A STUDY OF FLOW CHARACTERISTICS ON HYDRAULIC PHYSICAL MODEL OF TAWAU DAM SPILLWAY

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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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ABSTRAK

Alur limpah empangan ialah salah satu komponen yang paling penting bagi membolehkan projek memindahkan lebihan air dengan cara terkawal atau tidak terkawal untuk menjamin perlindungan projek. Halaju tinggi menyebabkan kerukkan dan hakisan di kawasan hilir dengan mewujudkan tekanan rendah atau negatif pada alur limpah. Selain itu, tekanan negatif menghasilkan peronggaan yang boleh menyebabkan kerosakan serius pada struktur alur limpah. Bagi menyelesaikan isu ini, pelesapan tenaga yang sesuai diperlukan untuk mengurangkan halaju air. Tujuan kajian ini adalah untuk mengkaji ciri-ciri aliran dan pelesapan tenaga yang sesuai pada alur limpah untuk Empangan Tawau. Alur limpah untuk Empangan Tawau ialah model fizikal berskala 1:30 yang dibina oleh Pusat Pengajian Kejuruteraan Awam, Universiti Sains Malaysia. Penyelidikan ini dilakukan untuk dua pelepasan berbeza iaitu 40 l/s dan 73 l/s. Penyelidikan ini juga tertumpu pada pengubahsuaian di lembangan dengan menggunakan pelesapan tenaga yang sesuai. Blok penampan digunakan sebagai modifikasi dalam penelitian ini. Blok penampan digunakan secara meluas untuk menstabilkan lompatan serta memendekkan kepanjangan lompatan dan memaksimumkan penyebaran tenaga. Data profil halaju digunakan untuk mengenalpasti ciri-ciri aliran alur limpah untuk Empangan Tawau. Berdasarkan kajian, ciri aliran bergantung pada jumlah pelepasan di dalam alur limpah. Jenis III lembangan digunakan dalam kajian ini dan ia menghasilkan lompatan-B. Daripada kajian kes ini, saiz ukuran blok penampan yang paling sesuai digunakan adalah (2x4) inci untuk mengurangkan lompatan hidraulik dan menjimatkan tenaga air.

ABSTRACT

A dam's spillway is one of the most crucial components. It allows the project to evacuate a surplus of water in a controlled or uncontrolled manner to guarantee the project's protection. High velocity causes scouring and erosion at the downstream area by creating low or negative pressure on the spillway slab. In addition, the negative pressure produces cavitation which can cause serious damage to the structure of the spillway. To solve this issue, the suitable energy dissipator is needed to minimized the velocity of water. The purposes of this project are to study the flow characteristics and to evaluate the suitable type of energy dissipator for the Tawau Dam Spillway. The Tawau Dam spillway is a 1:30 scaled spillway physical model and it is constructed by the School of Civil Engineering, Universiti Sains Malaysia. This research was carried out for two different discharges which are 40 l/s and 73 l/s. The research also concentrated on the modification in the stilling basin by applying the suitable energy dissipator. The end sill blocks were selected as the modification in this study because they are widely used to stabilize the jumps, shorten its length and maximize energy dissipation. The velocity profile data was used to identify the flow characteristics of the Tawau Dam Spillway. Based on the findings, the flow characteristics depend on the flow discharges in the spillway model. This research implemented the Type III stilling basin, which results in the B-jump. From this case study, the most suitable size of the end sill block is (2x4) inch is used to reduce the hydraulic jump and conserve the energy of water.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The spillway is one of the most significant components of the dam project systems. The spillway provides the project with a managed or unregulated release of excess or flood water to ensure safety. To prevent a dam from collapsing, the spillway is designed to release and regulate the flood stream. Due to the high flow rates that pass through the spillways and they frequently encounter problems such as cavitation and high flow kinetic energy.

The approved material complying with the specifications for roughness and turbulent flow scaling is developed for every part of the model water spillway. The inlet corner of the water is constructed correctly such that the approaching channel achieves uniform flows without surface waves. The toe of the stilling basin is made from a material that offers a conservative approximation of downstream scouring.

For this project, Tawau Dam physical model was chosen to study the flow characteristics of its spillway by designing suitable energy dissipator. The 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. Moreover, further investigation of the flow characteristic, the force exerted throughout the water boundary and predictable impact to the overall dam structure need to be done to fulfill all the requirements.

1.2 Problem Statement

The water flows from the upstream to the downstream and high energy of water is gained when it reaches the downstream part. This situation also happens when the water flows from the inlet to the outlet of spillways because it will enhance the energy of water to rise due to the height of the spillways. The structure at the bottom of spillways may tend to damage due to excessive energy conditions. Moreover, the high velocity of water also results in low or negative pressure on the spillway slab, scouring and erosion at the downstream part.

The energy dissipator is a device that protects downstream parts from erosion by reducing flow velocity to appropriate levels. Since a lot of mechanisms are used to dissipate energy downstream of the spillways, the energy is dissipated by internal friction and turbulence, as well as the effect and diffusion of the high-velocity flow in the mass of water.

