A STUDY OF FLOW CHARACTERISTICS ALONG ATAWAU SPILLWAY MODEL

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ABSTRAK

Spillway ialah struktur yang termasuk dalam kebanyakan empangan yang membantu mengawal aliran air, dengan membenarkan air mengalir melalui saluran tumpahan dan menghalang empangan daripada melimpah. Spillway direka bentuk dengan bantuan penstock dan pam. Alur keluar alur limpah ke hilir dari empangan disambungkan ke salur masuk alur limpah di hulu. Kajian ini melaporkan perubahan corak aliran dengan aplikasi penstock dan halaju aliran pada struktur model alur tumpahan dengan skala 1:30. Beberapa kes akan dijalankan dengan membezakan kedalaman bukaan penstock sambil membenarkan air mengalir di mana bacaan halaju air akan direkodkan menggunakan Nixon Streamflo Velocity Meter. Aliran air dari hulu ke hilir akan menghasilkan tenaga kinetik yang tinggi. Oleh itu, halaju aliran air yang tinggi akan berlaku yang boleh menyebabkan beberapa masalah seperti pemendapan, kerosakan peronggaan, dan pembentukan vorteks. Masalah ini boleh menyebabkan struktur menemui kegagalan. Oleh itu, profil aliran halaju dikenal pasti dengan menggunakan perisian Surfer 3D untuk mendapatkan pemetaan kontur halaju sebagai output daripada pengumpulan data. Peningkatan dalam halaju bergantung pada lebar dan kedalaman alur limpah penstock. Tujuan mencapai kontur halaju pada aliran air di alur tumpahan adalah untuk membuat beberapa pengubahsuaian pada masa hadapan pada model tersebut supaya model tersebut boleh digunakan secara berkesan sebagai panduan untuk membina empangan alur tumpahan sebenar dalam persekitaran sebenar.

ABSTRACT

Spillway is a structure that is included in most dams which helps to control the water flow, by allowing water to discharge via the spillway channel and prevent the dam from overflowing. Spillway is designed with the aid of penstock and pumps. The outlet of the spillway downstream from the dam is connected to the intake of the spillway upstream. This study reported the changes in flow pattern with the application of penstocks and the velocity of flow at the spillway model structure with scale 1: 30. Several cases will be conduct by differing the penstock opening depth while allowing water to flow where the velocity readings of water will be recorded using Nixon Streamflo Velocity Meter. Water flow from upstream to downstream will create high kinetic energy. Hence, high velocity of water flow will occur which may lead to several problems such as sedimentation, cavitation damage, and formation of vortices. These problems can cause the structure to meet failure. Therefore, the velocity flow profile is identified by using Surfer 3D software to obtain the velocity contour mapping as the output from the data collection. The increase in the velocity depends on the spillway width and depth of penstock. The purpose of achieving the velocity contour on the water flow at the spillway is to make some modifications in the future on that model so that the model can be used effectively as guidance to construct a real spillway dam in a real environment.

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LIST OF ABBREVIATIONS

MyDAMS	Malaysian Dam Safety Management Guidelines
CFD	Computational Fluid Dynamic
USBR	United States Bureau of Reclamation
DO	Dissolved Oxygen
ODE	Obliquely Descending Eddy
VOF	Volume Of Fluid
USACE	U.S. Army Corps of Engineers
RPS	Integrated Research Space
USM	Universiti Sains Malaysia
PPKA	Pusat Pengajian Kejuruteraan Awam

LIST OF SYMBOLS

C_d	Discharge coefficient
L	Length
g	Gravity of acceleration
Q	Discharge
H	Height of water level
V	Velocity
A	Cross-sectional area
d	Water column height
H_e	Total energy head on crest

CHAPTER 1

INTRODUCTION

1.1 Background of study

Spillway is one of the most important components of large and small dams as they are responsible for releasing excessive flow discharged from the reservoirs. Research made on the flow hydraulic characteristics such as the high velocity, pressure loss, cavitation probability, and aeration. Shockwaves are an aerated flow generated by the supercritical flow beneath the chute piers. Three types of standing waves are formed as a result of flow contact with the chute piers which are at the right downstream of the pier, in the middle of the chute, and on the sidewalls. This phenomenon impacts the flow domain and its hydraulic characteristics along the chute spillway. In this study, the experimental formation of shockwaves, the flow behavior along the chute, and mitigation measures are performed. The hydraulic performance of shockwave formation and development on gated spillways can be observed and determined based on gate opening parameter. The optimal opening strategy of the gate opening and reservoir operation able to reduce downstream damage such as increase the volume of water stored at the end of flood event and ensuring the safety of dam within reasonable limits.

Gates on the crest of a free spillway control the head, discharge, reservoir volume, and reservoir level increase in the spillway. The installation of gates raises a number of new complicated issues in hydraulics. According to Ansar et al. (2009), when gate opening is less than the critical depth and submerged when tail water depth is greater than critical depth, the flow conditions in gated spillways tend to be controlled.

