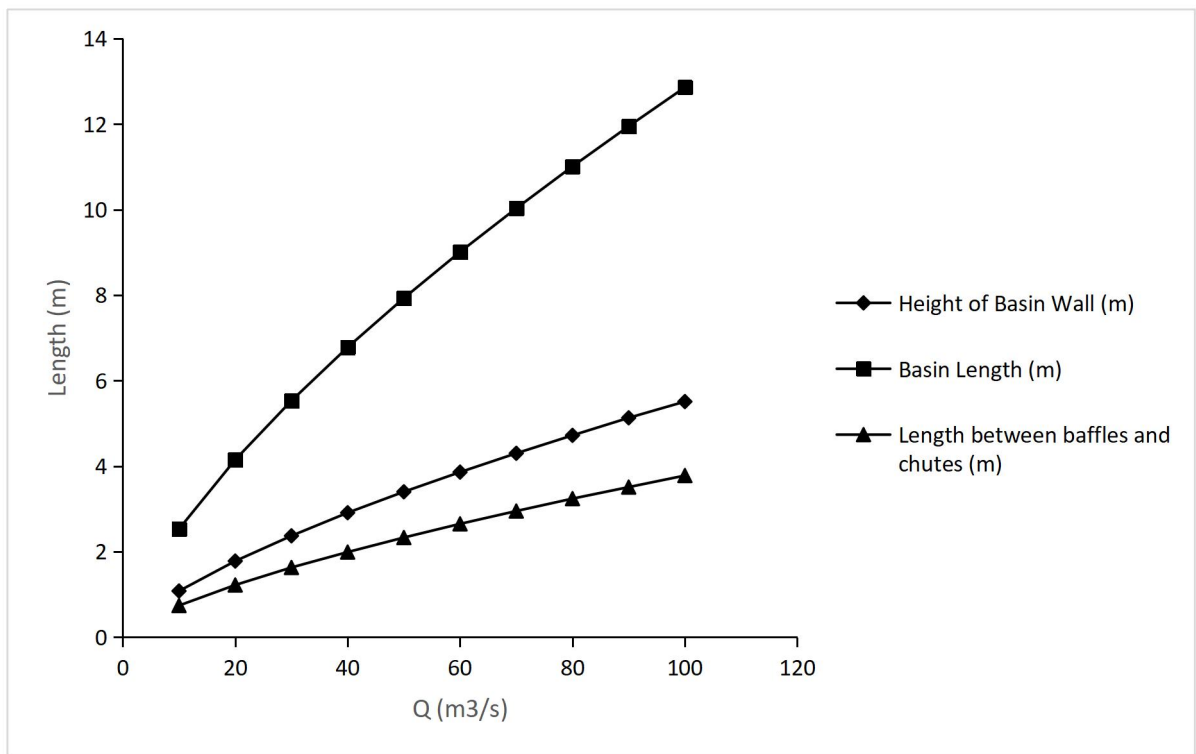


Fig. C8: The effects of velocity on the size of stilling basin 6 m width at 6 m/s

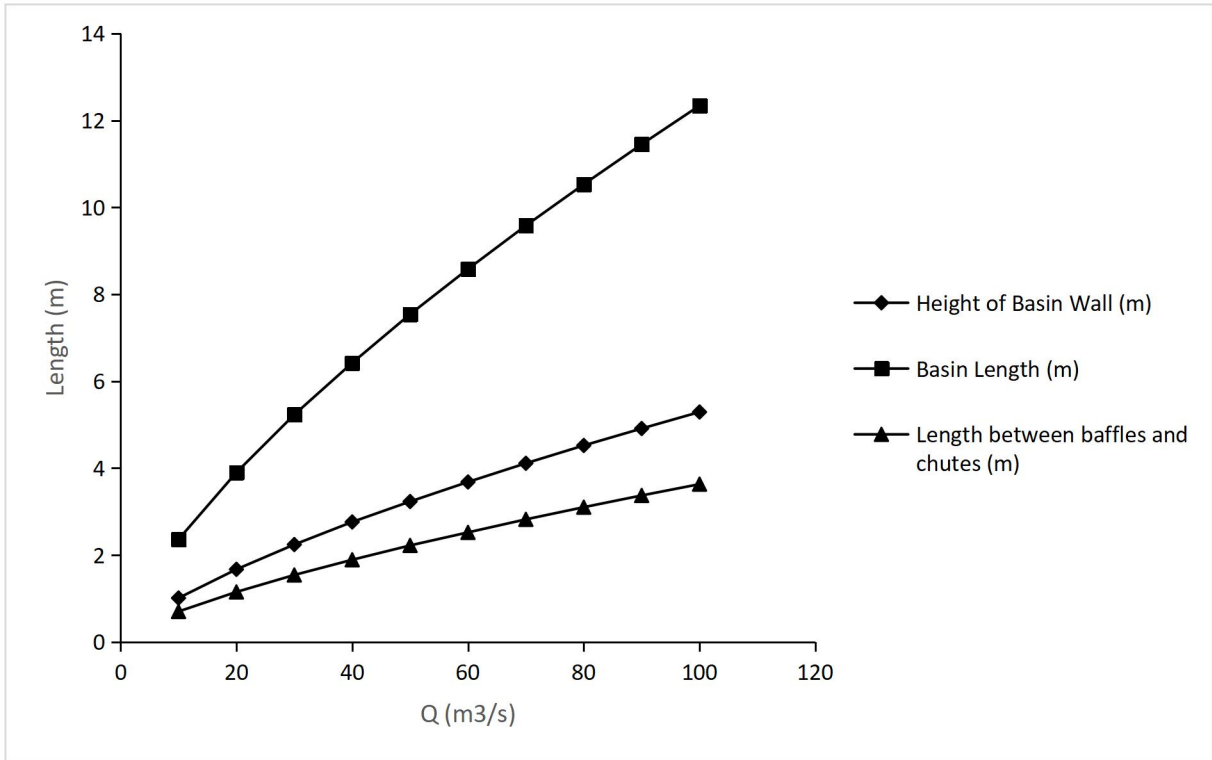


Fig. C9: The effects of velocity on the size of stilling basin 6 m width at 9 m/s