1.3 Objective

The objectives of this research are:

1. To study the flow characteristics along Tawau Dam Spillway.
2. To evaluate the suitable type of energy dissipator for Tawau Dam Spillway.

1.4 Scope of Work

The scope of work for the hydraulic model is to study the data collected from the physical model of Tawau Dam. According to the actual dimensions, the design scale for this model is 1:30. Two different discharge rates that should be tested which are 40 L/s and 73 L/s. The data set involves two different types of measurement which are the velocity at the selected point along with the model and the measurement of the height and the length of the hydraulic jump in the stilling basin.

For hydraulic jumps in the downstream zone, modifications to the stilling basin will be recommended to improve its efficiency if the flow appears to be unsafe. Moreover, the end sill block's impact on the hydraulic jump should be studied. The model is evaluated with and without an end sill block. Additionally, the end sill block comes in four different sizes to decide the good size for minimizing the hydraulic jump.

1.5 Justification of Research

The hydraulic physical model testing conducted in this study is vital to achieve the safe operation of the Tawau Dam Spillway during periods of heavy rain in the catchment’s upstream part. The hydraulic physical model enables evaluation to ensure the model accurately replicates the prototype.

Moreover, the study is expected to design a suitable energy dissipator by evaluating the flow characteristics of the Tawau Dam Spillway. The study also expected to minimize the high energy level of the water flow from the spillway to the downstream by using physical modelling. The high turbulent flow characteristics of the water flowing from the spillway to the downstream channel should be decreased through the appropriate design of the energy dissipator. Additionally, the energy dissipator minimizes scouring of the river's surface downstream. Furthermore, the energy dissipator is critical in preventing erosion of riverbeds and banks.

1.6 Limitation of the Study

Firstly, the limitation of this study is human error can occur as a result of the model creating artificial situations that do not always represent real situations. Human error also plays a significant role in the project's accuracy during data collection. Additionally, there are seven pumps used in total. As a result, the value of the discharge to be measured must be consistent for the overall seven pumps. The velocity is determined by the discharge value in the pump sump. To increase the velocity, the discharge also must be increased.

Secondly, the scale effect is one of the limitation of the study. Scale effects occur when the force ratios between a model and its prototype are not similar, resulting in deviations between the up-scaled model and prototype observations (Heller, 2011). The scale effects for a specific phenomenon increase with the scale ratio or scale factor. Moreover, when the model size decreases, scale effects are likely to increase and results of the up-scaled model may diverge from prototype observations. If $\lambda \neq 1$, the physical hydraulic model testing will always include scale effects, as it is impossible to accurately represent all force ratios. Similarity between the model and the prototype can be established by conducting tests in the physical model for configurations for which prototype data is available. If the relative parameters of the model and prototype correspond well, the substantial model and measurement effects can be ruled out, negligible scale effects are predicted. So, the similarity between the model and prototype is achieved.

1.7 Outline of Thesis

The thesis is distributed specifically into five chapters to enhanced research inspection and comprehension. The outline of each chapter are discussed below:

Chapter 1: Introduction – This chapter provides an overview of the thesis, then it continues with the problem statement and understand why this study is conducted, the research objectives to set the desired work goal, the scope of the work, justification of this research and finally limitation of work.

Chapter 2: Literature review – Provides a critical fundamental interpretation of the information needed based on the previous thesis and studies that are performed by other researchers according to the related topic which is physical modelling on the Tawau dam spillway.

Chapter 3: Methodology – Describes the research methodology of physical modelling. It will be discussed in further detailed on the flow of experimental work that will be done to achieve the objective of this research. This chapter is the most important section because it contains detailed procedures to complete this study using instrumentation.

Chapter 4: Result and Discussion – This section also one of the critical parts of this thesis because it will be highlighted the outcome of the experimental work when the result is obtained. The final result will be discussed along with the supporting facts and findings.

Chapter 5: Conclusion and Recommendation – This is the final chapter of the thesis which conclude all the result and information obtains from the research and recommendation for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The research of hydraulic physical modelling such as spillway which includes the design consideration of the spillway, type and characteristics of spillway, stilling basin, Froude number, and cavitation problems will be covered in this chapter. In addition, the energy dissipator such as hydraulic jump, baffle block and end sill block are also explained.

2.2 Physical Hydraulic Model

A physical model is a precision system that is used to simulate the physical phenomenon behavior (Firdaus Zulkefly *et al.*, 2019). Physical hydraulic model is often used during the design process to refine a system and ensure that it performs safely. A model can be considered as accurate if it is constructed and designed correctly.

In the design and rehabilitation of hydraulic structures, physical hydraulic models are frequently employed to forecast prototype performance (Chandra *et al.*, 2018). Physical modelling studies improve the hydraulic structure's safety by identifying and removing potential faults, resulting in lower construction and maintenance costs (DP Loucks, 2017).

Additionally, they are enormously beneficial when hydraulic structures and systems have peculiar designs or configuration and state-of-the-art analytical or computational methods cannot appropriately evaluate hydraulic parameters (Tung, 1996).

