A STUDY OF FLOW CHARACTERISTICS ALONG THE HYDRAULIC PHYSICAL MODEL OF KENYIR DAM SPILLWAY

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ABSTRAK

Disebabkan semua tenaga upaya diubah menjadi tenaga kinetik, air yang mengalir melalui pelimpah memiliki tenaga kinetik yang sangat tinggi.. Keadaan ini akan mengakibatkan kerosakan atau hakisan yang ketara di hujung limpahan, dasar saluran, dan hilir sungai. Untuk mengatasi masalah ini, halaju aliran air mesti dikurangkan. Pendekatan untuk masalah ini adalah dengan melakukan modifikasi di struktur penyebaran tenaga yang sedia ada, lembangan, untuk meningkatkan penyebaran tenaga sebanyak yang dapat dicapai dengan pengurangan halaju hilir. Blok penghadang digunakan sebagai modifikasi dalam penelitian ini. Blok penghadang digunakan secara meluas untuk menstabilkan lompatan serta memendekkan kepanjangan lompatan, dan memaksimumkan penyebaran tenaga. Pemilihan susunan blok penghadang dinilai dengan menempatkannya di tengah lembangan untuk mengenal pasti hasil yang paling berkesan dalam meminimumkan halaju aliran di hilir. Dari hasil penemuan tersebut, jelas ditunjukkan susunan blok penghadang di lembangan mempengaruhi penurunan halaju pada pelbagai nilai discaj. Pembentukan aliran menyilang juga dinilai pada saluran pembuangan pada setiap nilai discaj dengan jarak relatif dari saluran pengeluaran dan lebar saluran sebelum ke hilir. Untuk keadaan discaj 70.0 L/s dan 100.0 L/s, disyorkan pengubahsuaian pada lembangan Jenis II. Selanjutnya, penyempitan, pengembangan, atau kelengkungan harus dielakkan di pelimpah jenis *‘chute’* yang serupa dengan pelimpah Empangan Kenyir untuk mengehadkan penghasilan aliran silang dan perilaku aliran lain yang tidak sesuai.

ABSTRACT

Water flowing over a spillway has a very high kinetic energy because of the conversion of the entire potential energy to the kinetic energy. This circumstance will result in damage or significant erosion at the toes of the spillways, the weir bed, and downstream of a river. To solve this problem, the water flow velocity must be minimised. Physical modelling was implemented to this conundrum in order to modify the current energy dissipating structure, the stilling basin, to enhance energy dissipation as much as achievable by downstream velocity reduction. The baffles blocks were adopted as the modification in this study because they are widely used to stabilise the jumps, shorten its length, and maximise energy dissipation. A selection of baffle arrangements was evaluated by positioning them in the stilling basin's mid-span to identify the most effective outcome in minimising downstream velocity. From the findings, it is clearly shown arrangement of baffles blocks at the stilling basin impacts velocity reduction at various discharge cases. The formation of cross-waves was also assessed at the discharge channel at every discharge value with its relative distance from the sump and the width of the channel prior to the site. For discharge situations of 70.0 L/s and 100.0 L/s, modifications to the Type II stilling basin were recommended. Furthermore, constriction, expansion, or curvature should be avoided in chute spillways identical to the Kenyir Dam spillway to limit cross-wave generation and other unfavourable flow behaviours.

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LIST OF ABBREVIATIONS

CFD	Computation fluid dynamics
BB	Baffle blocks
PMF	Probable Maximum Flood
JHC	Jump Height Curve
TWRC	Tailwater Rating Curve
USBR	United States Bureau of Reclamation

CHAPTER 1

INTRODUCTION

1.1 Background of study

Dams was built as a water storage facility to accommodate sudden changes in the catchment area and generate electricity. Effective operation of existing water infrastructures is considered essential for the efficient use of water supplies (Rong et al., 2019). Dam breaks can occur due to inadequate spillway capability, structural fatigues and flaws, unstable slopes, earth slides, seepage, overtopping, and earthquakes.