AlMansori et al. (2020) found that, the flow separation rises linearly with the increasing of hydraulic head, up to seven times that of the design head. Xue et al. (2018) noted that shockwaves are affected by the width and type of spillway pier, slope of the chute, and depth of flow of the spillway chute. The spillway transverse flows and waves are less well-known difficulties, together with gate discharge coefficient, gates placement above the spillways, and flow profile separation. These waves are called as shockwaves, lateral shockwaves, and rooster tail waves. In 1998, the effects of chute lateral wall convergence and chute floor slope on rooster tail waves were also studied. Reinaur and Hager (1998) proposed a method for decreasing transverse waves and creating chute lateral walls. In a series of studies done in a horizontal channel and sloping chutes, Reinaur and Hager (1994) discovered that the characteristics of shockwaves were solely dependent on the ratio of approach flow depth to pier width. Energy dissipators were tested for their effectiveness in relation to different installation locations and heights in order to control the flow created by sluice gate. Based on the findings, it appears that using energy dissipators to minimize energy is an effective way as dissipators have been shown to reduce hydraulic jumps and preserve the riverbed under sluice gates. Wu et al. (2013) conducted experiments to study the characteristics of shockwaves. The results showed that the ratio of lateral cavity length to the bottom cavity length had a dominant effect in the intensity of the rooster tail.

Many studies have focused on measuring the hydraulic jump lengths and energy differences between upstream and downstream weirs in order to determine the length of aprons or decrease the hydraulic jumps through energy dissipation. Also, identifying the location of the wave formation, the characteristics of waves, and evaluating their pressure field and changes were all deemed important design hydraulic parameters. This information will be extremely helpful to assist the designers in design these structures.

1.2 Problem Statement

The Tawau dam has an open channel and chute-type spillway that controls volume of water discharged from dam. It is a controlled spillway that has gates to regulate the rate of flow. Mitigation measure should be taken as flow water discharged towards the downstream channel which have high velocity and kinetic energy may cause damage to the Tawau spillway. Cavitation damage can cause significant damage to spillway at large dams. This isdue to air concentration in flow, material's durability, irregularities along flow surface, and flow duration. Cavitation occurs in high velocity flow when pressures is lowered locally due to a flow surface irregularity. When vapour cavities enter a higher-pressure zone, they collapse and release high pressure shockwaves. Cavitation is formed from vapour cavities in liquid form. Besides, an air core vortex where air core may pass through the gate opening. Hammering effect produced by the collapse of the air core. Spraying downstream from the gate may cause a penetrating air core vortex which also known as rooster tail. Air core vortex frequently forms at hydraulic intakes, degrading hydraulic performance and also causing pump or turbine vibrations, resulting in efficiency reduction and operation instability. Furthermore, the hydraulic flood structure captures sediment carried upstream from the structure. In a dam reservoir, as water flowapproaches the inlet of the reservoir, the flow cross section increases, resulting in a reduction flow velocity and transport capacity, which leads to deposition of sediment. Coarse sediments are deposited at the upper part of the reservoir and delta formed. Finesediments are then deposited upstream of the dam axis along the flow direction. The assessment of damages based on damage of spillway dam model which correlates the damage with related variables such as economic variables and the affected area. This research study is being conducted to provide information on the flow characteristics by implementing different gate opening stages at the spillway. This can be used to quantify the risk of flooding for future mitigation efforts to reduce the negative impact and control flow effectively.

1.3 Objectives

a) To study the flow characteristics at different penstock opening.

b) To evaluate the impact of flow characteristics towards the hydraulic physical model of Tawau Dam.

1.4 Scope of work

The scope of work of hydraulic model includes data collection from the physical model of the Tawau Spillway. This study is done to identify the high velocity of flow at the Tawau spillway dam which can further cause the spillway to be damaged and flood risk. Generally, this research study will give an important element of Malaysia's flood risk analysis and flood damage assessment based on the velocity, discharge, and depth of flow where flow pattern at specified area can be observed. For this research, reliable model to study the impact of flow is essential. A spillway model with five penstocks at the inlet is analyzed through different penstock depth of few cases while water is being discharged. Two cases where all penstocks are opened at different depth and one penstock is opened at different depth accordingly are conducted and comparison of the cases are made. A miniature Nixon Streamflo Velocity Meter is used to measure velocities at discharge points. Hence, the results of flow achieve through this research gave a better understanding of the uncertainty that underlines the different depth opening of a penstock model at spillway to the speed of flow. The results obtained can be informative in flood risk management as they could bevery useful for future planning of flood mitigation measures and able to design a spillway dam with longer lifespan. Finally, the proposed vortex breaker able to eliminate vortices formed. Life, property, and environment can be protected from the dam failure.