Therefore, the physical model will integrate the necessary governing equations without the need for simplifying assumptions that are frequently required in analytical or numerical models (Kumar, 2015). Moreover, physical hydraulic models can be used to provide cautious and appropriate design or operational parameters for locations, structures, or systems that face thermal and erosion challenges (Burke, 2008).

2.3 Similitude Theory of Scaled Model

The aim of hydraulic similitude is to ensure that the model as closely as possible replicates the behavior of the prototype (Goda, 1985). There are three fundamental laws of similitude which represented as the geometric (similarity of form), kinematic (similarity of motion) and dynamic (similarity of forces). In general, the model's quantity ratio should be same as the prototype.

Geometric similarity requires an equivalent length ratio between the model and prototype. Kinematic similarity requires that the model and prototype have the same velocity and acceleration ratios. The dynamic similarity, the ratios of the four external forces of gravity (Fg), viscosity (Fv), surface tension (Fs), and elasticity (Fe) must be equivalent. This criterion is based on Newton's Second Law, which states that inertial force equals the total of these external forces (Briggs, 2013).

The gravitational forces, friction, and surface tension are the relevant forces in the majority of coastal hydrodynamics problems which consider as dynamic similarity (Chanson, 1999). Additionally, if similarity between model and prototype is to be achieved for flow circumstances influenced by inertial and gravitational forces, the Froude Numbers of the model and prototype should be same. Moreover, dimensional analysis demonstrates that for viscous forces, the Reynolds Number in the model and prototype should be same.

The Froude number (Fr) is one of the beneficial dimensionless quantity. It determines the tendency of liquid conditions to generate gravity waves (Campbell, 2020). As a result, the Froude number is formulated as follows:

i. Froude Number; $Fr = \frac{v^2}{gh} = \frac{inertia\ forces}{gravity\ forces}$ (Eq. 2.1)

Where,

Fr = Froude number

v = water velocity (m/s)

g = gravity (m/s^2)

h = hydraulic depth (m)

The flow states according to the Froude number are shown as below,

Fr = 1, critical flow and inertia forces are equal to the gravity forces

Fr > 1, supercritical flow (fast rapid flow) and inertia forces are more than gravity forces

Fr < 1, subcritical flow (slow flow) and inertia forces are less than gravity forces

The Reynold number is formulated as follows:

ii. Reynolds Number; $R = \frac{VL}{\nu}$ (Eq. 2.2)

Where: V = velocity

g = gravitational constant

L = characteristic length

ν = kinematics viscosity

Due to the fact that the same fluid is used on both the model and prototype, it is impossible to meet both the Froude and Reynolds number scaling criteria simultaneously. Thus, the most of models are run with Froude's similarity in consideration, which means that gravitational influences are dominant and that water's viscosity and surface tension play no essential role (Dalrymple, 1985).

The gravitational forces are the most important in free surface work, the Froude Number must be made equal to that of the prototype rather than the Reynolds Number. This guarantees the representation of surface profiles, rotating flow, and waves is accurate. The Reynolds Number is irrelevant for turbulent flow as long as both model and prototype have values within the same flow regime. If the lowered Reynolds Number of a model approaches the point of transition from turbulent to laminar flow, laminar flow may occur in the model but turbulent or transitional flow may occur in the prototype. This is clearly unacceptable and a minimum operational Reynolds Number must be selected. The relationship between model and prototype based on the Froude Number similarity can be derived as shown in Table 2.1.

Table 2.1: Relationship between Model and Prototype based on Froude Number Similarity

	Model		**Prototype (actual)**
Length	L_m	=	L_p/S
Velocity	F_m	=	F_p
	$Vm^2/(g.Lm)$	=	$V_p^2/(g.L_p)$
	V_m	=	$(V_p.V_p.L_m/L_p)^{1/2}$
	V_m	=	$V_p/(S^{1/2})$
Flow	F_m	=	F_p
	Q_m	=	$L_m.L_m.Q_p/(L_p.L_p.S^{1/2})$
	Q_m	=	$Q_p.L_p^2/(S^2.L_p.L_p.S^{1/2})$
	Q_m	=	$Q_p/(S^2S^{1/2})$
	Q_m	=	$Q_p/(S^{2.5})$

In conclusion, the spillway, chute, and stilling basin are modelled according to the Froude theoretical principles. The inertia and gravitational forces are well represented by the Froude Number, Fr. For instance, using the selected criteria and a model scale factor of Lr =30, the scale factors were calculated and given in Table 2.2.