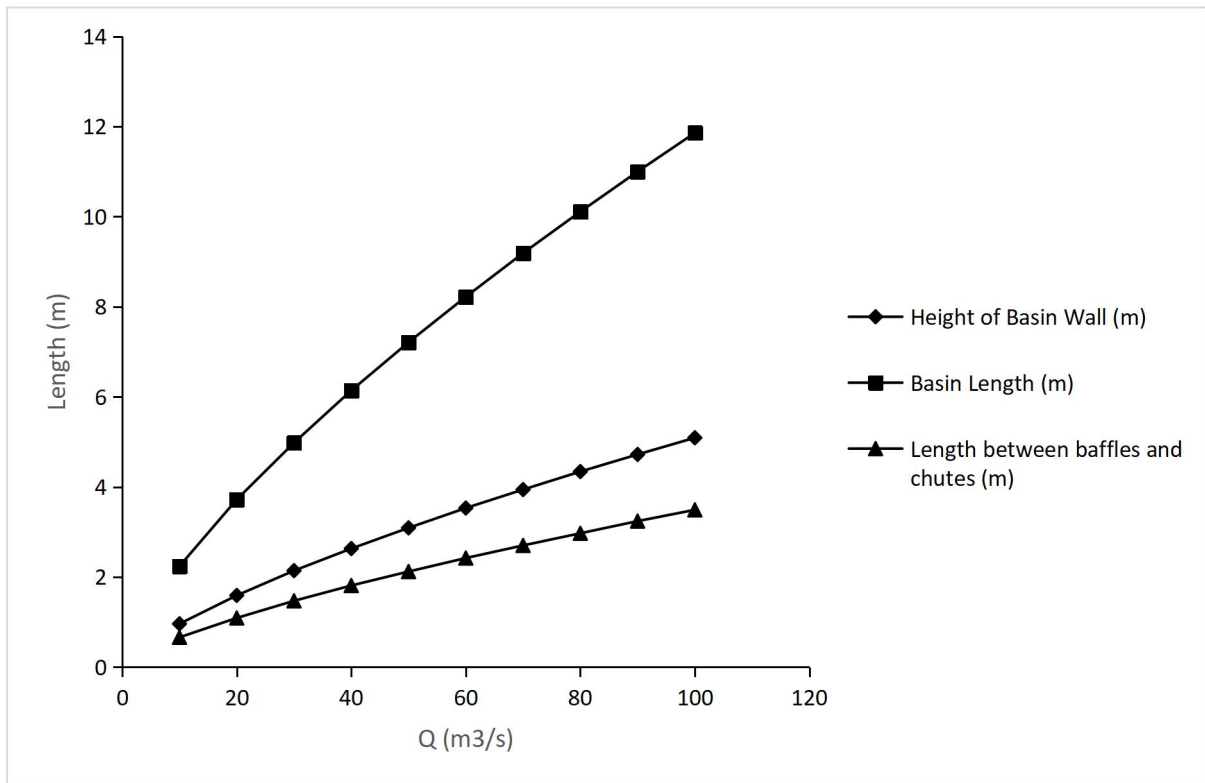


Fig. C10: The effects of velocity on the size of stilling basin 6 m width at 12 m/s

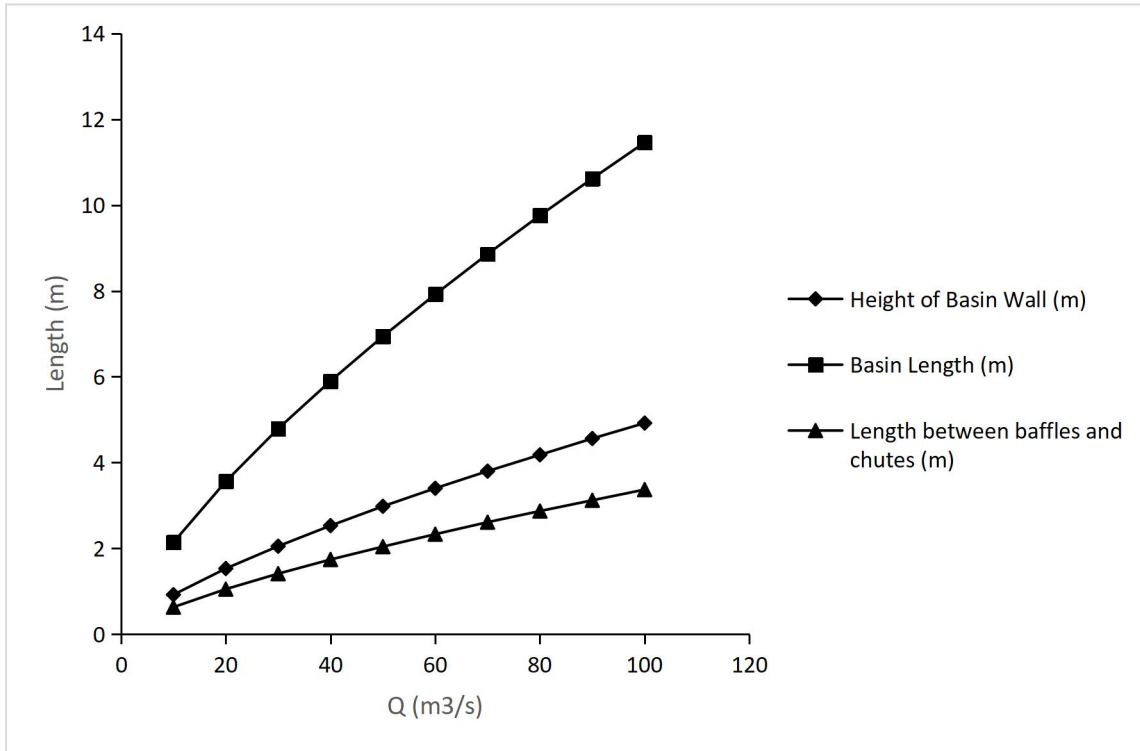


Fig. C11: The effects of velocity on the size of stilling basin 6 m width at 15 m/s

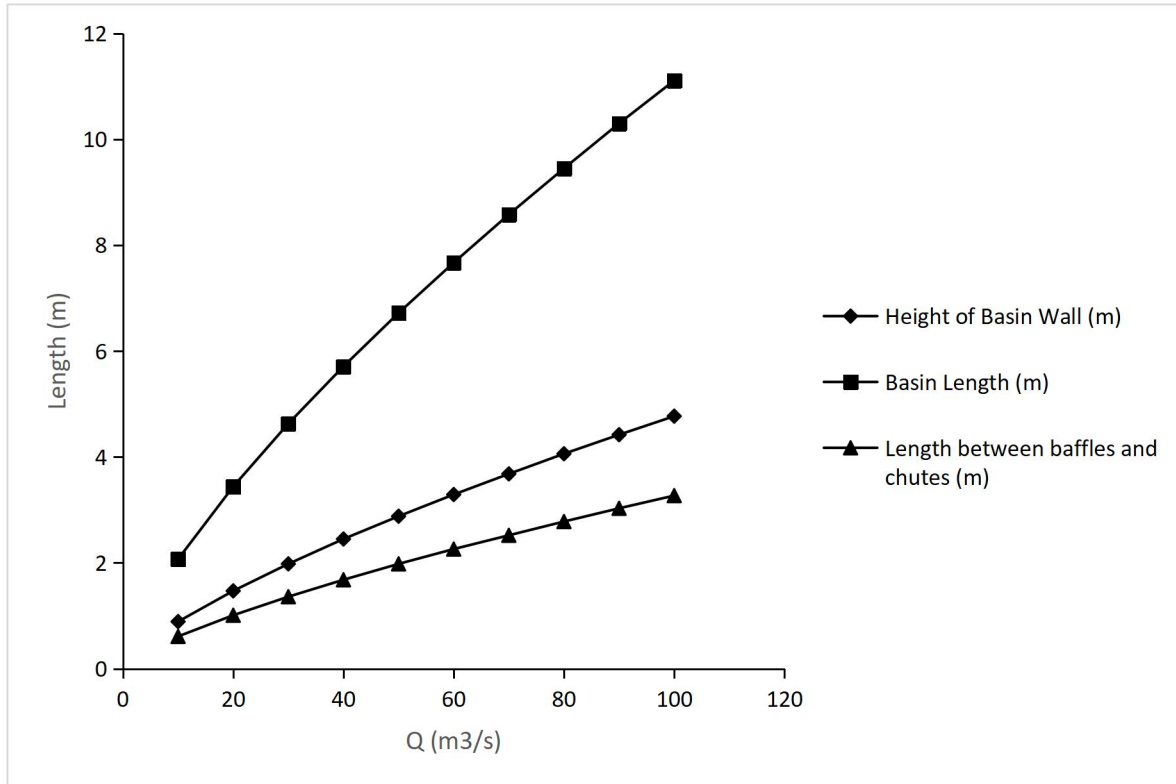


Fig. C12: The effects of velocity on the size of stilling basin 6 m width at 18 m/s

