ASSESSMENT ON FLOW CHARACTERISTICS OF TAWAU'S SPILLWAY HYDRAULIC PHYSICAL MODEL

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ASSESSMENT ON FLOW CHARACTERISTICS OF TAWAU'S SPILLWAY HYDRAULIC PHYSICAL MODEL

BY

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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PENILAIAN TERHADAP CIRI-CIRI ALIRAN ALUR LIMPAH TAWAU MODEL HIDRAULIK FIZIKAL

ABSTRAK

Alur limpah adalah antara struktur yang paling penting daripada projek empangan. Projek tersebut menyediakan dengan keupayaan untuk melepaskan air yang berlebihan atau banjir dengan cara yang terkawal atau tidak terkawal untuk memastikan keselamatan projek. Alur limpah adalah amat penting bagi kemudahan alur limpah untuk direka dengan kapasiti yang mencukupi untuk mengelakkan aliran melepasi dan keluar dari alur limpah terutamanya apabila jenis timbusan tanah empangan dipilih untuk projek tersebut. Halaju tinggi dalam tekanan rendah atau negatif pada papak alur limpah, mengeruk dan hakisan di kawasan hiliran.Selain itu, tekanan negatif membawa kepada peronggaan dan boleh menyebabkan kerosakan kritikal pada struktur alur limpah. Kajian ini bertujuan untuk mengkaji ciri-ciri aliran di sepanjang alur limpah seperti kedalaman air, halaju, tekanan dan pelesapan tenaga di lembangan penenang. Dam Tawau Spillway diskalakan pada 1: 30 alur limpah model fizikal telah dibina dan dipasang di Hydraulic Makmal Universiti Sains Malaysia. Kajian ini telah dijalankan ke atas dua kadar yang berbeza aliran (196 m3/s,dan 392 m3/s) dengan sejumlah 109 titik pengukuran bagi setiap case. Untuk memastikan aliran keluaran adalah selamat daripada menyebabkan kerosakan teruk pada kawasan hiliran, kajian telah memberi tumpuan kepada penenang lembangan juga. Berdasarkan keputusan,lompatan hidraulik, kedalaman dan halaju,Jenis III stiling lembangan sesuai untuk digunakan. Akhir sekali, Kes 2 telah disyorkan untuk digunakan Jenis II Stilling Basin untuk penilaian tempoh yang panjang. Oleh itu, Jenis III Stilling Basin adalah sesuai untuk kedua-dua, Kes 1 dan Kes 2.

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ABSTRACT

The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess or flood water in a controlled or uncontrolled manner to ensure the safety of the project. It is of paramount importance for the spillway facilities to be designed with sufficient capacity to avoid overtopping of the dam, especially when an earthfill or rockfill type of dam is selected for the project. High velocity results in low or negative pressure on the spillway slab, scouring and erosion at downstream area. Whereas, negative pressure leads to cavitation and may cause critical damage on spillway structure. This study aims to investigate the flow characteristics along spillway such as water depth, velocity, pressure and energy dissipation on the stilling basin. Tawau Dam's Spillway is a 1:30 scaled spillway physical model was constructed and assembled in Hydraulic Laboratory of Universiti Sains Malaysia. This study has been conducted on two different flow rate (196 m^3 /s, and 392 m^3/s) with total of 109 measurement points for each case.To ensure the release flow is safe from causing severe damage on the downstream area, the study was focused on stilling basin as well. Based on the results, hydraulic jump length ,depth and velocity thecurrent Type II stiling basin suitable to used. Lastly, the Case 2 has been recommended to use Type III Stilling Basin for long period assessment. Thus, it can be concluded that the Type II Stilling Basin is suitable for both Case 1 and Case 2.

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CFD	Computational Fluid Dynamic
PMF	Probable Maximum Flood
SDF	Spillway Design Flood

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Dams are built across river and streams to confine and utilize the flow of water for humans such as irrigation, generation of hydroelectricity, flood control, water supply and navigation. This confinement of water creates lakes or reservoirs. Hence, provision of a hydraulically efficient and structurally strong spillway is very important for the safety of the dam, and life and property along the river down below. Spillways and other flood outlets are designed to safely convey floods to the watercourse downstream from the dam and to prevent overtopping of the dam (Bhajantri et al.,2006).

The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess or flood water in a controlled or uncontrolled manner to ensure the safety of the project. It is of paramount importance for the spillway facilities to be designed with sufficient capacity to avoid overtopping of the dam, especially when an earthfill or rockfill type of dam is selected for the project (Coleman et al., 1987). A spillway model design involves a lot of parameters such as flow discharge, head level , and the velocity of the flow needed to considered. Thus, in order to design a well and compatible spillway structure the hydraulic characteristics of the flow had to go through different methods and safety features. This is because the behaviour of water will effect the velocity and pressure which can cause cavitation. Cavitation occurs in high velocity flow, where the water pressure is reduced locally because of an irregularity in the flow surface. As the vapour cavities move into a zone of higher pressure, they collapse, sending out high pressure shock waves (The Bureau Of Reclamation, 2015). This can result in dam failure due to long flow durations.

Tawau Dam’s spillway is built to an undistorted scale of 1:30 and inlet portion of the reservoir, the spillway approach channel, the weir, the chute, the stilling basin and a portion of the downstream channel is included. The length of the upstream approach channel and the downstream channel will be able to reproduce the flow conditions before and after passing through the spillway channel. Through the construction of the model, it will able to help in finding the required discharge capacity with flood of return period 10, 20, 50, 100, 1000, 10000 years and up to the PMF discharge, weir and chute flow conditions and required discharge capacity with flood of return period 10, 20, 50, 100, 1000, 10000 years and up to the PMF discharge (Sabah State Water Department, 2018).

1.2 Problem Statement

Designing a spillway should have sufficient capacity to discharge floods, likely to occur during the lifetime of the dam. For dams having large capacities and constructed near the upstream of settlements, Probable Maximum Flood (PMF) should be considered. This is because high level of discharge on the upstream will increase the depth and velocity of the flow over spillway and leads to overflow in the dam and severe damage on the downstream which can cause the dam to collapse.

Apart from that, due to the high velocity the pressure level of the flow over spillway will decrease till negative and lead to problems like cavitation. Therefore, the velocity of the flow from upstream needed to be reduced as it enters the downstream because it can cause damages to the spillway slab. As the flow enters the downstream, the velocity needed to be reduced by performing hydraulic jumps. This can be done by evaluating the flow characteristics based on flow discharge. Hence, the effectiveness of stilling basin design can be identified and is able to reduce velocity and kinetic energy before leaving the spillway with minimum damage to the intake river.