Table 2.2: The Model Scale Factor Used

Parameter	**Scale factor**
Velocity	$Vr = \frac{Vp}{Vm} = \sqrt{\frac{lp}{lm}} = \sqrt{30} = 5.48$
Time	$Tr = \frac{Tp}{Tm} = \frac{lp * Vm}{lm * Vp} = \sqrt{lr} = \sqrt{30} = 5.48$
Pressure	$Pr = \frac{Pp}{Pm} = \frac{\rho p}{\rho m} * \frac{Vp}{Vm} = 1 * lr = 30$
Force	$Qr = Vr * lr^2 = \sqrt{lr} * lr^2 = 30^{2.5} = 4930$
Discharge	$Fr = Pr * lr^2 = lr * lr^2 = lr^3 = 27000$

2.4 Spillway

The spillway is one of the most crucial components of a dam project and it is designed to safely discharge flooding from a dam into downstream area. The spillway protects the dam from overflowing by operating as a safety valve in the reservoir. The dam's height is determined by the maximum capacity of the reservoir. The standard level is the maximum reservoir capacity and the water is never deposited above this level. Thus, the spillway's safety is essential, as the dam can collapse due to overturning. The excess water is usually not permitted to overflow the dam because the top of the dam is usually used to create roads (Jamal, 2017).

A spillway is essential element of a storage and detention dam since it allows excess water or flooding that cannot be store within the time allocated space to be released (Julien *et al*., 2019). It assists during flood season by sustaining the high runoff when other facilities' capacities are exceeded. The excess water would be drawn from the reservoir and returned to the river's surface.

The spillway facilities must be built with sufficient capacity to prevent the dam from overflowing (USBR, 2014). Moreover, a spillway with a much larger capacity than needed would be an uneconomical design. So, the spillway must be hydro-dynamically and structurally stable to having sufficient discharge capacity. The surface of the spillway must be erosion-resistant to make sure it will be strong enough for the high velocities caused by water falling from the reservoir surface to the tail water (Abdel Aal *et al.*, 2018).

The term of spillway outlets refers to the collection of structures and equipment that necessary to ensure the safe operation and control of water released for the various purposes for which the dam is planned (Badanapuri, 2019). The examples of these structures are river outlet, penstock and canal outlets.

A spillway may be placed within the dam's body which located at one of its end or entirely away from it, independently in a saddle (Badanapuri, 2019). Moreover, spillway structures are composed of five distinct components which are an entrance channel, a control structure, a discharge channel, a dissipator of energy and an outlet channel (Badanapuri, 2019). Water is transferred from the reservoir to the control structure through the entrance channel which controls the reservoir's discharge. Then, the discharge conveyor transports water from the reservoir to the low-level energy dissipator on the riverbed. The energy dissipator is needed to reduce the high velocity of the flow that caused the scouring problem.

Numerous research on the physical hydraulic model of the spillways have been undertaken for a variety of purposes, including determining the energy dissipation factor. (Ahmad, 2018) is conducted the physical model study of spilling arrangement of the dam of Malana-II hydroelectric project on the discharging capacity of the under sluice spillways and an overflow spillway. For this study, the flip bucket used to dissipate energy from the flow over the overflow spillway was replaced with a hydraulic jump-type stilling basin created by pooling the water with a submerged weir (Ahmad, 2018).

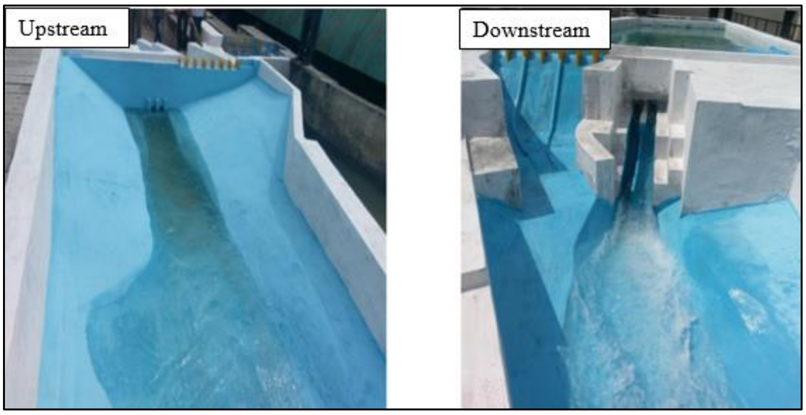

Figure 2.1: The View of the Model of Malana Dam (Source: Ahmad, 2018)

Moreover, the stepped spillway's over-flow, through-flow and under-flow breakers are investigated by (Gamal et al., 2018). The author created a physical model of four steps in the analysis to determine their effectiveness at dissipation energy. Breakers are set above the spillway's steps, and three distinct types of breakers are available, as illustrated in Figure 2.2. With the inclusion of an appurtenance such as a breaker, the experiment demonstrated a considerable improvement in dissipating energy through the stepped spillway. Thus, a comparison of energy dissipation in three different types of breakers reveals that the three-hole breaker performed the best in terms of energy dissipation (Gamal et al,. 2018).