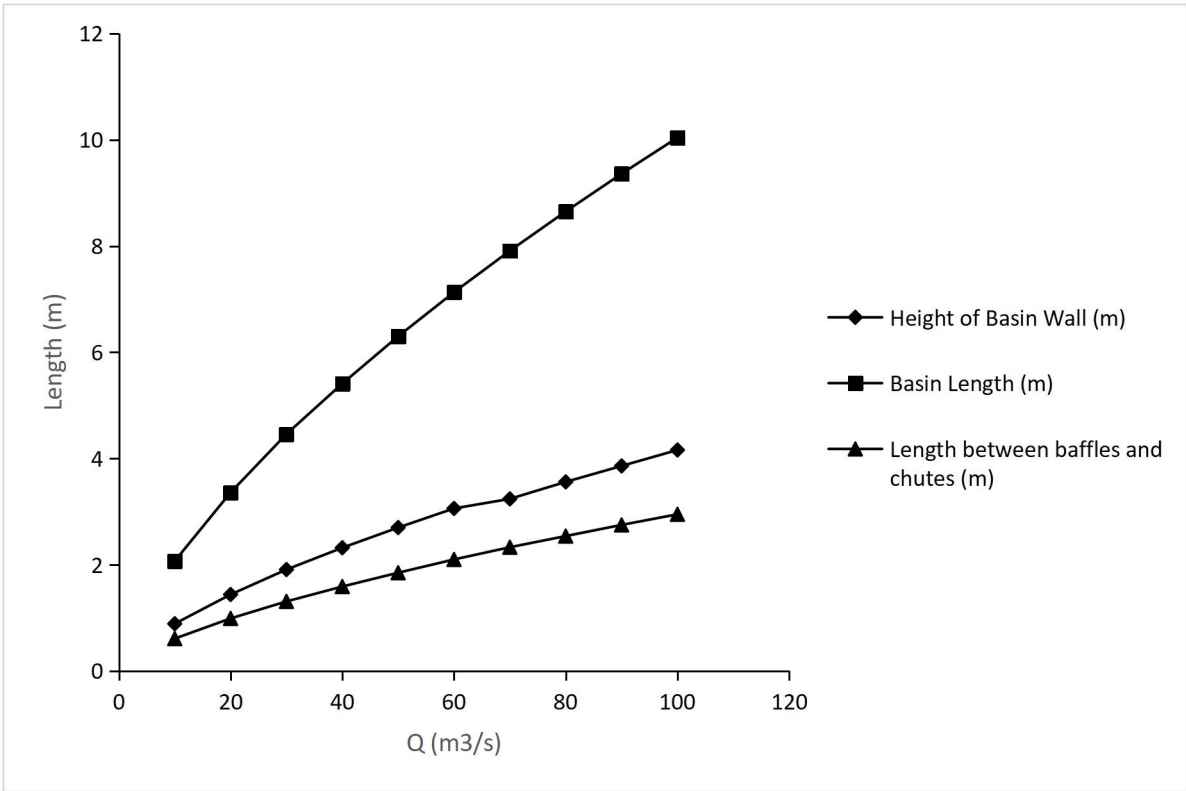


Fig. C13: The effects of velocity on the size of stilling basin 9 m width at 3 m/s

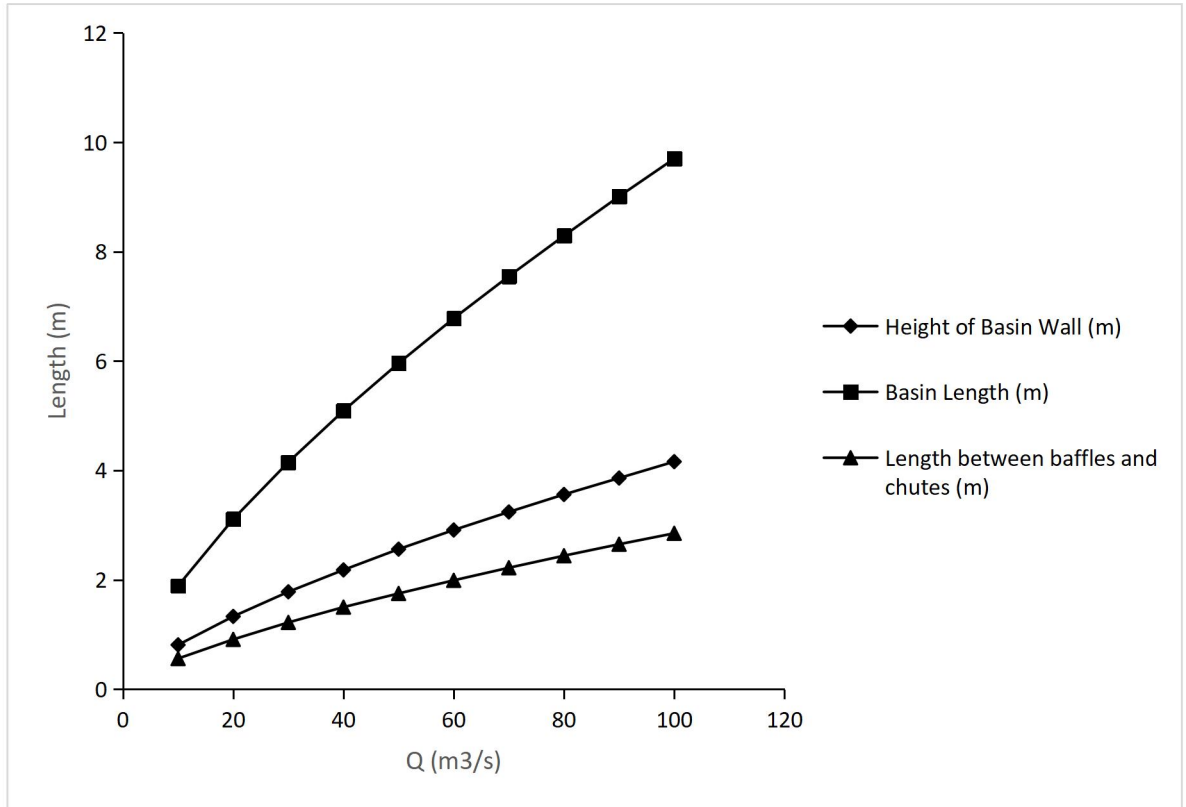


Fig. C14: The effects of velocity on the size of stilling basin 9 m width at 6 m/s

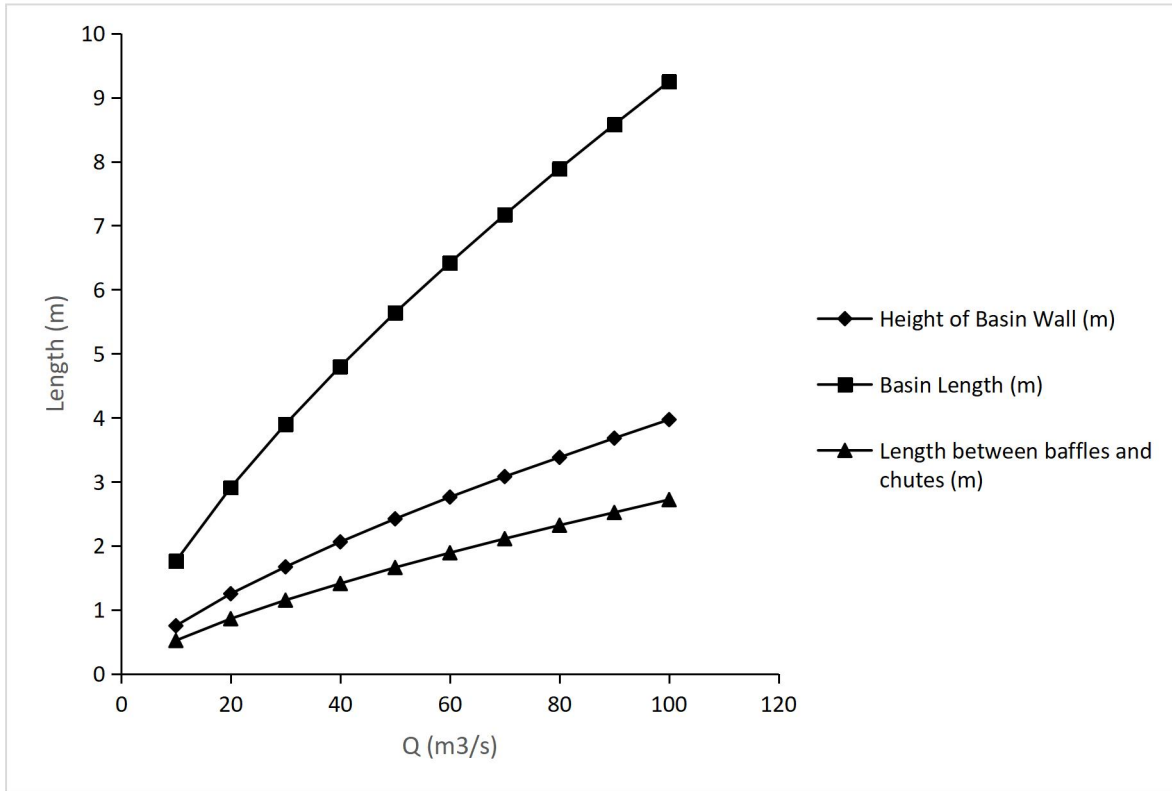


Fig. C15: The effects of velocity on the size of stilling basin 9 m width at 9 m/s