1.3 Objectives

The purpose of this physical model study is to determine the profile of water depth, flow velocity and water pressure of the spillway. Based on the flow characteristics, the capability of the proposed buffer block on the stilling basin will be identified. Hence there are 2 objectives of this study:

1. To study the flow characteristics of Tawau Dam’s spillway physical model.
2. To investigate the capability and effectiveness of proposed buffer blocks on the stilling basin.

1.4 Scope of Research

This study is concerned with the modelling the flow discharge in the Tawau dam spillway. This study involves on the method of physical model. For physical model of the spillway, hydraulic flow of data collection on the model will be conducted and recorded. The data involving three types of measurement such as water depth, velocity and pressure on selected points along the model and will be described in details in Chapter Three. For hydraulic jump at the downstream area, some modification will be recommended to the stilling basin if the flow seems to be unsafe to improve its performance.

1.5 Dissertation Outline

The thesis has been categorized into specific chapters for better viewing and understanding of the study. This dissertation consists of five chapters.

Chapter 1: Introduction – this chapter gives an overview of the thesis, followed by the problem statement to identify, and understand why this research was carried out and its relevance to current times followed by the objectives of this research in order to set the desired target of work and finally the justification of this research.

Chapter 2: Literature review-Provides an important fundamental understanding of related information based on vast researches and findings including hypothesis of the study.

Chapter 3: Physical modelling-Describes the research methodology of physical modelling. The spillway model was described and it leads to accomplish the designated objectives and answer to problems defined. This chapter will be the utmost critical part of the thesis. It contains procedures to complete this study using instrumentation.

Chapter 4: Result and discussion-Present results, analysis, discussion and result assessment of experimental. Velocity profile, pressure profile and surface profile is been identified.

Chapter 5 : Conclusion-Comprises all the data and information obtains, with conclusions including recommendations for this field of research in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter we will be reviewing on several topic regarding spillway structure which includes the design consideration of the spillway, type and characteristics of spillway, stiling basin, Froude number, and cavitation problems. Lastly, there will be discuss on hydraulic jump which are effected by the buffer blocks.

2.2 Spillway Structure

Spillway is one of the important structure of a dam project.It protects the storage dams by discharging the excess river flow during the flood times. The flood water discharging through the spillway has to flow down from a higher elevation at the reservoir surface level to a lower elevation at the natural river level on the downstream through a passage (Kharagpur, 2008). There are many types of spillways in the shape of different controlled and uncontrolled types which are used on dams based on requirements such as the discharge of different flow conditions.

Controlled spillway comes along with gates which will be raised or lowered to regulate the rate of flow by allowing the full height of the dam to used as a storage water.The water level will start going above the crest and will start flowing along the spillway when the reservoir level is full.However, for uncontrolled spillway does not have gates where, it allows water to flow down whenever the water level rises to the crest of the spillway.

2.2.1 Classification of Spillway

A spillway comes in different shapes and sizes which are designed based on the water level of the location and other parameters. There are 3 types of spillways which are service spillway, auxiliary spillway and emergency spillway. Service spillway consist of controlled and uncontrolled spillways where water is released at the maximum design discharge without causing severe damage to the dam. Auxiliary spillway is not frequently used but sometimes used as a secondary spillway if there is any structural damage or erosion during the operation. Lastly, emergency spillway acts as additional protection against overtopping of a dam and extreme conditions such as misoperation or malfunction of the service spillway (USBR, 2014). These spillways can be classified into some common types such as Drop Spillway, Ogee Spillway, Chute Spillway, Siphon Spillway and Side Channel Spillway.

When water falls freely vertically on downstream due to over flow it is known as drop spillway. Drop spillway is usually used on low dam and provided with nose to avoid damages on downstream. Sometimes, a small artificial pool is provided at the stilling basin for energy dissipation. Apart from that, ogee spillway is commonly shaped to elongated form to the underside of water flow over a weir (Bulu, 2006). An ogee spillway can easily used on dam valleys because the shape of the lower nappe is similar to a projectile and forms a parabola form before reaching the downstream surface. If the head of water is less than the designed head, the water jet adheres to the body of the spillway and creases positive pressure which reduces the discharge through the spillway (Jamal, 2017).

A chute spillway has a short crest where after the water flows, it is carried by an steep sloped open channel towards the downstream of the river. Chute spillways normally has baffle of concrete blocks which dissipated at the stilling basin and forms hydraulic jump to protect the toe of the dam from erosion. Side channel spillway usually located at the upstream and to the side of the dam to allow the water flowed over the crest to enter the side channel. It is then carried by the chute spillway to the downstream surface.

A siphone spillway usually works according to the principal of a siphone. The siphon pipe will be kept on the upstream side as well in contact with reservoir. When the water in the reservoir is up to or below the normal pool level, air enters the siphon through the vent and siphonic action cannot take place. When the air enter the siphon through the new exposed air vent, the flow will stop (Khatsuria, 2004). Lastly, in a stepped spillway the water flows over from the crest to the toes of the dam in a form of steps. It has the advantage over other spillways in that it acts also as an energy dissipator as the water comes down from the reservoir level to the tail water level.

2.2.2 Type and size of a spillway

Selecting the type and size of a spillway requires to focus on certain condition ,which are needed to be taken into consideration to construct a stable spillway. A spillway is designed based on the site condition such as the topography, geology and climate, the dam type, knowing the flood control requirements, hydrologic and seismic loading requirements, and diversion for the construction requirements. It is important to build a spillway based on the above factors to minimize the footprint of spillway control structures.

Apart from that, other pertinent factors also needed to given attention esspecially the characteristic of the flood hydrographic to identify the peak flood, the damages occur with or without a dam due to flood, effects of various dam and spillways combinations and the use of combined outlet facilities to serve more than one function such as the control of releases and passage of flood. Hence, the spillway to be designed should govern the size and capacity during the peak flood inorder to avoid dam failure which can cause any loss of life and property. By designing a storage with higher capacity due to the height of dam, the routed flood peak for spillway capacity will be lower.

As we know a spillway is designed based on the reservoir flood discharged at location. Through that we will be able to determine the maximum spillway discharge, maximum lake elevation and other dimensions such as the dam heights and reservoir capacities using elevation storage relationship of the reservoir needed for the design. Hence, the most economical type of spillway and suitable capacity which can withstand the discharge value can determine based on the height of the dam.

2.2.3 The Importance of Spillway

A spillway is a vital apparatus for storage and detention dam to release surplus water or floodwater that cannot be contained in the time allotted space (Julien, 2015). It helps during the flood period to sustain the high runoff when the capacities of other facilities exceeds. Then, the surplus water will be drawn out from the reservoir and send back to the river downstream surface.

A spillway acts as a safety valve in the reservoir against overtopping of dam. The height of a dam is fixed based on the maximum capacity of the reservoir. The normal pool level is actually the maximum reservoir capacity that never stored in the reservoir above this level. Hence, the safety of the dam’s spillway is very important because the dam may fail by over turning. Usually the top of the dam will used to build roads and the surplus water is not allowed to over top the dam (Jamal, 2017). So, building a spillway helps to stop the over topping of the surplus water and damages to the dam.