To avoid the occurrence of breaking of dam, spillway is designed to release and regulate the stream of floods. Due to the heavy flow discharge over the spillways, their structure and construction are very sophisticated, and they typically face difficulties such as cavitation and high flow kinetic energy. Pumping air next to the spillway surface with aeration systems mounted on the spillway bottom and also on the sidewalls is a common procedure to avoid cavitation and erosion of the spillway surface. (Al-husseini, 2016). Moreover, stream of water through the spillways generates high velocity and high energy at the toe of the spillway. This high velocity causes a severe force that can cause damage in the form of erosion to the downstream channel of the spillway, resulting in the scouring of the channel bed and sides, and continue to raise the depth of the scour at the toe of the spillway (Hayder and Jafar, 2015)

For this study, Kenyir Dam’s spillway's flow characteristics were assessed and designing suitable energy dissipater by physical modelling. The spillway of the Kenyir Dam is built to a distorted 1:50 scale which includes the main dam, dam station, substation, spillway, power station and the topology.

1.2 Problem Statement

The Kenyir dam has a chute-type spillway to control the reservoir supply level. Water spillage events have occurred over the years at the dam where the water level has exceeded the normal water level of the dam. However, the stream of water from the uncontrolled no-gate spillway towards the downstream channel is usually high in velocity and kinetic energy. If appropriate steps are not taken, the discharged water flow exceeds high velocities consistent with low pressures, which can cause cavitation damage on the spillway. Furthermore, if the spillway invert and sidewalls are exposed to constant removal of surface soil, the dam structure's stability could be jeopardised.

Hence, the velocity and the kinetic energy must be reduced by efficient energy dissipation. Energy dissipaters play a critical role in decreasing incoming energy to the downstream channel and facilitating the reduction of this high velocity. Therefore, this can be done by first studying and evaluating the flow characteristics based on the discharge and suitable design of the energy dissipater can be identified.

1.3 Objectives

The aim of this physical model studies is to study the profile of water such as depth, pressure, velocity, and discharge per unit. Based on the assessment, a suitable energy dissipater design can be identified. Thus, the two objectives of this study are:

1. To study the flow characteristics along Kenyir Dam spillway.
2. To design suitable type of energy dissipater for Kenyir Dam Spillway.

1.4 Scope of work

The hydraulic model's scope of work encompasses data collection from the physical model of the Kenyir Spillway. According to the prototype’s true dimensions the design scale for this hydraulic physical model of Kenyir Dam Spillway is 1:50. (model to prototype ratio). Three cumulative discharges have been tested: 50.0 L/s, 70.0 L/s and 100.0 L/s

The velocities at each discharge point were measured using a miniature Nixon Streamflo Velocity Meter during the results observation process. In addition, the height of the hydraulic jump was also measured. Finally, the baffle blocks were used with minimum dimensions recommended by United States Bureau of Reclamation (USBR).

1.5 Expected Outcome

The expected outcome is to design a suitable energy dissipator by studying the flow characteristics of the Kenyir Dam spillway. The next expected outcome is to reduce the high energy level of the water flow from the spillway to the downstream through simulation of the physical modelling. Through the adequate design of the suitable energy dissipator, the high turbulent flow characteristics of the water flow from the spillway to the downstream channel should be reduced. Moreover, the energy dissipation of the flow also should be enhanced as well.

1.6 Importance and Benefits

The significance of designing the suitable energy dissipator in dams will help enhance the performance of the spillway of the dam. The energy dissipator also prevents the scouring of river surface downstream. Moreover, the energy dissipator plays an important role in protecting the riverbeds and banks from erosion.

It also ensures the structural agility of the dam itself as well as the adjoining structural parts such as powerhouse, canals are not undermined or governed by the high-level turbulent flow.

1.7 Dissertation Outline

The thesis paper has been categorised into several chapters for a better understanding of this study. Hence, this paper contains five chapters.