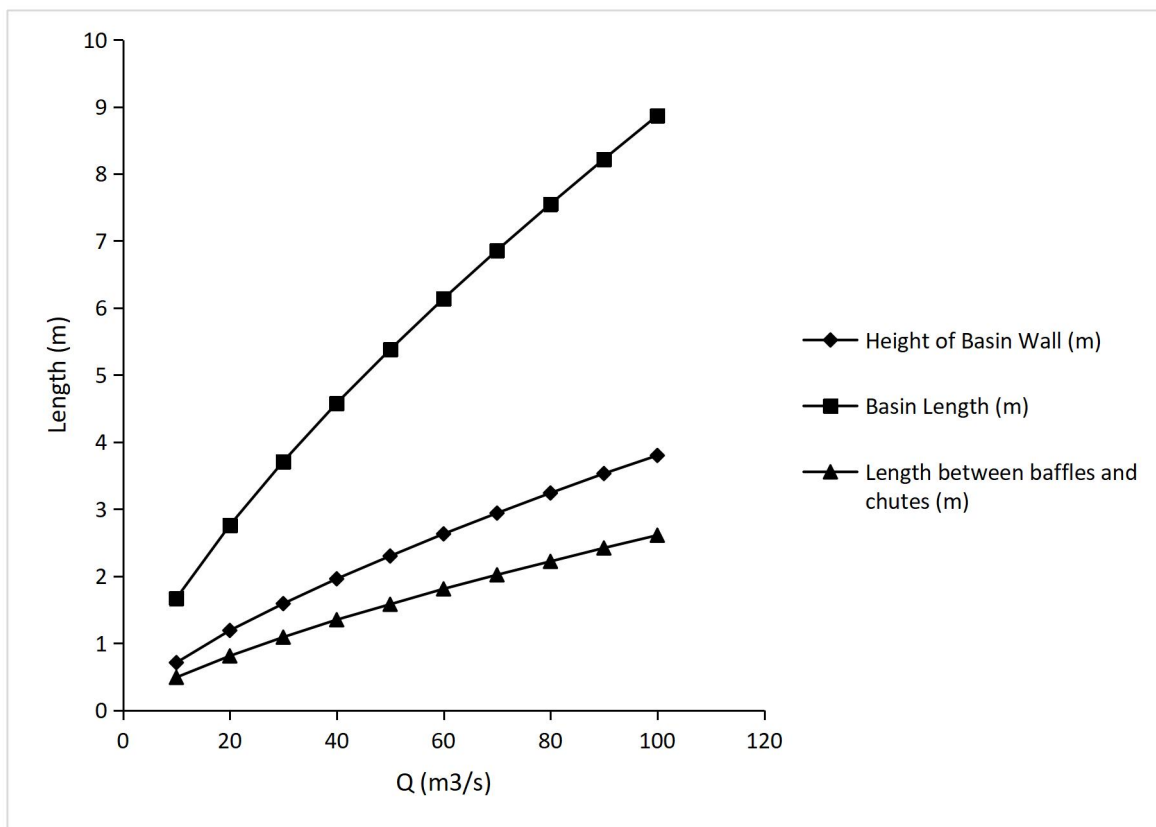


Fig. C16: The effects of velocity on the size of stilling basin 9 m width at 12 m/s

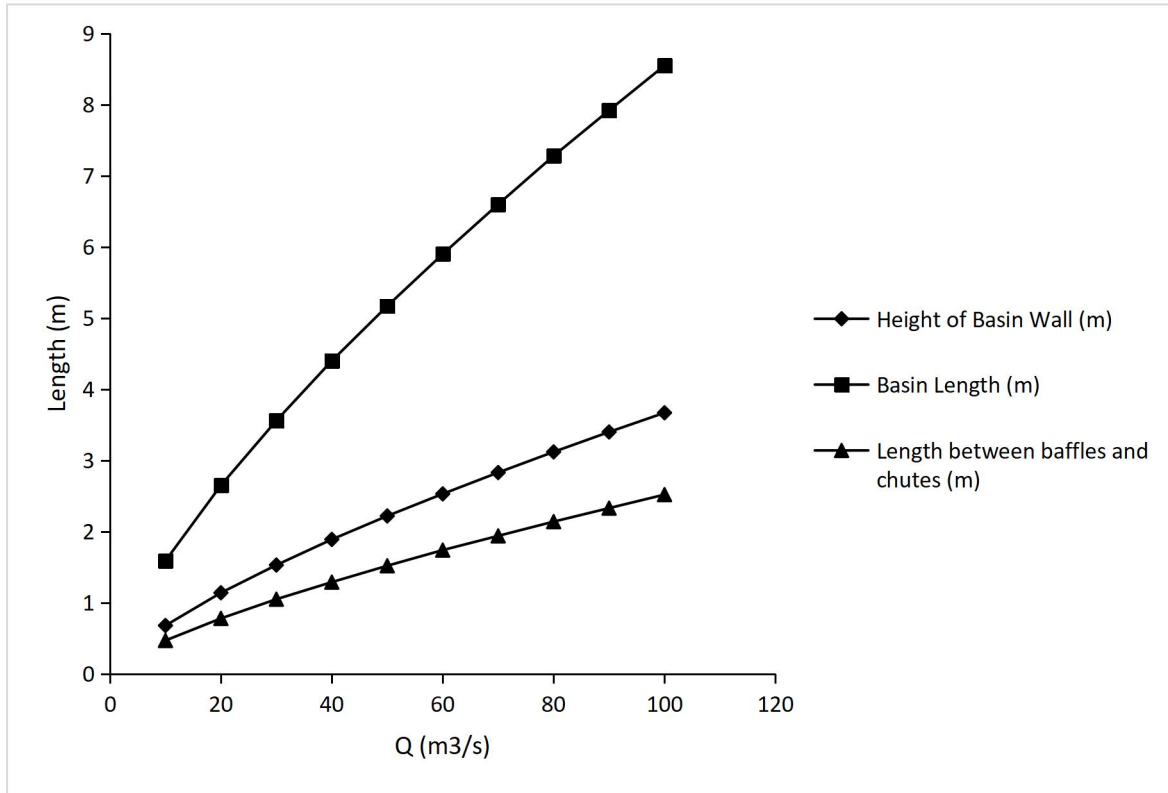


Fig. C17: The effects of velocity on the size of stilling basin 9 m width at 15 m/s