1.5 Dissertation Outline

This study consists of a total of five chapters consist of introduction, literature review, methodology, results and discussion, and conclusion. Chapter 1 of this study discussed background of study, problem statement, objectives, scope of work, as well as dissertation outline.

Chapter 2 is the literature review which discusses the research articles and journals findings done by the previous researchers that are related to the topic. For instance, spillway dam model, characteristics of flow, factors influencing damage of spillway dam, and flood risk assessment which are breakdown into several components and further reviewed.

Chapter 3 refers the methodology of this study. Overall flowchart is presented which covers method applied on the physical modelling and software used for data collection and data analysis such as Microsoft Excel and SURFER.

Chapter 4 is related to the results and discussion of this study. Results obtained from the data that have been analyzed will be discussed thoroughly to satisfy the project outcomes required.

Chapter 5 is the conclusion of the study which concludes or summarize the overall project achievements of results that have been discussed based on the objectives stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In Malaysia, Malaysian Dam Safety Management Guidelines (MyDAMS) are referred where legislation, regulations, and standards are followed for the management of dam safety. These include dams used for water supply, hydropower, irrigation, flood mitigation, water quality management, sediment storage, and recreation. The spillway at dam is designed to supply water from the reservoir to the downstream for all discharges up to the design flood level. The flow of water is controlled by gates that are raised and lowered to allow the passage of water. SURFER software can be used to interpret and analyze data in contour mapping form where the level of flow velocity can be determined by observing the color mapping that can be differentiate.

2.2 Spillway Dam Model

The spillway dam model used scale in model physical test to evaluate and achieve optimum hydraulic design of the spillway dam based on related hydraulic parameters. Design should meet the specifications for great hydraulic performance and at the same time increase the safety during operation.

2.2.1 Physical model

Physical model can be applied to study and propose appropriate solutions to various flow and sediment problems. Huang et al. (2018) built a physical model of the Wushe Reservoir to investigate flood runoff, sediment models, and the trap efficiency of the reservoir to predict the reservoir lifespan. This is due to severe sediment problems. Based on the results of the model, the calibration of the Brune’s curve and the understanding of sediment movement in the reservoir were performed. State Hydraulic Works (DSI) carried out a physical model study at a scale of 1/60 by taking into account laboratory facilities to determine the hydraulic properties of the dam reservoir according to Ozcan (2011). Figure 2.2.1 shows the Brune's curve comparison with experimental results. The study of the physical model investigated several flow characteristics such as flow velocity, pressure, water level, and the performance efficiency of the spillway chute aerator. Physical model was made according to the original and real project, and then the final design was obtained by making improvement on the design in accordance with the hydraulic conditions. Issa et al. (2012) investigated the impact of reservoir water level and inflow flow rate on bed load transport rate using a physically based distortion model. Results obtained showed that increasing the reservoir level reduced the bed load as the reservoir water level caused backwater, which altered the flow at the river segment. Physical model can be used to investigate and provide solutions for various flow and sediment problems. According to Briggs (2013), the advantage of physical model is represented flow events accurately, allowing for the determination of empirical coefficients for various mathematical models as well as the calibration of mathematical models. Physical models also less expensive and safer than prototype studies. Scale effects due to laboratory space limitations and expense constraints are among its drawbacks. In addition, it is less accurate compared to prototypes and more expensive than numerical models.

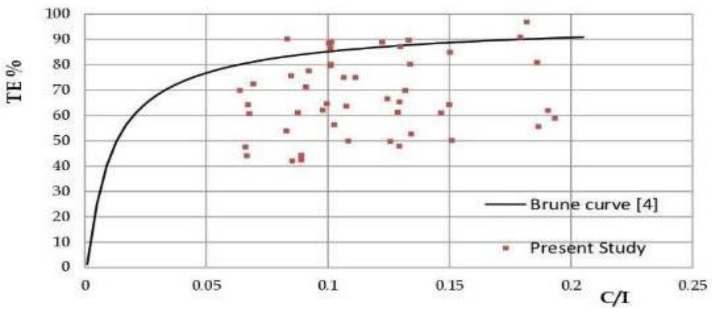

Figure 2.2.1: Comparison of experimental result and Brune's curve

2.2.2 Gate opening

Spillway gates design purpose is to maximize the dam's storage capacity and at the same time increase the storage capacity at required water level. Gates are raised or lowered based on volume of water and time taken during the operation in order to ease the water flow discharge and most importantly to prevent flood event. Generally, sluice gates are used to manage water flow in a reservoir, river, or embankment system. In an irrigation and flood control dam, the sluice gate acts as a supporting structure.