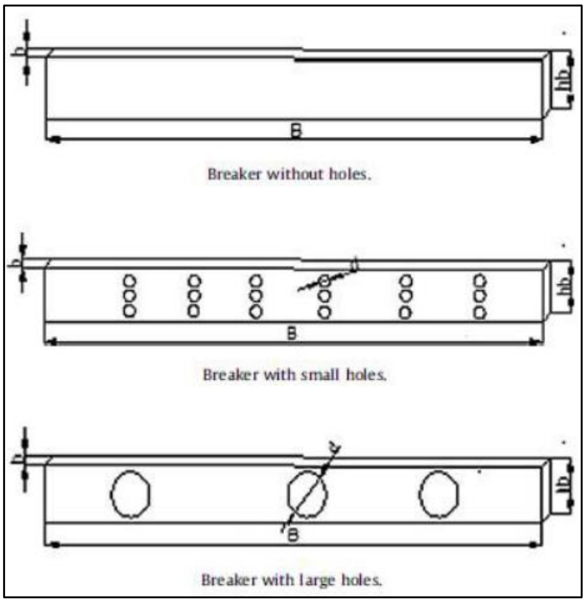

Figure 2.2: Types of Beaker Used (Source: Gamal et al., 2018)

In addition, the concept of a hydraulic jump-type stilling basin for the canal at Warana dam's overflow weir is investigated by (Yadav, 2015). A physical model research is conducted using Froude's model law in order to determine the percentage of energy dissipator and the location of the jump based on the amount of discharge flow, the subcritical depth of flow and the initial Froude number. The experiment is carried out in the laboratory with a varied discharge ranging from the design charge to approximately 20% of the design discharge. The author found that the energy dissipation design maintains the stilling basin's length within a safe range (Yadav, 2015).

2.4.1 Classification of Spillway

Reclamation classifies spillways into three categories based on their frequency of use (USBR, 2014). It can be classified into service spillway, auxiliary spillway and emergency spillway.

A service spillway allows controlled and uncontrolled discharged from a reservoir without causing substantial damages to the dam, dike or appurtenant structures due to the maximum design discharge. Service spillways are usually extremely durable, erosion-resistant structures which made primarily of cast-in-place reinforced concrete and channel defence with riprap.

Auxiliary spillways are used infrequently and can act as a secondary spillway. During activity, the auxiliary spillway can sustain some degree of structural damage or erosion due to maximum design discharge. Auxiliary spillways can be less durable, erosion-resistant structures which include some cast-in-place reinforced concrete, channel defence with riprap and/or unarmored excavated channels.

An emergency spillway is intended to provide extra protection towards overtopping dam and/or dike which classified as uncommon or severe condition such as the malfunction of the service spillway or fail of the outlet works during the PMF condition. Emergency spillways are the least durable and erosion-resistant structures which consisting of some cast-in-place reinforced concrete, channel defence with riprap and/or unarmored excavated channels.

Figure 2.3: Straight Ogee Service Spillway and Fuseplug Auxiliary Spillway (Source: USBR, 2014)

Figure 2.4: Gated Service and Auxiliary Spillway (Source: USBR, 2014)

Figure 2.5: Gated Service and Emergency Spillway (Source: USBR, 2014)

2.4.2 Type and Size of Spillway

When determining the type and size of a spillway, certain conditions must be considered in order to create a safe spillway. A specific type of spillway is chosen and planned for each project based on its specific function, hydrology, release specification, topography, dam protection and economics (Kamel & Abdulhameed, 2016). The spillway type can be categories into two systems which are controlled and uncontrolled (USBR, 2014). There are various type of spillway which are drop, ogee, side channels, shaft, labyrinth and chute spillways.

The overflowing water falls freely and almost vertically on the downstream side of the hydraulic system is classified as a drop spillway (Jamal, 2017). The design is appropriate for weirs or low dams. The crest of the spillway is equipped with a nose to prevent the waterjet from colliding with the structure at the downstream foundation. Occasionally, a basin is built at the downstream to provide a small artificial pool that called as a water cushion. This cushion act as energy dissipators.

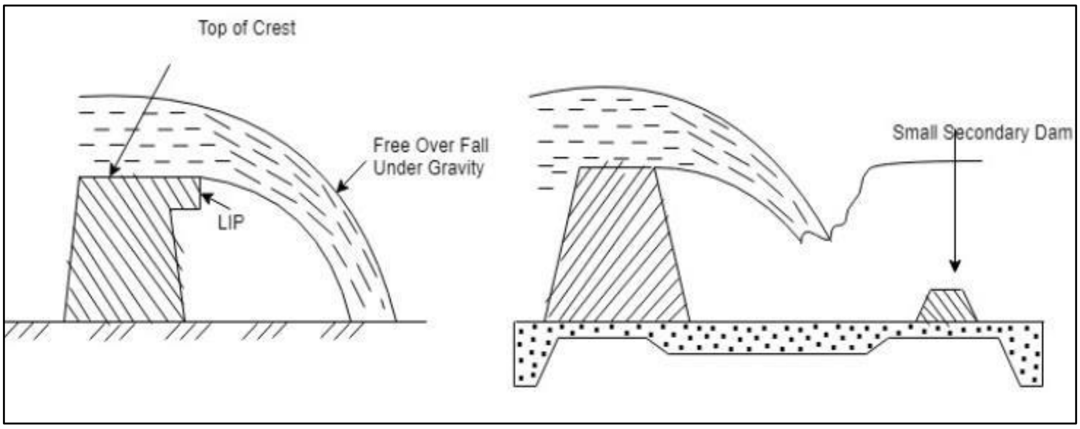

Figure 2.6: Drop Spillway (Source: Kharagpur, 2008)