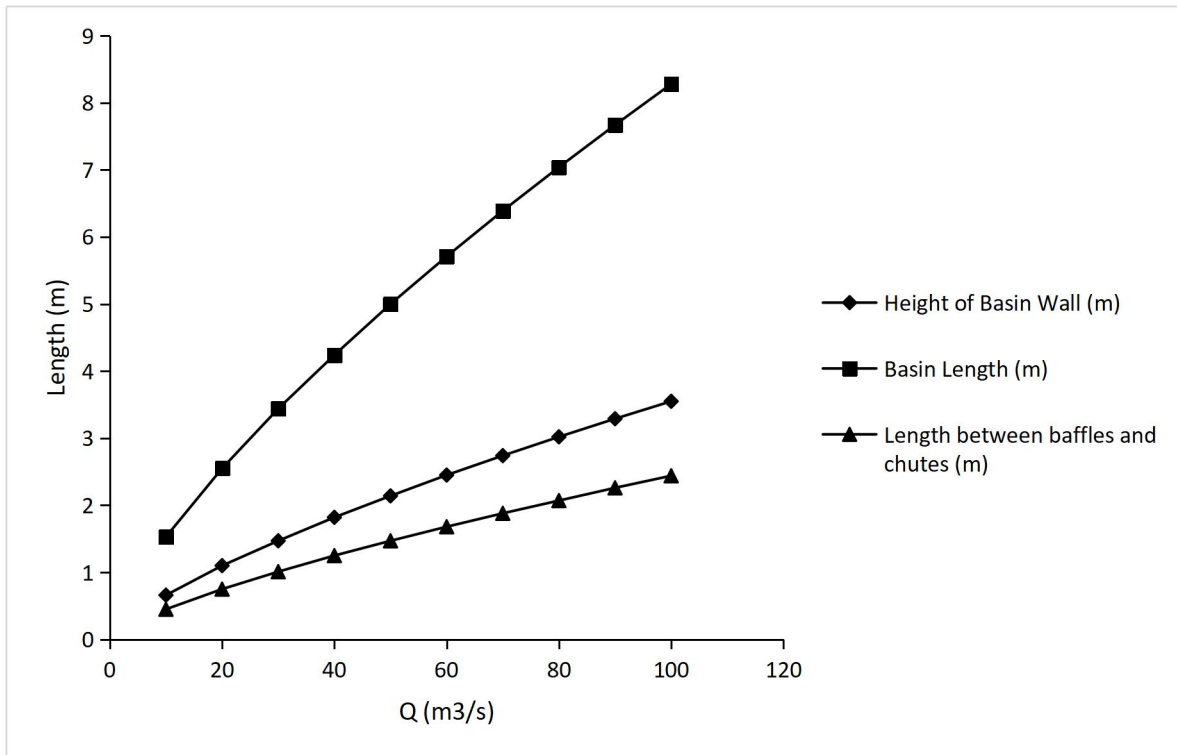


Fig. C18: The effects of velocity on the size of stilling basin 9 m width at 18 m/s

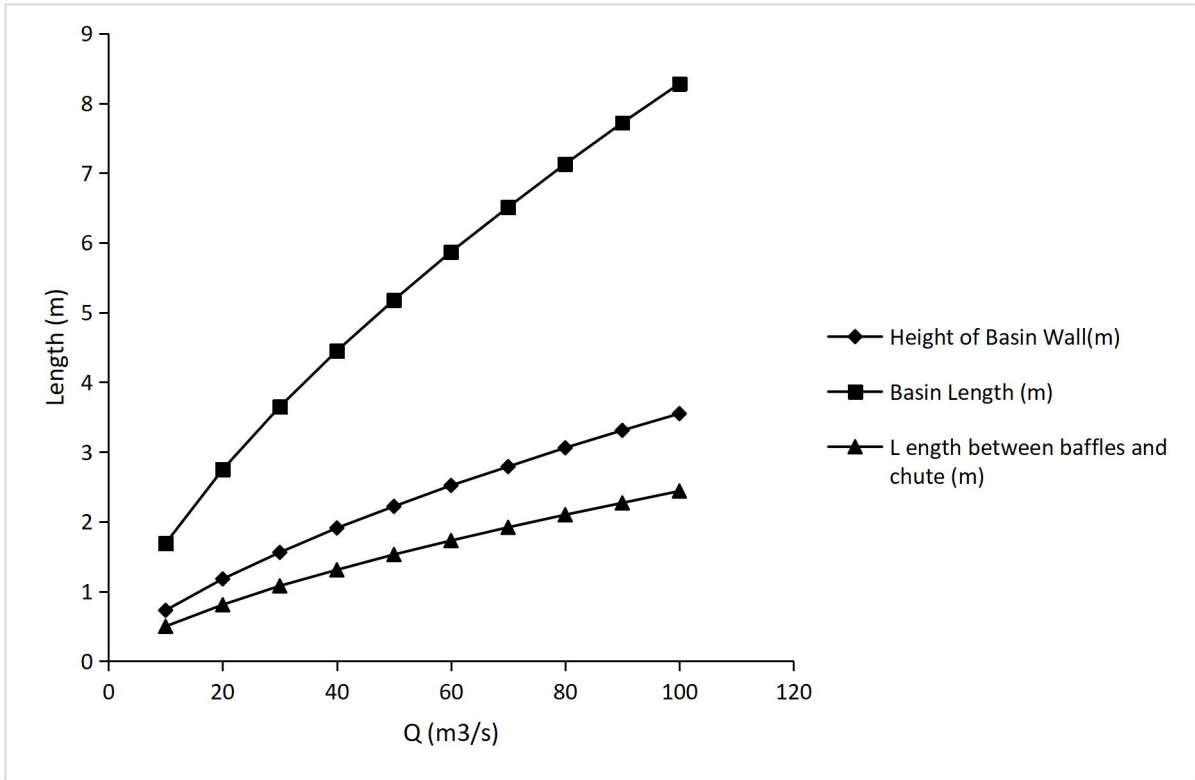


Fig. C19: The effects of velocity on the size of stilling basin 12 m width at 3 m/s

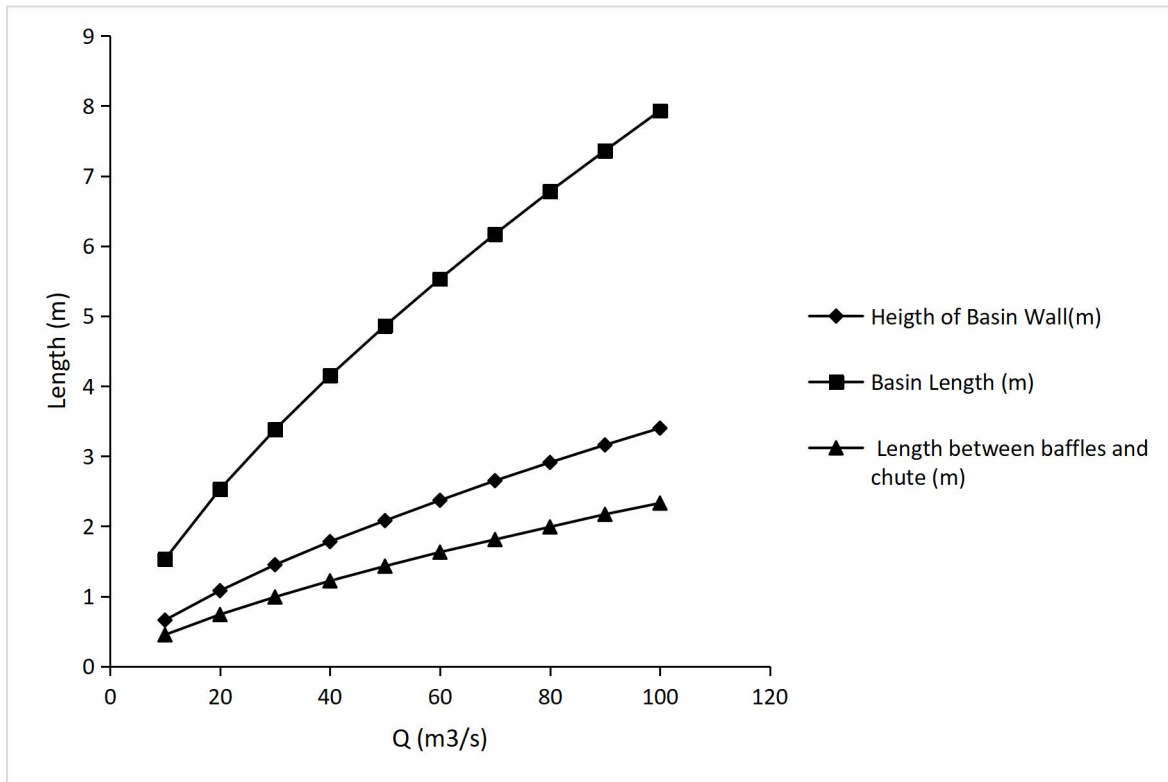


Fig. C20: The effects of velocity on the size of stilling basin 12 m width at 6 m/s