Thus, it is important to provide the spillway at the suitable location. Generally, the spillways are provided either within the body of the dam, one or both sides of the dam or completely separated from the dam. Failure to provide at the right location might end causing dam failure and loss of lives.

2.3 Stilling Basin

Stilling basins are used to dissipate the energy of water when it exits the spillway. The purpose of a stilling basin is it helps in preventing scouring that occurs due to the high speed of velocity when the water reaches the downstream surface. The scouring can damage the foundation of the dam by causing erosion at the downstream and might lead to overtopping. One of the method of dissipating the energy is by forming hydraulic jump which helps in changing the transition flow from supercritical to subcritical flow.

Stilling basins comes in different types such the inclined chute design which includes the USBR Stilling Basins Type II – IV and SAF Stilling Basins. These designs are usually selected based in the Froude Number of the flow and velocity.

2.3.1 Stilling Basin Elements

There are different types of stilling basins elements which are commonly used such as chute blocks, baffle blocks, and end sills as shown in Figure 2-1. Chute blocks is made up from concrete blocks and has inclined sections of the spillway. These blocks is usually positioned at the head of the stilling basin to create turbulence where it forms the hydraulic jump. The incoming jet of water is furrowed and partly lifted from the floor, producing a shorter length of jump than what would have been without them (Khatsuria, 2004). This action helps stabilising the flow as well improve the jump.

Other than that, baffle blocks are freestanding concrete blocks which are build in the main basin but only used when the flow of the velocity is less than 20 m/s. These is because high force is subjected on the baffle blocks and also can cause cavitation on the downstream surface. These baffle piers, sometimes called friction blocks, are very useful in small structures, such as low spillways and weirs (Khatsuria, 2004).

End sills is in the form of lip which is located at the tail of the basin with or without the blocks. The sill height plays an important role at the stilling basin because it has significant impact on the energy dissipation. The dentated sill diffuses the residual portion of high velocity jet reaching the end of the basin (Khatsuria, 2004). The taller the sills, the lesser the overall length of the stilling basin.

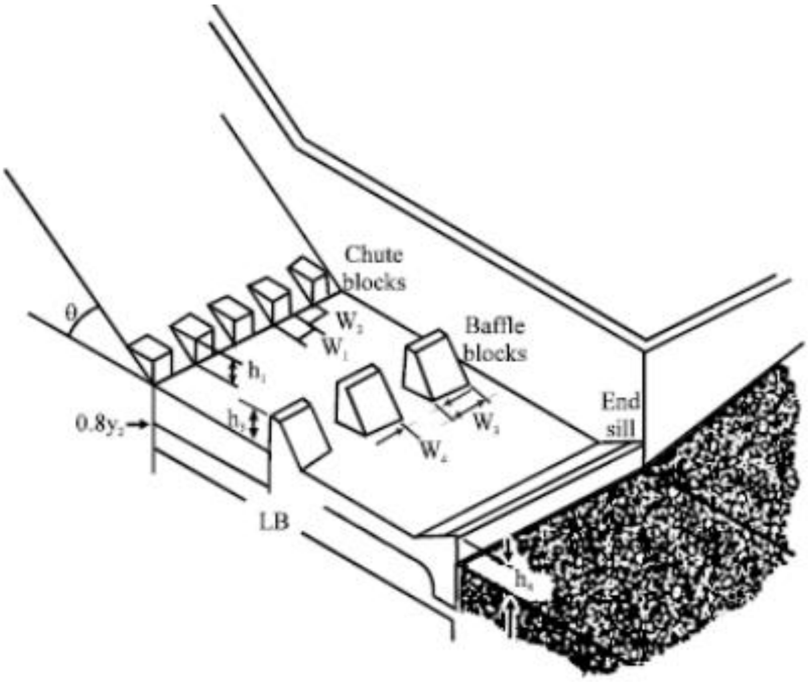

Figure 2-1 : Stilling Basin Elements(Source : USBR, 2008)

2.3.2 Types of Stilling Basin

Hydraulic jump stilling basins are type of irrigation structures which are constructed downstream of chutes, gates and spillways to dissipate excess kinetic energy. The dimensions of such structure depend on the jump length and the sequent depth of the jump (Bejestan and Neisi, 2009). Peterka (1978) has classified the hydraulic jump into several categories based on the upstream Froude number and they are USBR Type II, USBR Type III, and USBR Type IV.

Firstly , USBR Type II stilling basin on Figure 2-2 utilizes the chute blocks and a dentate end sill to dissipate the energy to reduce the velocity of the flow. However, baffle blocks are not used because the tailwater depth will be higher than 5%. This is because it did not meet the required safety factor to stabilize the hydraulic jump. The flow is lifted and the energy is dissipated by the eddies wave due to the low Froude numbers. When the Froude number is more than 4.5 and the flow of the velocity is more than 20 m/s, Type II stilling basin is recommended. The height and width of the chute blocks of Type II stilling basin usually will be as same as the depth of the incoming flow and the length of basin will depend on the Froude number and incoming flow depth. Vischer and Hager (1999) recommend that this type of structure is designed economically in terms of length, tailwater level, scour, and cavitation.

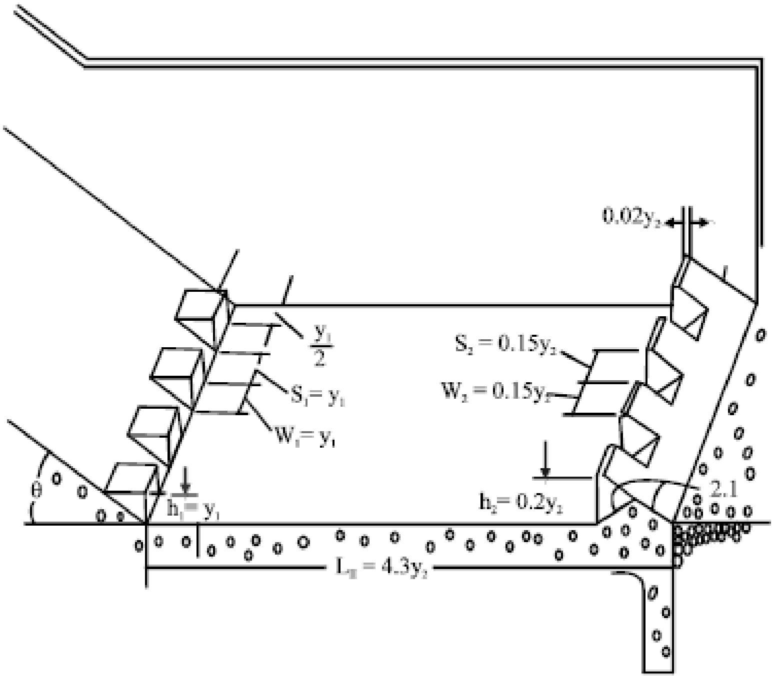

Figure 2-2 : USBR Type II (Source : USBR, 2008)

Next is USBR Type III Stilling Basins on Figure 2-3 which creates a steeper hydraulic jump and reduces the wave action at the downstream surface. This type helps in reducing the length about 60% due to the chute blocks, baffle blocks and end sill. The Froude number should be greater than 4.5 and the velocity at the upstream should be in the range of 15m/s -18 m/s due to the large factor of safety against jump sweepout. However, Type III is restricted to small spillways because it considered too conservative and consequently overcostly for carrying small discharges at moderate velocity.