The ogee spillway is typically used in rigid dams and it is improvement form towards drop spillway. The spillway's crest is designed to resemble the lower nappe of a water sheet that passing over an aerated sharp crested weir (Imanian & Mohammadian, 2019). Besides, an ogee spillway is often formed in an elongated shape to accommodate water flow over a weir (Bulu, 2010). The maximum head is taken into account when designing the ogee spillway. If the actual head exceeds the designed head, the lower nappe deviates from the ogee profile and separated from the spillway surface. At the point of separation, a negative pressure and the air bubbles are formed. When the water head is less than the designed head, the waterjet complies to the spillway's body and lowering the spillway discharge (Jamal, 2017).

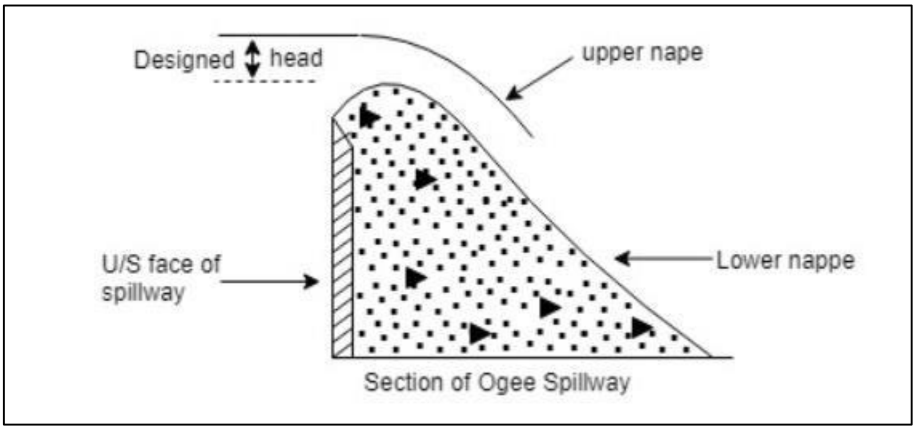

Figure 2.7: Ogee Spillway (Source: Kharagpur, 2008)

The side channel spillway is a form of hydraulic system that can be used in variety of situations. The crest of a side channel spillway is commonly perpendicular to the dam wall and this is the primary distinction between side channel spillways and other forms of spillways (Chandra, 2018). Water that flows over the spillway's crest is deposited in a channel which is running along its length. A side channel spillway is one with a control weir that is parallel to the upper section of the spillway discharge.

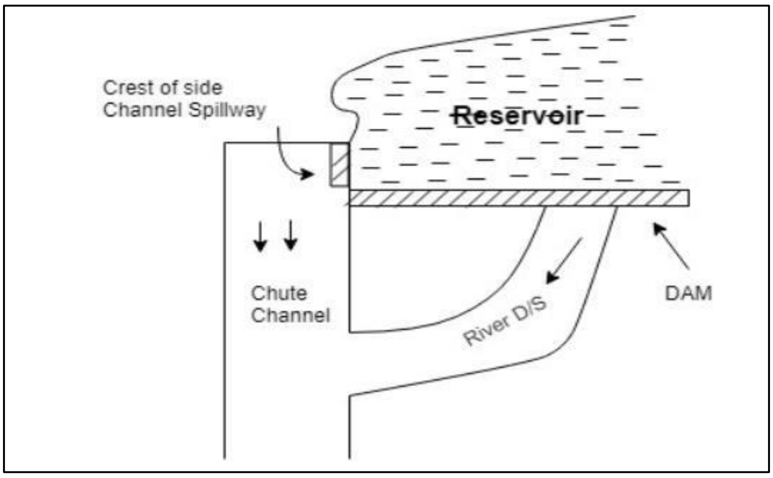

Figure 2.8: Side Channel Spillway (Source: Kharagpur, 2008)

Shaft spillways are made up of a circular crest that guides the flow to an inclined or vertical axis which is linked to a low gradient tunnel (Nohani *et al.*, 2015). The axis relation to the tunnel is accomplished through a bend with the appropriate radius which effectively transports the water to the downstream dam. It is preferable not to build a concrete spillway on the body in the embankment dam. Thus, the dam body reduces the chance of scouring and saturation of the downstream shell of the dam.