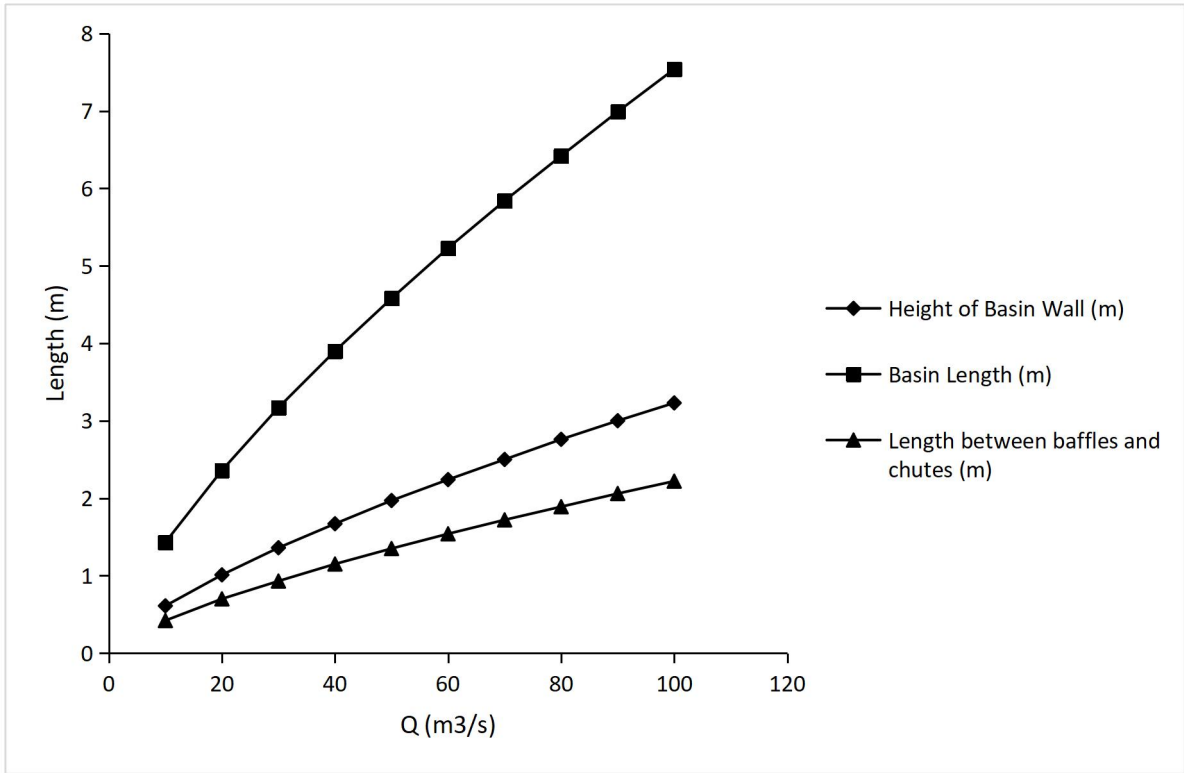


Fig. C21: The effects of velocity on the size of stilling basin 12 m width at 9 m/s

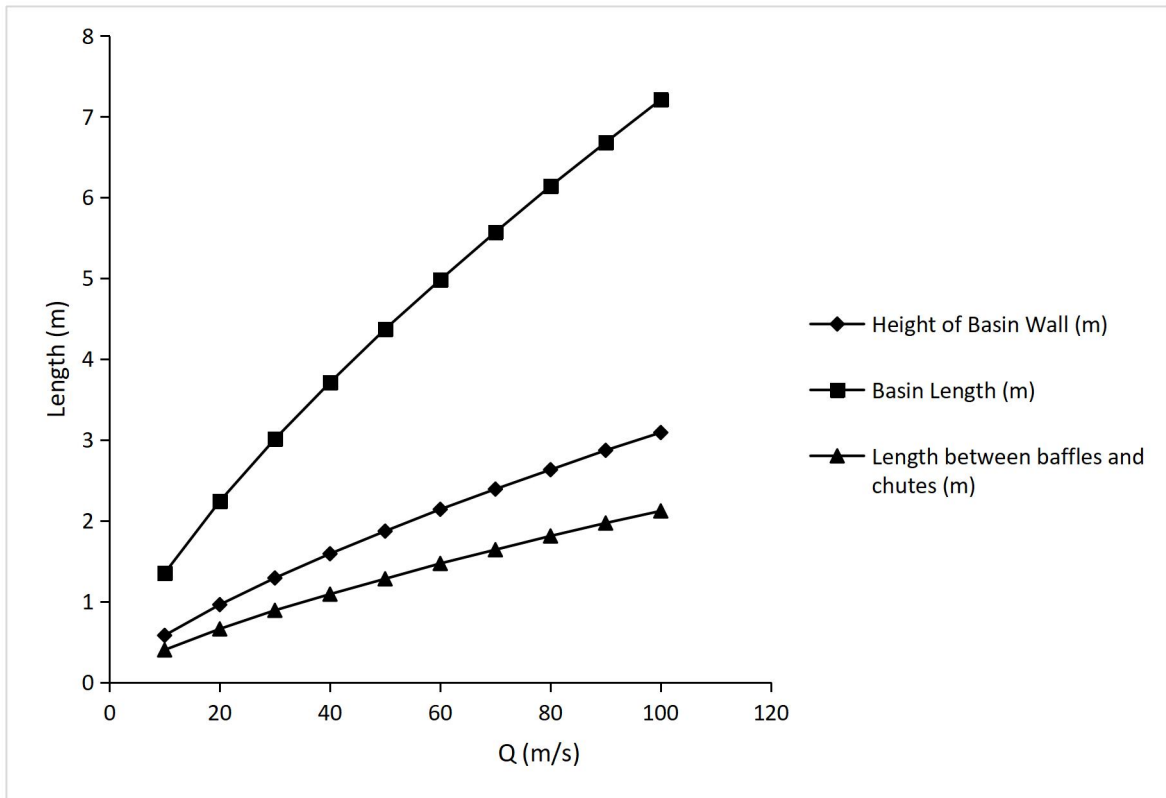


Fig. C22: The effects of velocity on the size of stilling basin 12 m width at 12 m/s