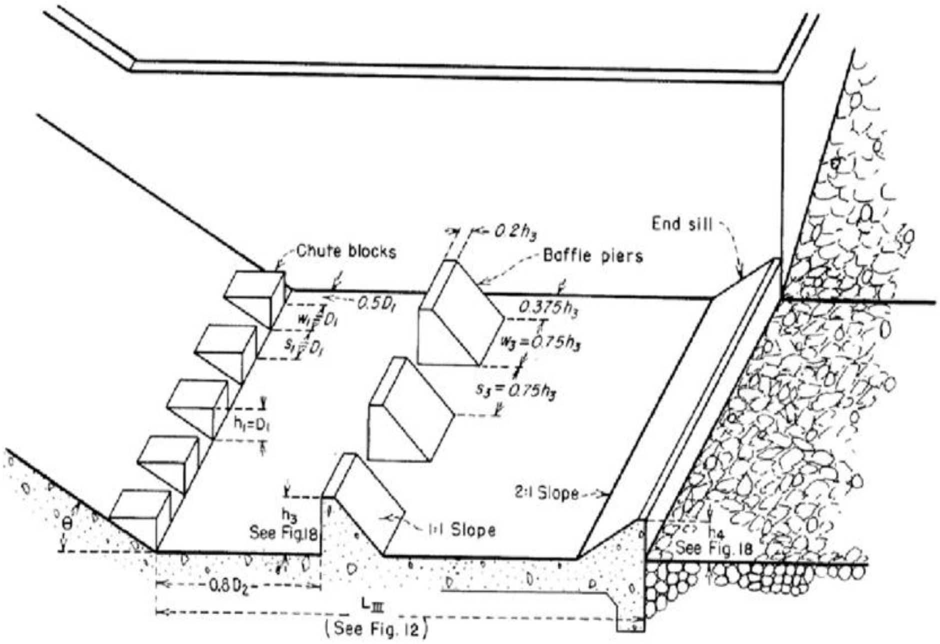

Figure 2-3 : USBR Type III (Source : USBR, 2008)

Moreover, USBR Type IV Stilling Basins on Figure 2-4 has the characteristics of the hydraulic jump for Froude numbers between 2.5 and 4.5. The low Froude number range is encountered principally in the design of canal structures, but occasionally low dams and outlet works fall in this category (USBR, 2008). This basin is applicable only to rectangular cross sections and the oscillating waves are generated in this range of Froude number, they are tried to be controlled at source by providing large chute blocks (Garg, 2006).

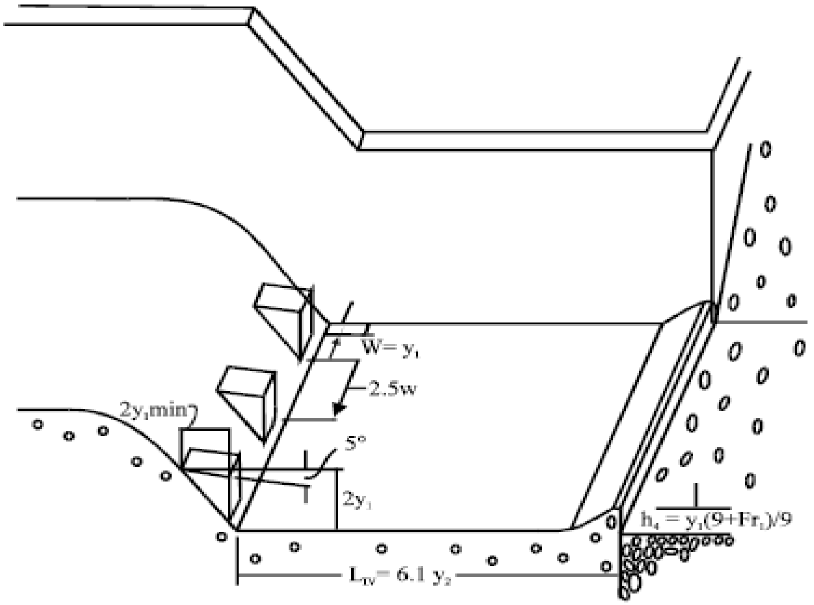

Figure 2-4 : USBR Type IV (Source : USBR, 2008)

The Saint Anthony Falls (SAF) stilling basin on Figure 2-5 size is reduced by combining the use of baffles and sills when the Froude number is in between 1.7 and 17. When the toe of jump located at the basin upstream end, the length of the basin can be reduced. The chute blocks at the entrance of the basin increase the inflow depth and reduced the high velocity flow into a number of small streams. Whereas, the end sill deflects the forward bottom current to the surface, and induces a ground roller. Generally, SAF is used on smaller structures such as culverts and canals which leads to more effective approach to energy dissipation.