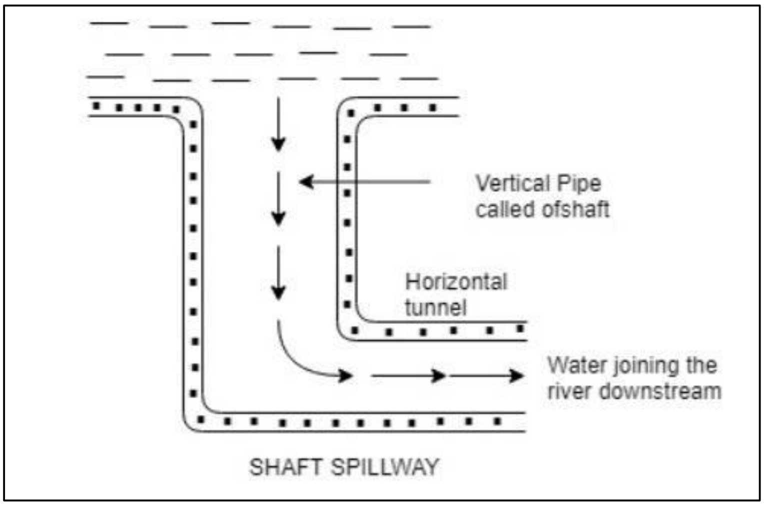

Figure 2.9: Shaft Spillway (Source: Kharagpur, 2008)

A labyrinth spillway is a plan view folding of an overflow weir that result in a longer total effective length for a given overall spillway width. A labyrinth spillway has benefits over a straight overflow weir and ogee crest (Tullis, Amanian & Waldron, 1995). The overall length of the labyrinth weir is usually three to five time the width of the spillway. By raising the crest while retaining the spillway capacity, labyrinth flow can be used to increase storages (USBR, 2014). The major parameter that must be taken into account are the length and width of the labyrinth, the crest height, the labyrinth angle, the number of cycles while the minor parameter such as wall thickness, crest form and apex configuration also important in designing the labyrinth spillway (Tullis, Amanian & Waldron, 1995).

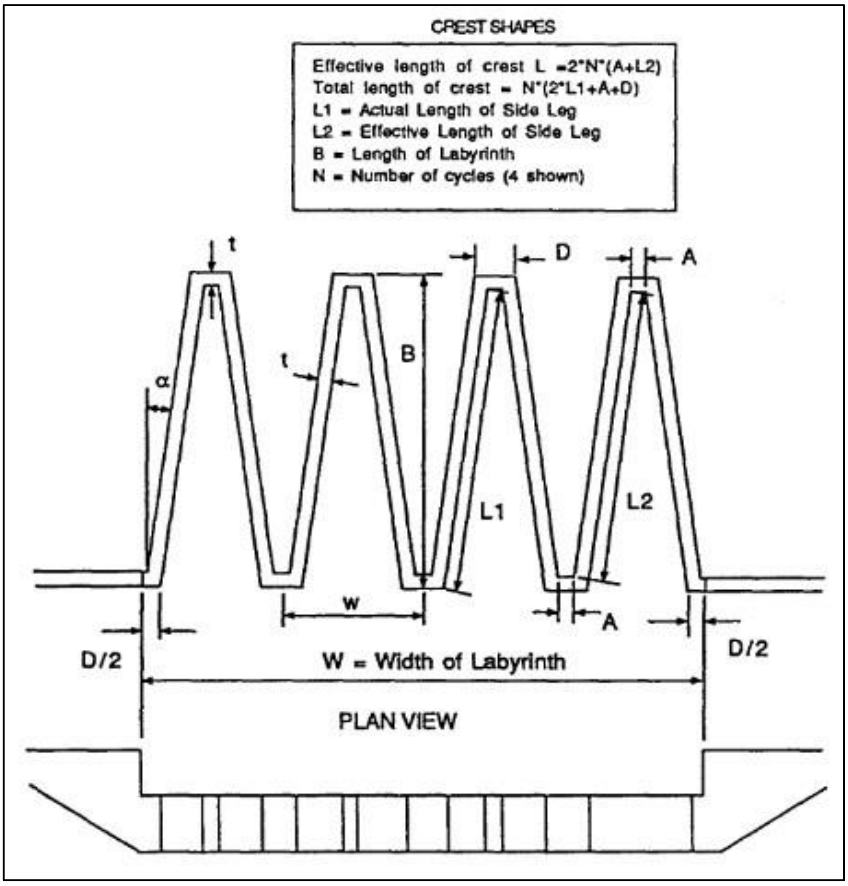

Figure 2.10: Labyrinth Spillway (Source: Kharagpur, 2008)

A chute spillway has a short crest from which the water flows downstream into a steeply sloped open channel. Typically, chute spillways have a baffle blocks that dissipates the water in the stilling basin and creates a hydraulic jump to protect the dam's toe from erosion (Bulu, 2010).

Generally, the control system is parallel to the conveyance channel. The channel's flow is supercritical (Jamal, 2017). A chute spillway can be positioned next to the dam or farther away in a suitable saddle.