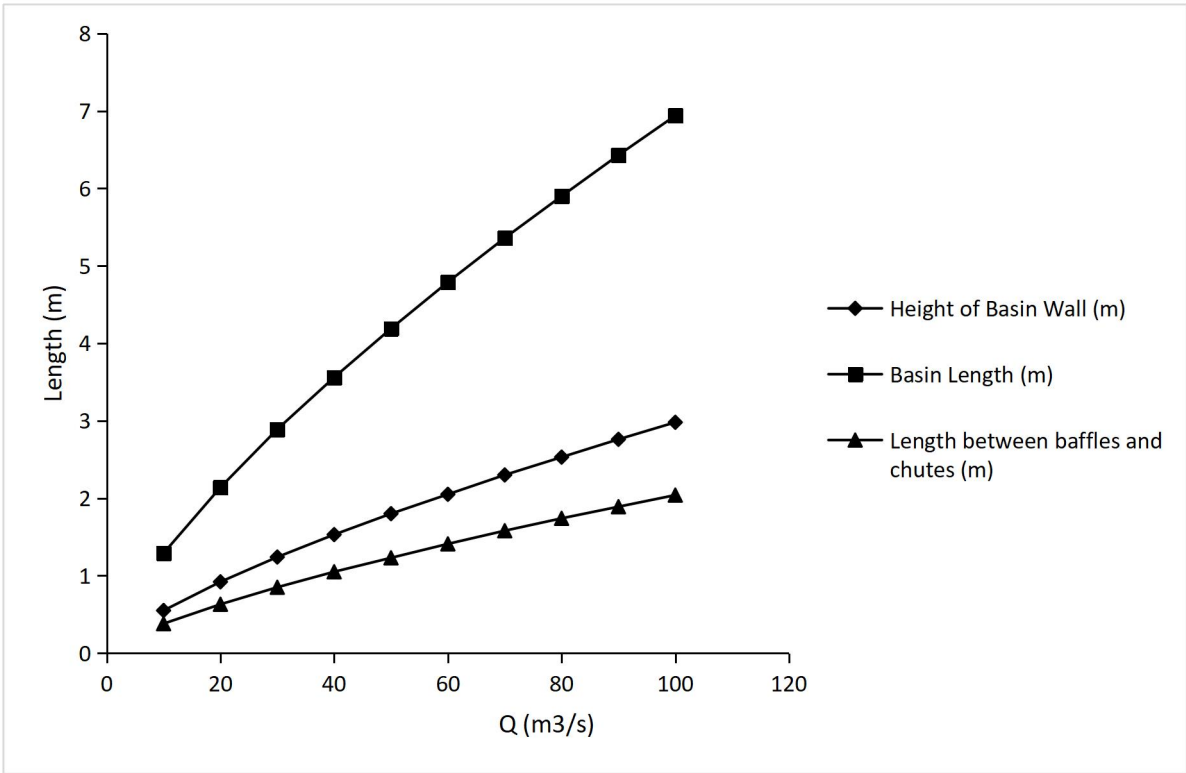


Fig. C23: The effects of velocity on the size of stilling basin 12 m width at 15 m/s

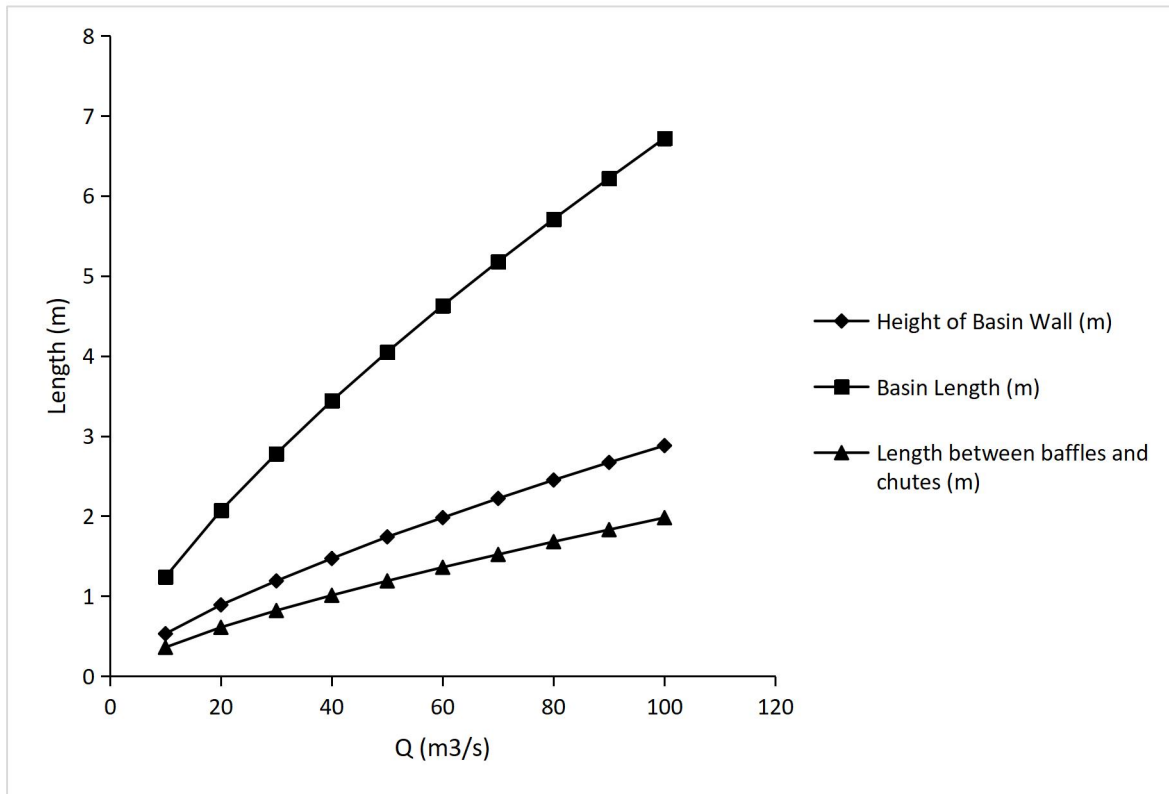


Fig. C24: The effects of velocity on the size of stilling basin 12 m width at 18 m/s

**APPENDIX D – THE DESIGN CODE FOR UNITED STATE BUREAU OF
RECLAMATION TYPE III STILLING BASIN USING MATLAB COMMAND
WRITE-UP**

USBR TYPE III STILLING BASIN DESIGN

```
% clearing previous variables and figures

clear all

close all

clc

format short

% input parameters: Width_of_basin_WB Design_discharge c

% Design_discharge=200:200:30000;

% Q1=Design_discharge;

% note A=y1*W instead of A=y1*Spillway_crest_length % Spillway_crest_length=183;

% Crest_length_of_Spillway=183;

% creating loop parameters

Q1_start=1; Q1_step=1; Q1_end=200; %Q1_start=50; Q1_step=50;

Q1_end=400; %Q1_start=200; Q1_step=200; Q1_end=30000; 5000 5000 30000

WB_start=2; WB_step=1; WB_end=25; %WB_start=2; WB_step=1;

WB_end=12;

c_start=2; c_step=1; c_end=30; %c_start=2.2; c_step=0.05; c_end=2.50;

Q1_length=numel(Q1_start:Q1_step:Q1_end);

WB_length=numel(WB_start:WB_step:WB_end);

c_length=numel(c_start:c_step:c_end);

% initializing first table
```

```

total_row_size=Q1_length*WB_length*c_length;
Q1_s(total_row_size,1)=0;   WB_s(total_row_size,1)=0;   q_s(total_row_size,1)=0;
c_s(total_row_size,1)=0;   y1_s(total_row_size,1)=0;
velocity_V1_s(total_row_size,1)=0;
Fr1_s(total_row_size,1)=0;   y2_s(total_row_size,1)=0;
% initializing second table
Height_of_basin_wall_Hj_s(total_row_size,1)=0;
Basin_length_LT_s(total_row_size,1)=0;   %WB_s(total_row_size,1)=0;
Lw_s(total_row_size,1)=0;
% initializing third table
h1_s(total_row_size,1)=0;   W1_s(total_row_size,1)=0;   S1_s(total_row_size,1)=0;
Number_of_chute_blocks_Nc_s(total_row_size,1)=0;   H3_s(total_row_size,1)=0;
Lu_s(total_row_size,1)=0;
L1_s(total_row_size,1)=0;   W3_s(total_row_size,1)=0;   S3_s(total_row_size,1)=0;
Number_of_baffle_NB_s(total_row_size,1)=0;   H4_s(total_row_size,1)=0;
L5_s(total_row_size,1)=0;
commandwindow
pause('on')
for Q1=Q1_start:Q1_step:Q1_end
    for WB= WB_start:WB_step:WB_end
        for c=c_start:c_step:c_end
            Q1_count0=((Q1-Q1_start)/Q1_step)+1;
            WB_count0=((WB-WB_start)/WB_step)+1;
            c_count0=((c-c_start)/c_step)+1;

```

```

All_count=round((((Q1_count0-1)*WB_length*c_length)+((WB_count0-1)*c_length)
+c_count0);          %1.1550e+04

Prejump_depth=(Q1/(c*WB))^(2/3); y1=Prejump_depth; %Prejump_depth=2.875;

gravity_g=9.81;

Area_A1=WB*y1; %Area_A1=L*y1; area calculation changed

velocity_V1=Q1/(Area_A1);

Fr1=velocity_V1/((gravity_g*y1)^0.5);

    if Fr1 < 4 %changes non suitable values to zero%

        continue

    elseif Fr1 > 9

        continue

    elseif velocity_V1 < 1

        continue

    elseif velocity_V1 > 30

        continue

    end

Postjump_depth=(y1/2)*(-1+((1+
(8*(Fr1^2)))^0.5)); %Postjump_depth=18.79; %y2=(y1/2)*(-1+((1+ (8*(Fr1^2)))^0.5))

% L=Spillway_crest_length;

H=Prejump_depth;

q=Q1/WB;

y2=Postjump_depth;

% Flow parameters %

% Flow parameters %