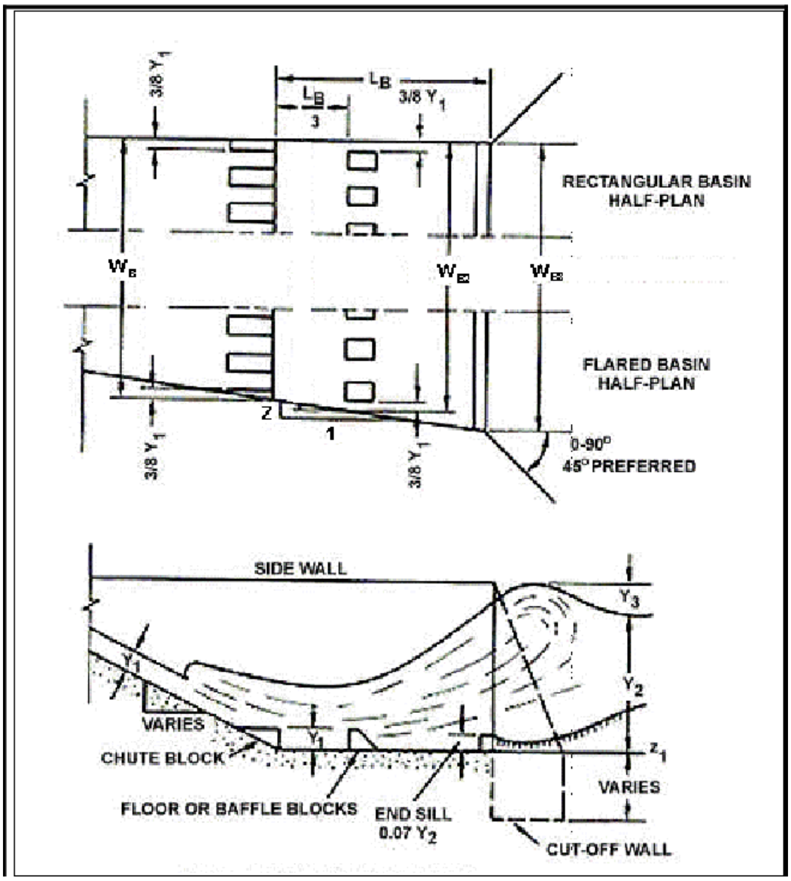

Figure 2-5 : USBR Type SAF (Source : USBR, 2008)

2.3.3 Hydraulic Jump

A hydraulic jump is known as a sudden turbulent transition of supercritical flow at the upstream to subcritical at the downstream. A hydraulic jump can be identified when it forms at the junction of a sloping channel with the horizontal floor (Choudhury et al., 2016). The amount of energy dissipated in a jump increases with the rise in Froude number of the supercritical flow (Kharagpur, 2008).

Usually the flow near appurtenances is rapidly changed and the velocity distribution is not uniform which leads to difficulty to analyze the formation of the jump. Based on the experiment done, it shows the force acting on the sill in a jump reduces the speed of the flow towards the downstream. This change in force on the sill is probably due to a change in the velocity distribution from one end of the jump to other, since non uniform distribution of velocity is characteristic of such rapidly varied flow (Masch et al., 1969).

Figure 2-6 : Hydraulic Jump of Case 2

It is possible to find out the pre jump length (y_1) and velocity (V_1) if a the discharge per unit width (q) value is given through the spillway. The energy lost in the hydraulic jump is given at equation 2.1. The length of the jump affects the size of the stilling because of the horizontal distance of the toe of the jumps up to a level at the water surface after reaching the maximum level. Towards the end of the jumps, the water surface will slowly become flat which lead to large personal errors in determining the jump length. Bradley and Peterka (1975) have experimentally found the length of hydraulic jumps and plotted them in terms of the incoming Froude number (F_1), and post-jump depth (y_2).

$$EL = (y2 - y1)3 / 4y1y2 \tag{2.1}$$

A hydraulic jump has the capability to scour the erosion at the downstream of the dam. The energy flows over the spillway at a high speed from the upstream till it reaches the downstream. If the same velocity is maintained at the natural stream bed, the areas will be critically erode. By, having a proper and good design, a good form of hydraulic jump will happen, where the depth of flow abruptly changes (Mott et al., 2006).

2.4 Froude Number

Froude number (Fr), is a dimensionless number governing the flow in terms of flow control in a open channel hydraulics in ratio form of inertial and gravitational forces. It is usually used for scalling free surface flows, open channels and hydraulic structures (Chanson, 2003). The Froude number can be computed based on equation 2.2 below.

$$F_r = \frac{v}{\sqrt{gL}} = \frac{Inertia\ force}{Gravitational\ force} \tag{2.2}$$

Where,

F_r = Froude number

v = water velocity (m/s)

g = gravity (m/s^2)

L = hydraulic depth (cross sectional area of flow/ top width) (m)

When;

Fr = 1, critical flow,

Fr > 1, supercritical flow (fast rapid flow),

Fr < 1, subcritical flow (slow / tranquil flow)

Apart from that, the value of the Froude number can be classified according to the flow condition.

Classification of flow:

Subcritical Flow - The flow is deep and moves slowly with a low energy. The Froude Number is less than one.

Critical Flow – The flow which has a perfect balance between the gravitational and inertia force. The Froude Number is equals to one.

Supercritical Flow - The flow is extremely shallow and moves fast with a high energy state. The Froude Number is greater than one.

2.5 Summary

In summary, in this Chapter we have learn what are the requirements for designing a spillway. It also includes the methods of reducing the speed along spillway which avoid the damages on the downstream. Apart from that, the flow along the spillway is categoried in few terms which will be later used on based on the results obtained on Chapter 4.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter methodology will focus on the physical experiment procedures of the physical model Tawau Dam's spillway in order to achieve the objective of this study. Apart from the procedure, this chapter consists of several main topics such as the data collection, experiment set-up, and measurement types.

3.2 Tawau Spillway Model Description

The spillway model was scaled down to 1:30 of the prototype size in order to match the real spillway model dimension accurately. The construction of the scaled model will be made of suitable construction material and quality assurance so that the spillway model dimensions can be scaled proportionally in the scaled model. The importance of this physical hydraulic model is to determine the velocity profile and the pressure exerted throughout the water boundary. The construction of this physical hydraulic model will be constructed by the China CITIC Wijaya Construction Sdn.Bhd in the Hydraulic Laboratory of School of Civil Engineering, Universiti Sains Malaysia.

The model scaling is the most important considerations in the design of physical model, it is because the availability of error such as physical properties of fluid in viscosity or surface tension can lead to disproportionate large effect on model performance. The suitable scale had been selected which is 1:30 from the actual site size, within this consideration, the construction of fixed bed model is used in the physical model. The figure below shows the overall proposed physical hydraulic and the details. The physical model is 10.45m long, 3.508m wide and 2.88m height based on Figure 3-1.