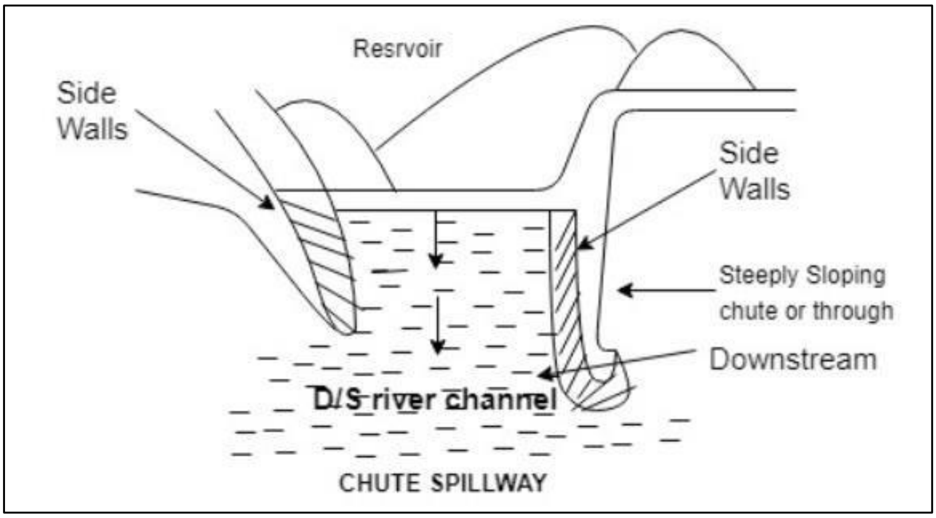

Figure 2.11: Chute Spillway (Source: Kharagpur, 2008)

2.5 Stilling Basin

The stilling basin is the most frequently used form of energy dissipator. It is transforming the supercritical flow from the spillway to the subcritical flow consistent with the downstream river regime (R. Agha Majidi, 2020). The function of a stilling basin is to prevent the scouring that caused by the high velocity of the water as it reaches the downstream part. Scouring will erode the dam's base at the downstream area and it can be resulted to overtopping (Padulano *et al.*, 2017).

A well-designed stilling basin not only improves the dissipation characteristics of a hydraulic jump, but also shortens its duration and remains stable its position so that the jump will not sensitive to tailwater level fluctuation. In a stilling basin, the kinetic energy generates turbulence form and it is eventually lost as heat energy. The stilling basins that are frequently used for spillways are the hydraulic jump type. This is because of the energy is dissipated through a hydraulic jump. Stabilizing a hydraulic jump in a stilling basin is accomplished by the used of appurtenances such as chute blocks, basin blocks and end sill (Kamel, 2015).

The chute blocks are constructed of concrete blocks and feature inclined spillway sections. These blocks are typically placed at the head of the stilling basin to generate turbulence where the hydraulic jump is formed. The incoming jet of water is furrowed and raised partially from the surface and it is resulting in a shorter jump duration (Khatsuria, 2004). This step contributes to the flow's stabilization and at the same time it also improves the jump.

Apart from that, baffle blocks are self-contained concrete blocks that are constructed inside the main basin but are only used when the flow velocity is less than 20 m/s. This is because a high a high force is applied to the baffle blocks, which can result in cavitation on the downstream part. These baffle blocks are extremely useful in small structures such as low spillway and weirs (Khatsuria,2004)

The end sills are shaped like a lip and situated at the tail of the basin, either with or without blocks. At the stilling basin, the sill height is essential since it has a direct effect on energy dissipation (Khatsuria, 2004). The taller the sills, the shorter the overall length of the stilling basin.

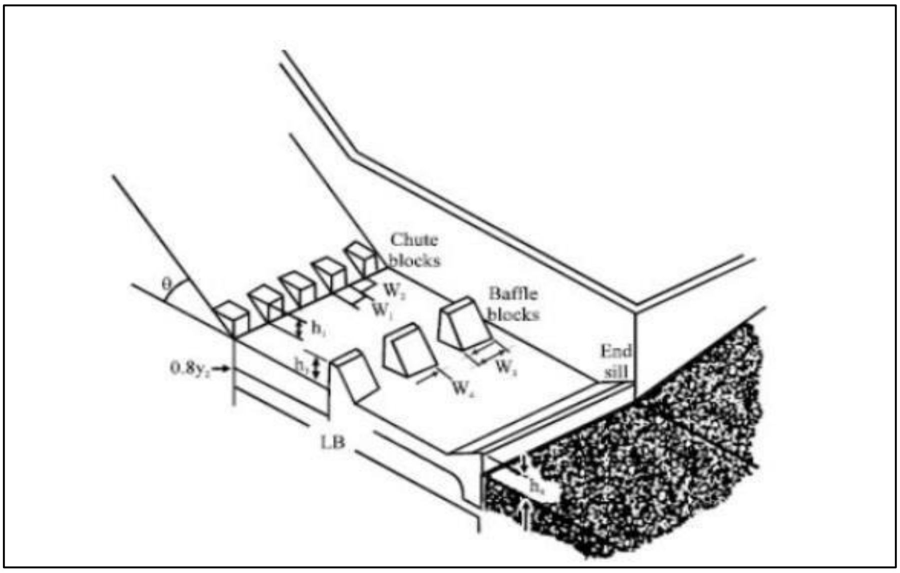

Figure 2.12: Elements of the Stilling Basin (Source: Kamel, 2015)