```

```

% For Basin sizing

% For Basin sizing

Basin_length_LT=2.72*y2;

Height_of_basin_wall_Hj=((y2-y1)^3)/(4*y1*y2);

Height_of_basin_wall_Hj=Height_of_basin_wall_Hj+(Height_of_basin_wall_Hj/6);

Distance_bt_chute_and_baffle_Lw=0.8*y2;

Lw=Distance_bt_chute_and_baffle_Lw;

% Width_of_basin_WB=6; %((between 3m and 6m)*Independent variable)

Chute_block_height_h1=y1;

h1=Chute_block_height_h1;

Chute_block_width_W1=y1;

W1=Chute_block_width_W1;

Chute_block_spacing_S1=y1;

S1=Chute_block_spacing_S1;

Number_of_chute_blocks_Nc=round(WB/(2*y1)); % rounded to whole number

    if Number_of_chute_blocks_Nc == 0

        continue

    end

% Baffle Piers%

% Baffle Piers%

Height_of_baffle_pier_H3=y1*(0.6+(Fr1/6));

H3=Height_of_baffle_pier_H3;

Top_thickness_of_baffle_Lu=0.2*H3;

Lu=Top_thickness_of_baffle_Lu;

Base_thickness_of_baffle_Ll=1.2*H3;

```

```

L1=Base_thickness_of_baffle_L1;
Width_of_baffle_W3=0.75*H3;
W3=Width_of_baffle_W3;
Spacing_of_baffle_S3=W3;
S3=Spacing_of_baffle_S3;
Number_of_baffle_NB=round(WB/(2*W3)); % rounded to whole number
% End sill%
% End sill%
Height_of_end_sill_H4=y1*(1+(Fr1/18));
H4=Height_of_end_sill_H4;
Length_of_end_sill_L5=2*H4; %pls verify length of end sill formula
L5=Length_of_end_sill_L5;
% Generating the large values for table 1
Q1_s(All_count,1)=Q1; WB_s(All_count,1)=WB; q_s(All_count,1)=q;
c_s(All_count,1)=c;
y1_s(All_count,1)=y1; velocity_V1_s(All_count,1)=velocity_V1; Fr1_s(All_count,1)=Fr1;
y2_s(All_count,1)=y2;
% TEble1=[Q1 WB q c y1 velocity_V1 Fr1 y2]
TEble1=[Q1_s WB_s q_s c_s y1_s velocity_V1_s Fr1_s y2_s];
% Generating the large values for table 2
Height_of_basin_wall_Hj_s(All_count,1)=Height_of_basin_wall_Hj;
Basin_length_LT_s(All_count,1)=Basin_length_LT;
Lw_s(All_count,1)=Lw;
TEble2=[Q1_s WB_s c_s Height_of_basin_wall_Hj_s Basin_length_LT_s Lw_s];
% Generating the large values for table 3

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```

h1_s(All_count,1)=h1; W1_s(All_count,1)=W1; S1_s(All_count,1)=S1;
Number_of_chute_blocks_Nc_s(All_count,1)=Number_of_chute_blocks_Nc;
H3_s(All_count,1)=H3; Lu_s(All_count,1)=Lu; L1_s(All_count,1)=L1;
W3_s(All_count,1)=W3; S3_s(All_count,1)=S3;
Number_of_baffle_NB_s(All_count,1)=Number_of_baffle_NB; H4_s(All_count,1)=H4;
L5_s(All_count,1)=L5;
TEble3=[Q1_s WB_s c_s h1_s W1_s S1_s Number_of_chute_blocks_Nc_s H3_s Lu_s L1_s
W3_s S3_s Number_of_baffle_NB_s H4_s L5_s];
    end
    zaa_final=Q1_length*WB_length*c_length;
    percentate_Done= ((All_count/(zaa_final)*1)*100);
    disp(['percentate Done ',num2str(percentate_Done),'%'])
    end
end
pause(3)
clc
[TEble1_vec_row,TEble1_vec_column]=find(TEble1(:,7)); %obtains the row vector of
suitable value with fraud number in the correct range
TEble1_re=TEble1(TEble1_vec_row,:);
TEble2_re=TEble2(TEble1_vec_row,:);
TEble3_re=TEble3(TEble1_vec_row,:);
[TEble1_vec_row1,TEble1_vec_column1]=find(TEble3_re(:,7)); %obtains the row vector of
suitable value with fraud number in the correct range
TEble1_re1=TEble1_re(TEble1_vec_row1,:);
TEble2_re1=TEble2_re(TEble1_vec_row1,:);

```

```

TEble3_re1=TEble3_re(TEble1_vec_row1,:);

% Other parameters calculation

% Other parameters calculation

% Arranging table

% Arranging table

% column names

x_a100{1,1}=' Q ';x_a100{1,2}=' WB '; x_a100{1,3}=' q'; x_a100{1,4}=' c';
x_a100{1,5}=' y1 '; x_a100{1,6}=' V1 '; x_a100{1,7}=' Fr1'; x_a100{1,8}=' y2 ';
x_a200{1,1}=' Q ';x_a200{1,2}=' WB '; x_a200{1,3}=' c'; x_a200{1,4}=' Hj
';x_a200{1,5}=' LT '; x_a200{1,6}=' Lw ';
x_a300{1,1}=' Q ';x_a300{1,2}=' WB '; x_a300{1,3}=' c'; x_a300{1,4}=' h1
';x_a300{1,5}=' W1 '; x_a300{1,6}=' S1 '; x_a300{1,7}=' Nc'; x_a300{1,8}=' H3 ';
    x_a300{1,9}=' Lu '; x_a300{1,10}=' L1 '; x_a300{1,11}=' W3 '; x_a300{1,12}='
S3 '; x_a300{1,13}=' NB';x_a300{1,14}=' H4 '; x_a300{1,15}=' L5 ';

% row names

BA1=1:size(TEble1_re1,1); %obtains size of double modified table

BA1_row='row_';

BA2{numel(BA1),1}=0; %initializing

BA3{numel(BA1),1}=0; %initializing

% BA4{1,numel(BA1)}=0; %initializing

for ty=1:numel(BA1)

BA2{ty,1}=num2str(flipud(BA1(1,ty))); % converts numbers to string and puts them in
diferent cell position

BA3(ty,1)=strcat(BA1_row,BA2(ty)) ; % concatenate y_axis to form an alphanumeric
name

```

```

end

% end of naming rows

% TEble1=[Q1 WB q c y1 velocity_V1 Fr1 y2]

% TEble2=[Height_of_basin_wall_Hj Basin_length_LT WB Lw]

% TEble3=[h1 W1 S1 Number_of_chute_blocks_Nc H3 Lu L1 W3 S3
Number_of_baffle_NB L5 ]

% TEble1

% TEble2

% TEble3

% Generating tables

% Generating tables

Teble1=array2table(TEble1_re1,...
    'RowNames',BA3 ,...
    'VariableNames',x_a100 );
    display(Teble1)

Teble2=array2table(TEble2_re1,...
    'RowNames',BA3 ,...
    'VariableNames',x_a200 );
    display(Teble2)

Teble3=array2table(TEble3_re1,...
    'RowNames',BA3 ,...
    'VariableNames',x_a300 );
    display(Teble3)

size_of_TEble3_re=size(TEble3_re);
size_of_TEble3_re1=size(TEble3_re1)

```

%

filename='christopher16.xlsx';

writetable(Teble1,filename,'Sheet',1,'Range','B2','WriteRowNames',1)

writetable(Teble2,filename,'Sheet',2,'Range','B2','WriteRowNames',1)

writetable(Teble3,filename,'Sheet',3,'Range','B2','WriteRowNames',1)