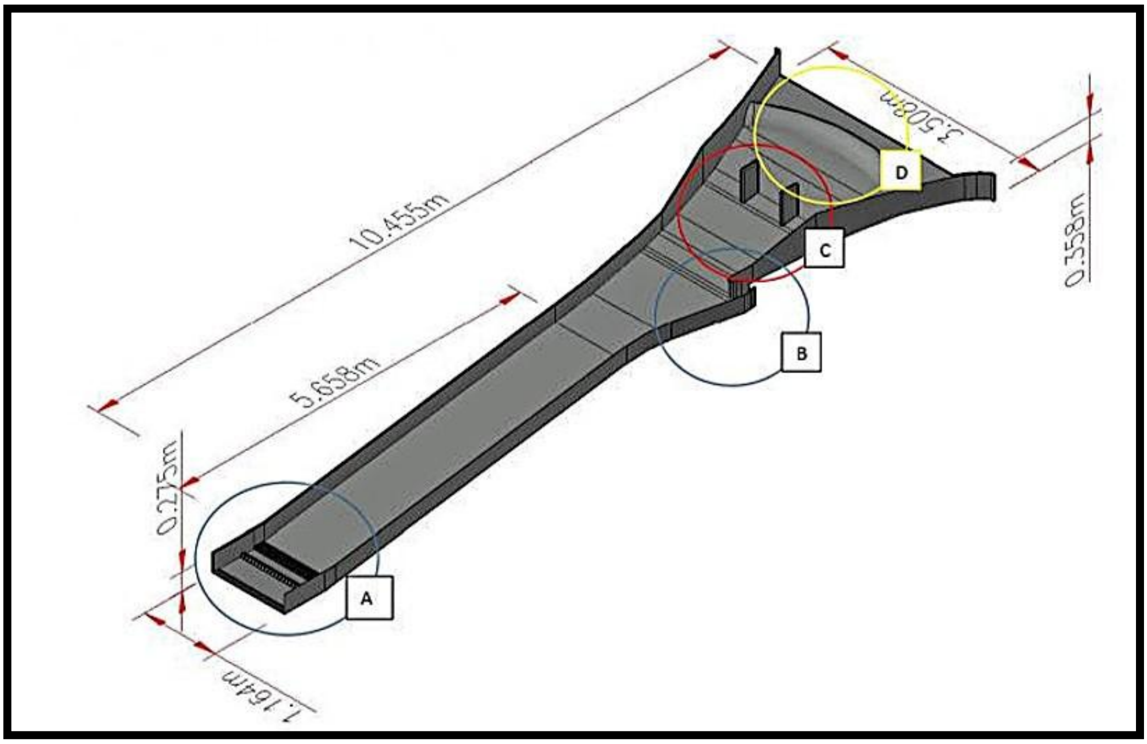

Figure 3-1: Proposed Physical Model for Spillway (Source: Skim Bekalan Air Tawau Fasa III, 2018)

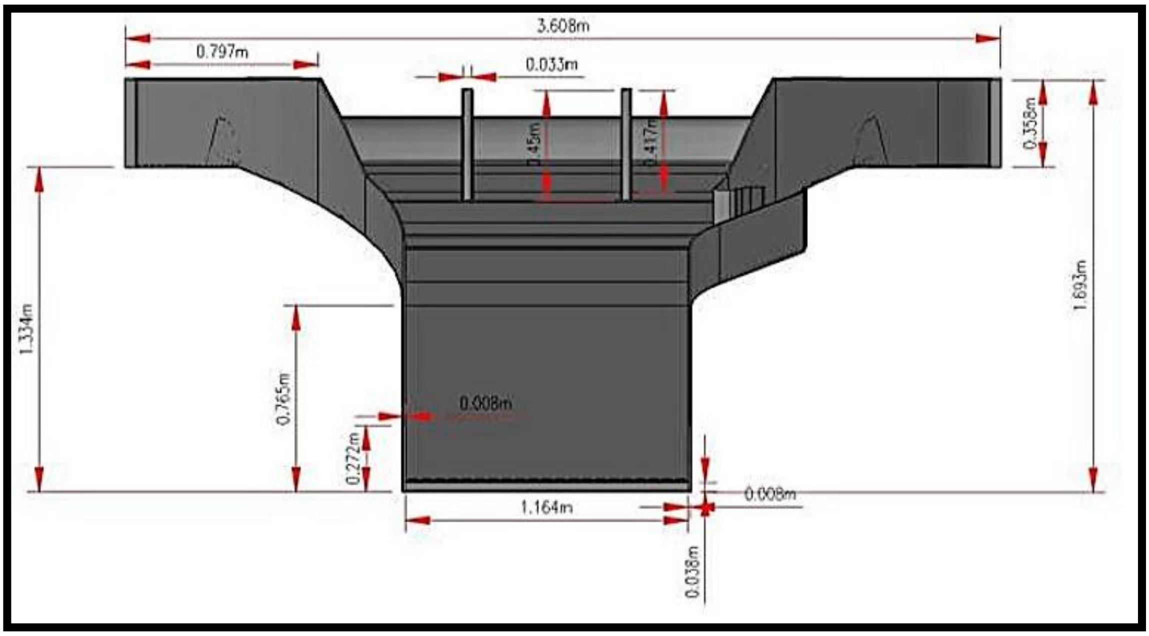

Figure 3-2 : Proposed Physical Model for Mid-Crest of Spillway (Source: Skim Bekalan Air Tawau Fasa III, 2018)

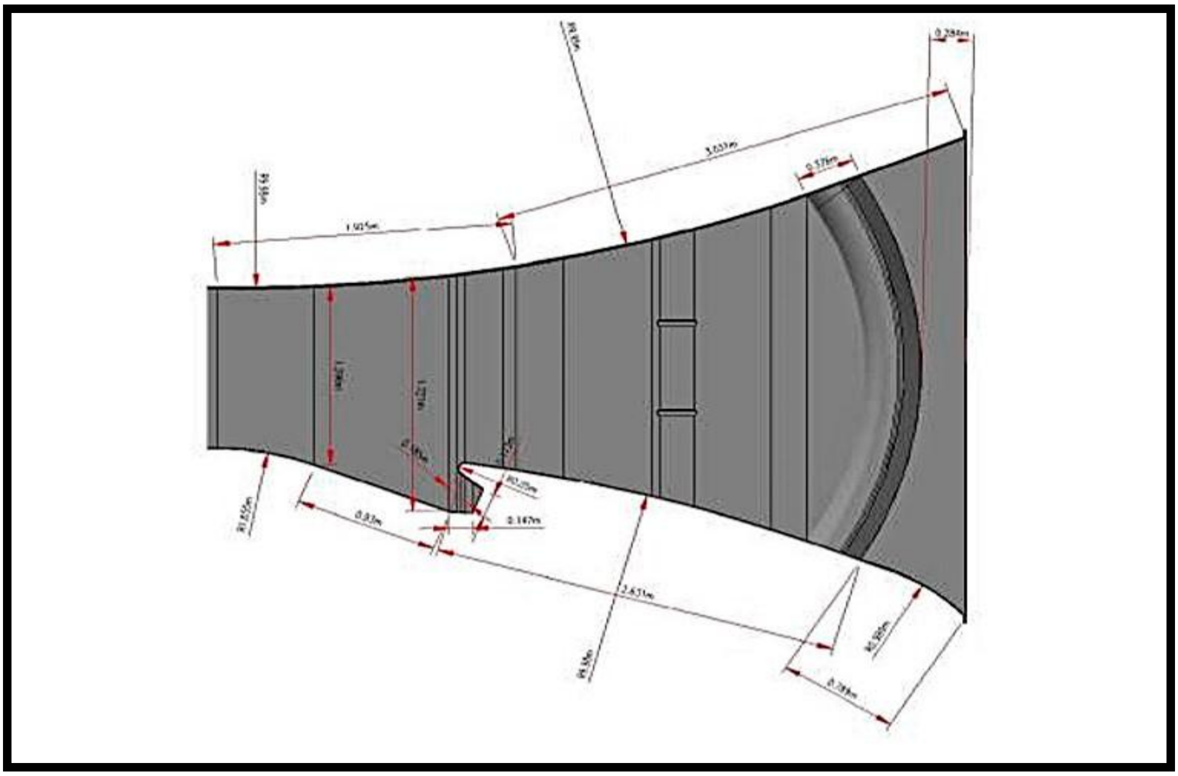

Figure 3-3 : Proposed Physical Model for Side View of Spillway (Source: Skim Bekalan Air Tawau Fasa III, 2018)