Linsley et al. (1992) concluded that the discharge from a storage reservoir is regulated by gates and valves operated on the basis of the judgment of the project engineer. Sakakima et al. (1992) made similar comment where, for the extremely big flood, a reservoir operator must control the gates to protect the reservoir and the downstream reference point by relying on his judgment. The operation of the spillway gate depends on the amplitude of the incoming flood profile, and the volume of the storage reservoir, which is the volume of the void above the top of the spillway up to the elevation below the crest of the dam by buoyancy limit, the dam safety, downstream flow rate, and the potential for a larger flood to follow the current. Choudhury (2010) stated that the model results suggest that damage at downstream locations could have been reduced substantially if the water inflows could have been predicted well in advance. Valerino et al. (2010) applied a heuristic model based on many routing simulations from reservoirs in the basin to minimize downstream emissions. Their model predicts flood inflow so that some reservoirs release excess flow before the flood hydrograph arrives which release the smallest possible downstream outflow during peak inflows. Hektanir et al. suggest a procedure for defining operational rule sets for gated spillway for optimal management of flood routing of artificial reservoirs. They construct flood storage reservoir of a dam with a gated spillway which is divided into 15 sub-storages, where the critical water level is the surface elevation.

2.2.3 Shape of wall

Shape of guide wall of spillway has a significant impact on the flow pattern. Wang and Chen (2010) investigated the Yutang dam spillway to reduce vortex flow and separation on the guide wall. They suggested that the wall should be modified and given a new shape to eliminate the vortex in front of the gate which can lead to failure of dam. The flow at the inlet of the side spillway is influenced by the guide wall. The guide wall tends to produce flow separation, which reduce the spillway's discharge capacity. An ideal shape for the guide wall which eliminates cross waves in the maximum flood design can be obtained using Computational Fluid Dynamic (CFD) tool.

2.2.4 Freeboard

Dam failures may occur as a result of spillway problems such as insufficient spillway capacity, blocked spillway, wind and landslide generated waves where overtopping happened. Minimum freeboard for dams with low and moderate hazard potential can be determined using risk analysis to overcome the dam failure. USBR (2012) proposed an approach for analyzing and designing freeboard to prevent an embankment dam from overtopping due to wind-generated waves and reservoir configuration. For flood management purpose, freeboard is a factor of safety above flood level. By referring to Table 2.2.4 below, the freeboard must exceed the minimum freeboard required for safety purpose.

Table 2.2.4: Minimum freeboard for dams

Reservoir Fetch (Length)	Freeboard
Under 200 m	300 mm
Up to 400 m	450 mm
Up to 800 m	600 mm
Over 800 m	Comprehensive assessment required

2.2.5 Boundary conditions

The top of the water level at the inlet is the standard atmospheric pressure, and the bottom of the water level is the flow velocity inlet with the mean velocity of the intake section. According to the water level at the inlet. The spillway's outlet is the boundary of pressure at standard atmospheric pressure. All of the structure's borders are regarded fixed walls, including the bottom, chamber, left, and right bounds. All boundary conditions are shown as in Figure 2.2.5.

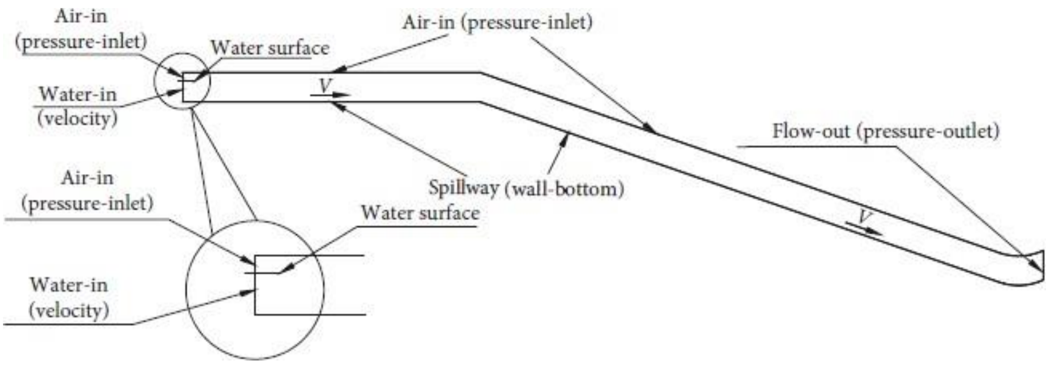

Figure 2.2.5: Definitions of boundary conditions

2.2.6 Sharp-crested rectangular weir

Weirs are most regularly used control structures in hydraulic flood structures (Kumar S et al., 2012). A weir is a regular obstacle in an open stream that controls the flow. Weirs can be categorized based on their shape, nature of discharge, width of crest, and nature of crest (Emad Abdul Gabbar et al., 2011). In hydraulic structure, it ranges from weirs or sluices gate where small volume of water may be discharged and flow to the overflow spillways of a dam. Sharp-crested weirs are the most often used weirs, although their narrow shape limits their application to laboratory, small artificial channels, and streams (Bagheri S et al., 2010). Anderson R.M et al. (2012) has come out a solution to overcome these practical constraints by creating various types of weirs where the crest length is increased. In most cases, length of weir is increased while width of weir remains unchanged in order to increase the discharge according to Khode B.V et al. (2010). Figure 2.2.6 shows the sketch of sharp-crested rectangular weir.

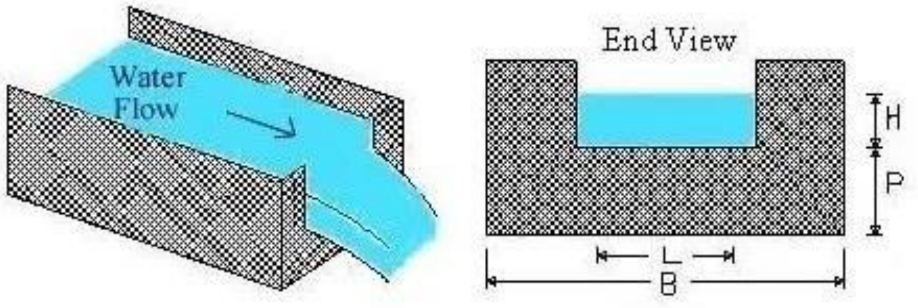

Figure 2.2.6: Sharp-crested rectangular weir

For control weir or sharp-crested rectangular weir, flow rates at water head for different flows can be derived as equations follow:

$$Q = 0.000235[(h_1 - h_2)\ 12.6]^{1/2}\ m^3/s \quad (2,1)$$

$$Q_{sharp-crested\ weir} = \frac{2}{3} C_d (2g)^{1/2} H^{3/2}\ m^3/s \quad (2,2)$$

Where,

C_d = Discharge coefficient

L = Length of weir

g = gravity of acceleration

H = height of water level

2.3 Characteristic of flow

For this research study, the characteristics of flow that overflows a weir alter from upstream to downstream are studied. Flow velocity, water level, Froude number, flow pattern, tailwater depth, hydraulic jump, and backwater are among the changes in characteristics of flow.

2.3.1 Flow velocity

Flow velocity from higher stream should be lowered to avoid scouring and damage at downstream structures. According to Chanson (1994), typically, if the flow velocity in the spillway exceeds 20 m/s – 30 m/s, aerators are recommended to overcome cavitation damage at the surface. In some cases, precautions have been reported if flow velocities exceed 30 m/s – 35 m/s even if the surface of the spillway is very smooth and well-constructed (as cited in Cassidy and Elder, 1984; Chadwick and Morfett, 1986; Novak et al., 1990). Kramer and Hager (2005) experimentally studied the size distribution of air bubbles, air concentration and flow velocity. They concluded that the rate of bubbles rise in chute flows depends on Froude number.

Besides, the water approaching weir has a velocity known as velocity approach, which is supposed to be uniform throughout the weir.

$$V = \frac{Q}{A} \tag{2,3}$$

Where,

V = Velocity of approach

Q = Discharge over the weir

A = Cross-sectional area of channel at side of the weir on the upstream

2.3.2 Froude number

According to Te Chow (1959), the dimensionless Froude number quantifies a hydraulic jump's temporally dependent shape.

$$Fr = \frac{v}{\sqrt{gd}} \tag{2,4}$$

Where,

v = velocity of incoming flow at top of the jump

d = water column height at the lowest point in the jump

g = gravitational acceleration

Based on Harry W. Morrison Dam (HWMD) study, the parameters of the hydraulic jump can be characterized by the Froude number, which influence the spectral content of seismic and acoustic energy. Investigation is done where the energy of the surrounding seismic and acoustic wavefields is systematically adjusted and compared to the Froude number of the wave produced below the HWMD.

2.3.3 Water level

The level of water is a significant factor in determining the amount of water discharged. The design of sluice gate allows for easy monitoring of water levels. The floodgates are opened and closed in response to the water level in dam, ensuring that the water level does not exceed the capacity of dam, which could cause damage afterwards.

2.3.4 Flow pattern

Baker (1954) presented baker charts which are one of the most commonly used flow pattern maps to determine flow regimes and predict transitions between flow patterns. Figure 2.3.4 depicts several flow patterns in horizontal pipes. Rahimi (2010) concluded that among the flow patterns in figure below, the degree of structural disruption increases from annular and bubbly flow to stratified flow and then to slug and plug flow. The geometry or phase distribution of the flow field usually refers to the flow pattern or flow regime which depends mainly on the flow velocity. Shock loads are created when moving liquid slugs encounter barriers such as valves and pipe bends based on Thorley (1991). Pipe vibrations, blowout, blowback and even the possibility of cavitation can be caused by enclosed air pockets in a pipe flow or known as close channel.