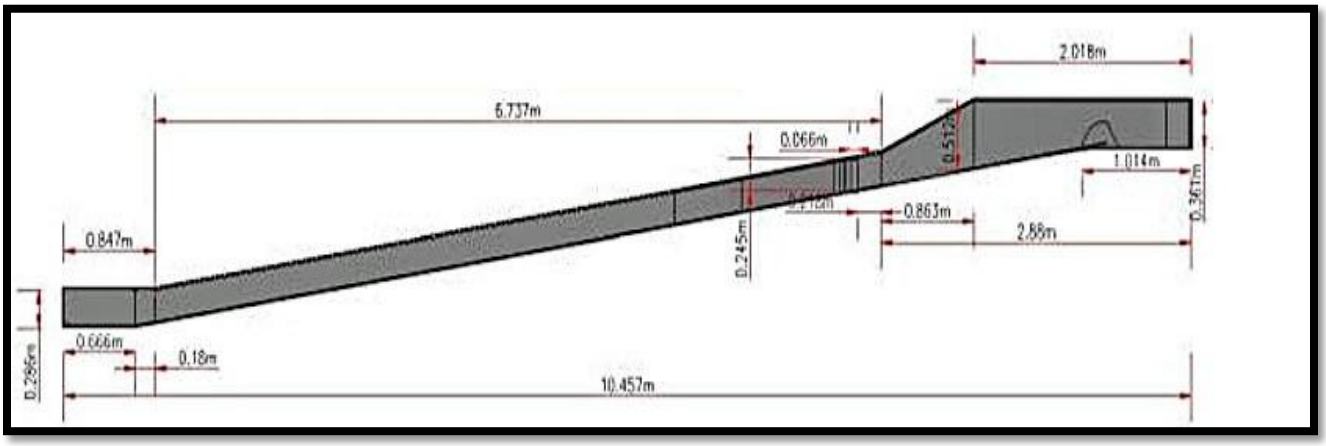

Figure 3-4: Proposed Physical Model for Top View of Upstream Spillway (Source: Skim Bekalan Air Tawau Fasa III, 2018)

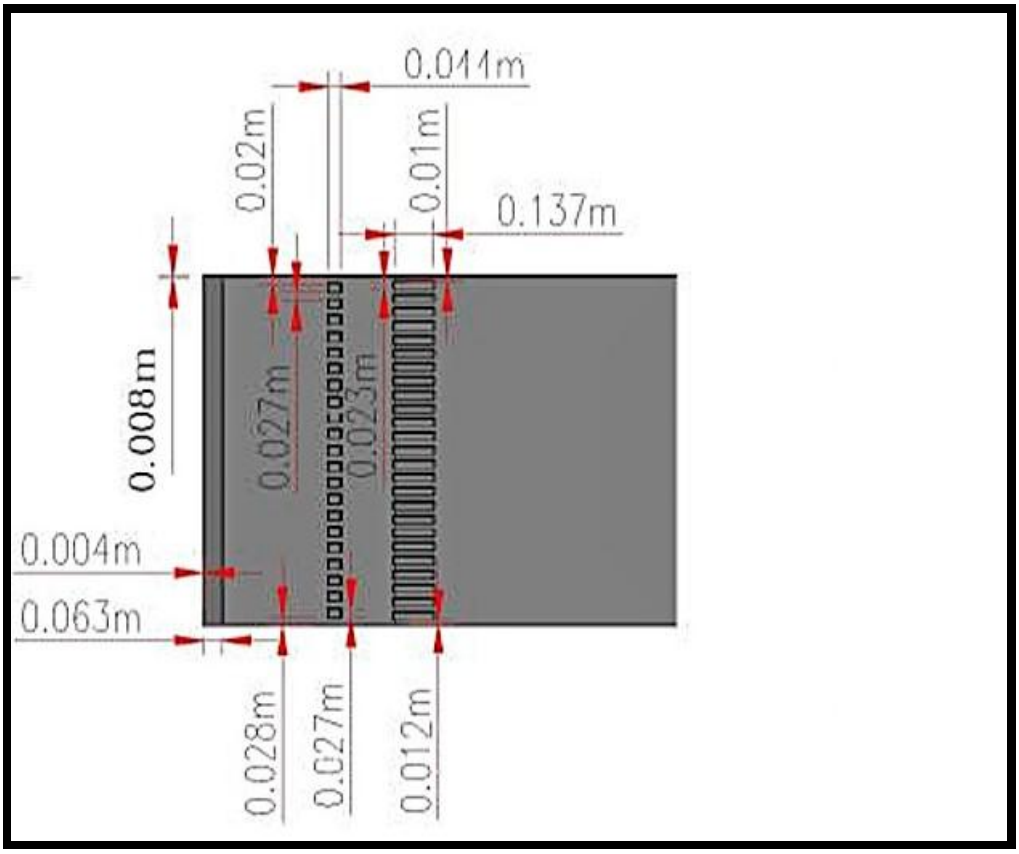

Figure 3-5 : Proposed Detailing of Stilling Basin of Spillway (Source: Skim Bekalan Air Tawau Fasa III, 2018)