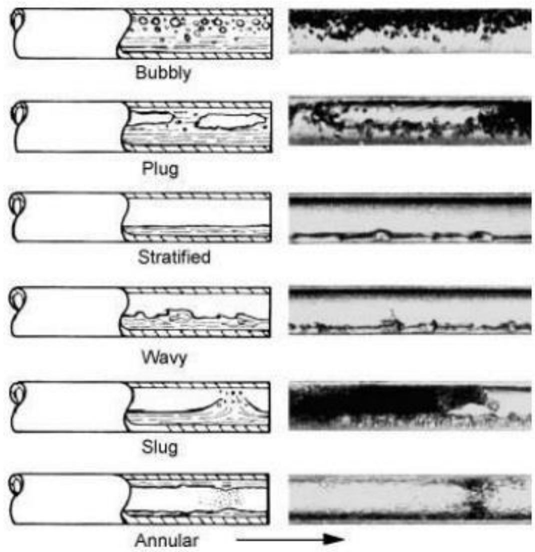

Figure 2.3.4: Two-phase flow patterns in horizontal pipes (Baker, 1954)

2.3.5 Tailwater depth

Chanson (1994) stated that aeration efficiency increases as tailwater depth increases. The effect of tailwater depth is limited as there is no infinite bubble penetration depth. Popel (1974) has observed that the efficiency of aeration remains constant where depth of water downstream is greater than 2/3 times of the falling height. Novak (1978) said that the depth of tailwater must be 0.6 times the drop height to give effect to the dissolved oxygen (DO) efficiency. The depth of tailwater is crucial in predicting oxygen transport at spillway. When the spillway model was set to a fixed height, the depth of the tailwater is directly proportional to the discharge rate and flow regime.

2.3.6 Hydraulic jump

Conversion from supercritical flow to subcritical flow in an open channel is referred as hydraulic jump. Large-scale turbulence, surface waves, energy dissipation, and air entrainment are all characteristics of this process. The “roller” is the term used to describe the large-scale turbulence zone. Degoutte et al. (1992) determined that there are two forms of jet flow which are fully developed hydraulic jumps and partially developed hydraulic jumps. Hydraulic jumps with fully formed inflow conditions showed higher void fractions in the first half of the roller and higher bubble count indicate greater bubble break-up. With fully developed inflow conditions, it is consistent with higher interfacial velocities and turbulence intensities in the first half of the jump roller. An experimental study was undertaken to analyze the hydraulic jumps at each stage, minimize the hydraulic jump length, and maximize the discharge per unit width using a large-scale model.

2.3.7 Backwater

Yang et al. (2018) used the water surface uniformity index to study the water surface improvement effect of a bend with a permeable spur dam, and the results showed that the use of a permeable spur dam can significantly improve the water surface effect of the bend when it is installed at proper angle and position in the bend. The height of the backwater in front of the permeable embankment effects the height of the side walls of the bend when installed in the bend. Yang et al. (2018) conducted an analysis of the height of backwater in front of the permeable spur dike and then a theoretical derivation was made based on the analysis to calculate the maximum height of the backwater in front of the permeable spur dike in terms of the principle of conservation of momentum. Hence, the results obtained can provide as reference for the design of the sidewall height of the chute curve. In a river bend, a levee which can be defined as an elongated obstacle with one end lying on the bank and the other end protruding into the flow to improve navigation, improve flood control (as cited in Huthoff et al. 2012) and protect banks from erosion (as cited in Ouyang & Lu 2016).

2.3.8 Turbulence intensity

The turbulence intensity plays an important role in aerated flow. Brocchini and Peregrine (2001) discussed free surface turbulence by taking into account the stabilizing effects of gravity and surface tension on the destructive effects of turbulent kinetic energy. The flow pattern of stepped spillway is more turbulent compared to smooth spillways. Felder and Pfister (2017) pointed out that the physical processes that leads to air entrainment were similar regardless of the roughness of the spillway. Hence, investigation was done to determine the turbulence level in self-aerated flows between air and water using hydraulic physical model. Chanson highlighted on the distribution of air concentration based on the theory of turbulent diffusion and predicted the entrained bubble sizes and presented the relationship between air concentration and bubble frequency.

2.3.9 Area of inundation

One of the most important parameters to control flow and avoid flood damage is by identifying the area of inundation. The information area of inundation obtained help to reveal the area that is exposed to flood risk. Thus, the area which have high probability for flooding to occur should be avoided in early stages during the planning phase before dam is constructed.

2.3.10 Time of occurrence of flood

Tawau area in Sabah receives strong winds and rains during Southeast monsoon season from November till March in 2022. The urban flood hazard in Tawau area is classified as high which means that it is predicted that at least once in the next 10 years, potentially devastating and life-threatening urban floods are expected. It is important to analyze the time of occurrence of the flood as in particular to analyze probability of flooding of set period of time in monthly, seasonal, or annual. Besides, the level of urban flood hazard must be considered while making project planning decisions, project design, and construction works.