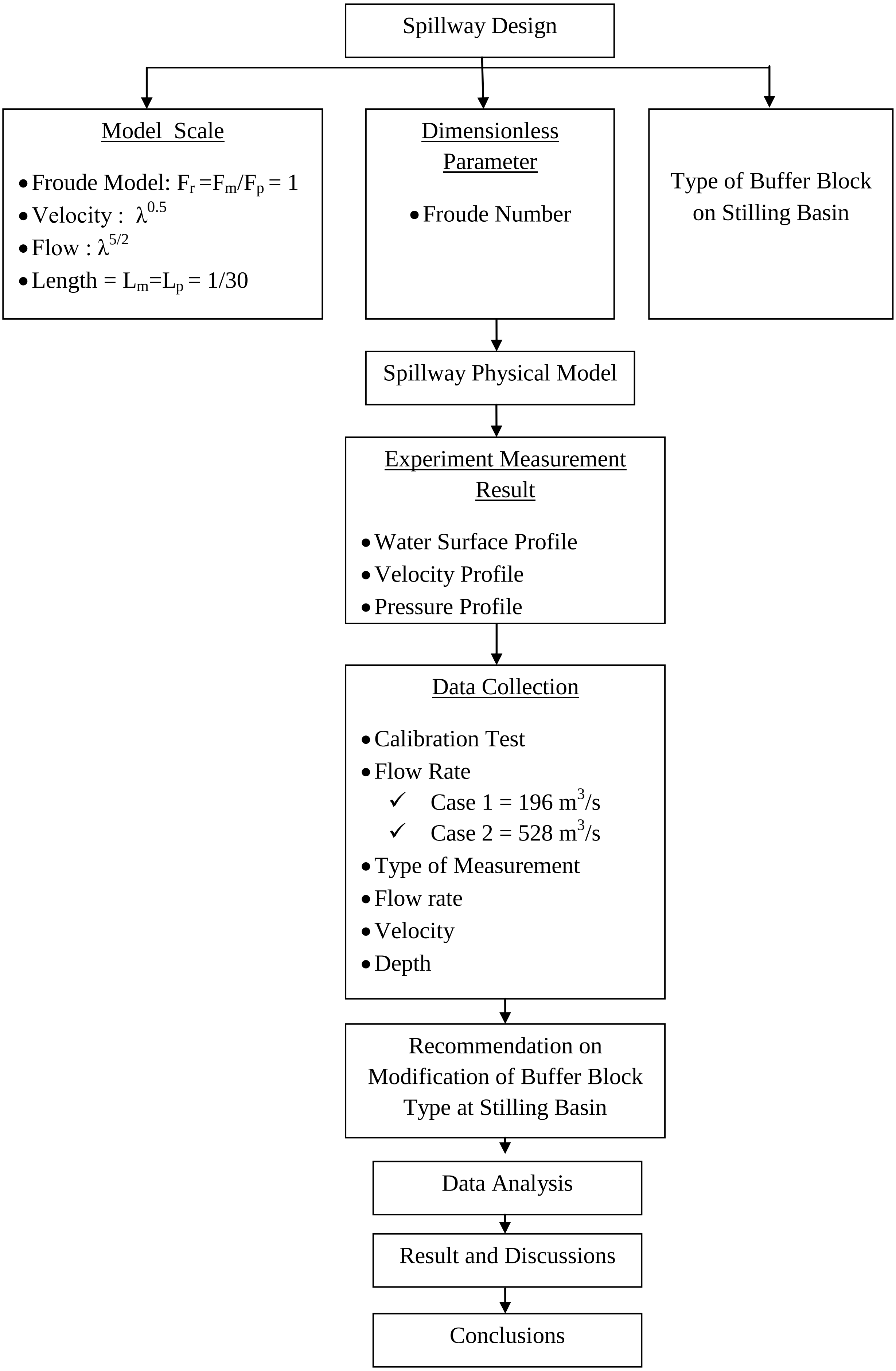

Figure 3-6 : Flow Chart of the overall study

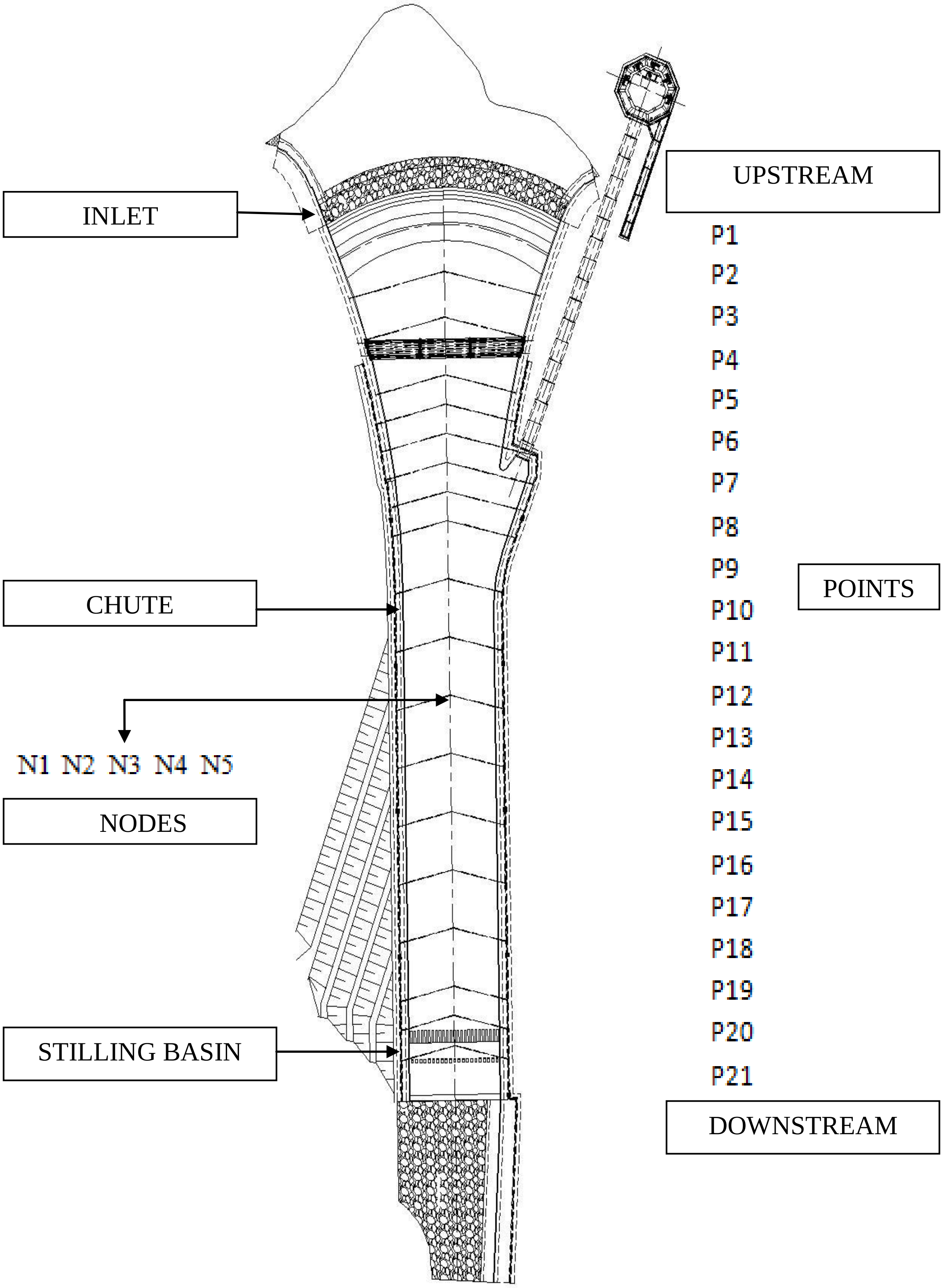

Figure 3-7 : Detailed Plan View of Tawau Dam' Spillway