2.3.11 Duration of flooding

The duration of rainfall is a critical factor that should be considered as it may affect the severity and scale of damage by floods. The duration of flooding is different over various areas and growth periods. Generally, the duration of flooding is longer during the monsoon rainfall that occurred for several days.

2.4 Factors Influencing Damage of Spillway Dam

During design process of new dams, it is vital to ensure that flow control structures or hydraulic structures are in good condition, well-operated, and have appropriate capacity. Hence, it is essential to determine the factors that influenced damage of spillway dam to evaluate the situation and allow for future intervention, proper design planning, and implementing measures. There are several factors of spillway dam damage:

1. Watershed runoff and sediment yield
2. Cavitation damage

3. Air entrainment

2.4.1 Watershed runoff and Sediment Yield

Flows and sediment loads carried by rivers are generated by watersheds along river basins. Storage volumes to accommodate incoming sediment and erosion control are recommended to reduce sediment flow in order to delay eventual filling of reservoirs. Erosion control alone cannot achieve the sediment balance required to stabilize reservoir storage capacity and achieve its continued availability and sustainable use (Tigrek and Aras, 2011). The drainage outlet near the riverbed at the bottom of the dam plays an important role in terms of safety and operation of the reservoir. Excessive bed load sedimentation can lead to clogging at the bottom outlet. For example, Ram pen reservoir, located in Canton Schwyz, the irregular operation of the aqueducts leads to the clogging of the bottom outlets (Boillat, Dubois et al., 2000, Boillat and Pougatsch, 2000).

Sediment transport is where suspended particles move at the downstream of a dam spillway along the water flow. The study of sediment transport in dam structures is necessary for determining erosion and deposition, which can damage the dam structural stability. Some studies, such as Nicklow and Mays (2000), Chang et al. (2003), Ji (2006), and Hadihardaja (2006) have studied reservoir operation in connection to reservoir sedimentation control. According to the findings, because of reservoir sedimentation issues, it is required to design reservoir operations for sediment control which can provide good performance. Hubl and Fiebiger (2005) designed open check dams to capture all or part of sediment and large woods from floods or debris flows.

Sediment control within the watershed by reducing erosion and sediment trapping upstream from the reservoir using check dams on sediment management through the reservoir, which includes controlling the flow during periods of high sediment load and flushing and removing deposited sediment in the reservoir using various appropriate techniques, such as dragging method as recommended by Annandale et al. (2016).

2.4.2 Cavitation damage

Peterka (1953) found that cavitation-induced erosion was not observed when the average of air concentration was in range of 0.01 to 0.06. Robinson (2001), Xu et al. (2010), and Brujan (2012) used advanced techniques to study the mechanism of erosion damage and found that the interaction between air bubble and cavitation bubbles is the mechanism that helps to prevent erosion damage. Air concentration controls the performance of the bubbles, including the chord length and the form of frequency. According to this study, the size of bubble and frequency are important parameters for erosion damage control. A decrease in cavitation index and flow velocity more than 25 m/s can lead to cavitation problem which cause chute bottom to be damaged. Thus, this will adversely affect the safety of the spillway. Chanson (1998) studied that cavitation on open channels and chute spillways indicate that flow aeration is an accurate, practical, inexpensive, and economical method of eliminating cavitation damage.

2.4.3 Air entrainment

Chanson (2008) stated that air pockets and air bubbles are trapped at the interface and trapped in the discontinuity between the colliding jet and the inflowing body of water. At the plunge position, air entrainment is caused by surface disturbances by jets, air boundary layers, or free surface shear layers as cited in Ervine (1998). Ervine (1998) showed that the maximum aeration rate per unit jet width depends on the jet velocity. Numerical modelling and experiments are often necessary to understand the process of air entrainment.

2.4.4 Free surface vortices

Through mechanical interactions between the surface and vortex, the free surface behaviors are strongly dependent on the collapse level and the depth of ambient water layer. Based on Figure 2.4.4, Nadaoka et al. (1989) discovered three-dimensional turbulent formations with vortex pairs extending after the breaking wave face in an obliquely downward orientation or known as obliquely descending eddy (ODE) while Kubo and Sunamura (2001) discovered another form of vertical flow caused by backwater collapse of wave surfaces due to horizontal counter-rotating vortices. The downward flow produced by the vortices, known as a downburst, transports the entrained bubbles formed into depth.

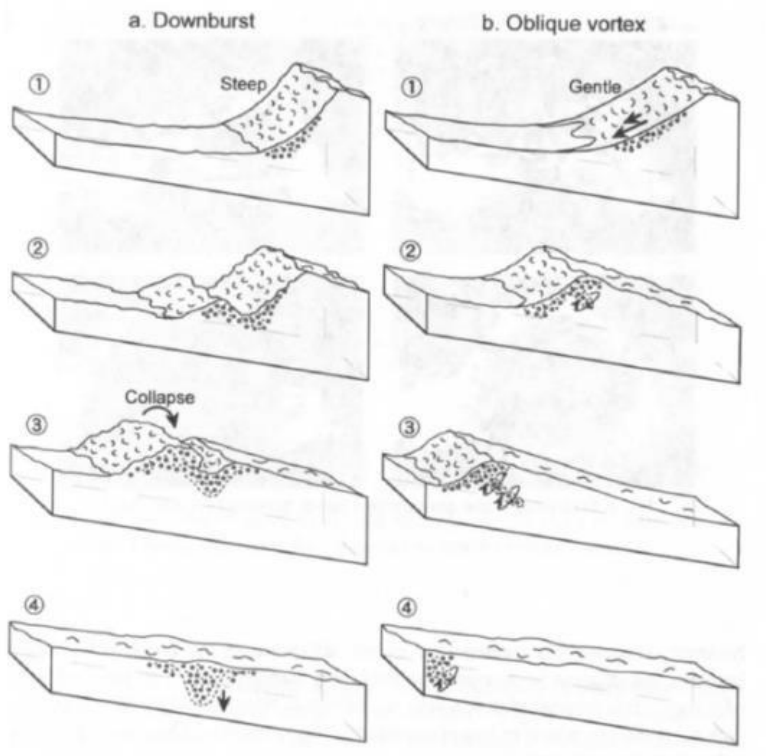

Figure 2.4.4: Schematic representations of downburst and obliquely descending eddies after Kubo and Sunamura (2001)

2.5 Flood Risk Assessment

Flood risk assessment is used to assess risk of flooding caused by various flooding mechanisms. The main objective of flood risk assessment is to minimize the flood losses and damages which has been widely studied since 1950s. Flood risk is comprised of three major elements which are hazard, exposure, and vulnerability. Hazard is commonly described as the probability of flood event to occur. Exposure is the exposed elements such as land use and individual building assets that are vulnerable to risk. Vulnerability is defined as the potential of flooding affects the community and assets (Romali et al., 2018). In the simplest terms, flood risk is the result of flood hazards and their consequences. Flood risk assessment is carried out using hydrological data, topographical data, land use data, and river management structures to apply a hydrological or hydraulic simulation model. The most important information needed to establish a simulation model is information on past floods such as rainfall, the water level, volume of flow discharge, and flow depth.

2.5.1 Volume Of Fluid (VOF)

Haun et al. (2011) and De Schepper et al. (2008) used the VOF model, and Euler-Euler approach to simulate two or more immiscible fluids with interface tracking such as combination of water and air flows with free surface of under pressured conditions. In a bottom spillway, the water-air flow is the most recommended to be used as a continuous medium. FLUENT, a finite volume code has been certified for multiphase and turbulent flow simulations. FLUENT was successfully employed by De Schepper et al. (2008) to mimic flow regimes predicted by the Baker chart. FLUENT was used by Baylar et al. (2009) to predict air injection rate of venturi flows. Liu and Yang (2011) used FLUENT to simulate air pocket transfer in pipe flows. The software was used by Politano and Carrica (2007), and Politano and Arenas (2011) to compute dissolved gas dynamics at downstream of dam. It is necessary to conduct three-dimensional transient simulations to analyze the overall behavior of the bottom spillway when the gate is opened.

2.6 Empirical Formulation

Empirical formulas were developed based on the findings of experimental tests that were utilized to construct the formulas that are commonly used to calculate the discharge in spillway.

2.6.1 Discharge coefficient

Asadi et al. (2005) studied the influence of suspended load on side channel discharge coefficient. The discharge coefficient is influenced by the flow suspended load, with the discharge coefficient decreasing as the suspended load increases. Discharge in spillway can be calculated based on formula below.

$$Q_L = C.L.H_e^{1.5} \qquad (2,6)$$

Where;

Q_L = Discharge (m^3/s)

C = Discharge coefficient for free flow

L = Effective length of spillway (m)

H_e = Total energy head on the crest (m)

Effective length can be computed by referring equation below (USBR 1987)

$$L = L' - 2\,(N.K_p.K_e).H_e \qquad (2,7)$$

Where;

L' = Net length of the crest

N = Number of piles

K_p = Pier contraction coefficient

K_e = Abutment contraction coefficient

H_e = Energy head on the crest

The geometry of piles and abutments have an impact on both contraction coefficients. This formula accounts for the effect of side contractions, which is comparable to the decrease in discharge capacity proportional to the energy head. To calculate the discharge over gated spillways, USACE (1992) proposed the following equation.

$$Q = C_g.A.\sqrt{2gH} \qquad (2,8)$$

Where:

Q = Discharge (m^3/s)

C_c = Discharge coefficient for orifice flow, computed from Figure 1

A = Area of orifice opening (m^2)

g = Gravity acceleration

H = Energy head to the center of the orifice (m)