Chapter 1: This chapter briefly explains the basic essence of the research and offer an outline of the contents of this study. This chapter outlines the philosophical context for what the researcher will study, including the scientific problems, theories, and basic research structure.

Chapter 2: This chapter establishes a well-documented argument for the analysis of research topics, and to formulate a research methodology. This chapter sets out the theoretical context for the thesis and outlines the topic, the basic research problem, the question(s), and the design elements.

Chapter 3: This chapter contains the method of study of the dissertation. In further depth, study technique, the research methodology, the data collection processes, the preparation of the dataset, the research procedure, the form of data analysis, the ethical considerations and the research constraints of the project are explained in this chapter.

Chapter 4: The aim of this chapter is to summarise the data obtained, interpret the data, and report the findings. This part of Chapter 4 briefly reiterates the problem statement, approach, research question(s), hypothesis(s) or phenomenon, and then makes a statement as to what will be discussed in this chapter. The results of the research should be presented as briefly as possible in Chapter 4, keeping the synopsis of the results for Chapter 5.

Chapter 5: This chapter presents a concise overview of the context for the analysis. In this chapter, assumptions, connotations, and recommendations will be made.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of chapter

Several topics will be reviewed within this chapter such as spillway and its importance, spillway types, energy dissipation below the spillway, hydraulic jumps, location of the hydraulic jumps affected by the jump height (JHC) and tailwater rating curve (TWRC), Froude number (Fr). Last but not least, stilling basin and its components as well as the type of stilling basins will be discussed as well.

2.2 Spillway

Spillways are concrete-based hydraulic structures in dams, to control the water discharge into the downstream in order to prevent overtopping of the dam (Gu et al., 2017). Spillway can be operated in either two ways which are controlled mechanism and uncontrolled mechanism. Five basic components that the spillway is made of is control structure, discharge carrier, energy dissipator, inlet and outlet channels (Nigam et al., 2016).

A controlled spillway has gates that can be raised and lowered to regulate the downstream and utilise the dam's maximum height for water storage purposes. The gate mechanism allows water to be stored above the spillway crest level with maintaining the gates closed and opened when excess water has to be let out. As for the uncontrolled spillway, it is a simple ramp-like structure where it is designed to allow water to flow out whenever the water level reaches the crest height. The surcharge storage is the temporary storage between the maximum and normal reservoir level in uncontrolled spillways.

Moreover, spillways is usually placed near the diversion weirs since it is known for its high hydraulic efficiency (Daneshfaraz and Ghaderi, 2017). The design of top of the dam must be exceeding the maximum reservoir level subsequent to the design flood used for the spillway design since the effective storage is up to the normal reservoir level. Besides, several factors for spillway design have to be considered such as type of dam and the suitable spillway type required, hydraulic conditions and external factors such as topographical and foundation conditions which ensures the stability of the dam. The design of spillway must also meet the Probable Maximum Flood (PMF) requirement to withstand severe meteorological and hydrological conditions that is expected to occur.

2.2.1 Type of spillways

Different spillway types can be built depending on the site conditions as well as other parameters involved. Moreover, spillways are classified into overflow and type of channel depending on the position. These main spillway types are directed down into sub-categories of spillways.

As for the overflow type of spillway, Ogee spillway is one of these types since it has controlled weirs. The ogee-shaped or s-shaped follows the lower surface of the horizontal jet from the aerated sharp-crested weir. Atmospheric pressure level is maintained at the crest throughout the design head and pressure becomes positive when water reaches the lower part of the head. This cause negative pressure built-up on the higher head pressure at the crest which will increase the water discharge. The discharge is greater at the higher heads than the head lower than the design head due to crest resistance (Kamel and Abdulhameed, 2016).

This is also due backwater effect where it transmits the subtle current backwards creating a sinuous pattern of the upstream due to differences in gradient in water level which induces variations in discharge (Awang et al., 2020).

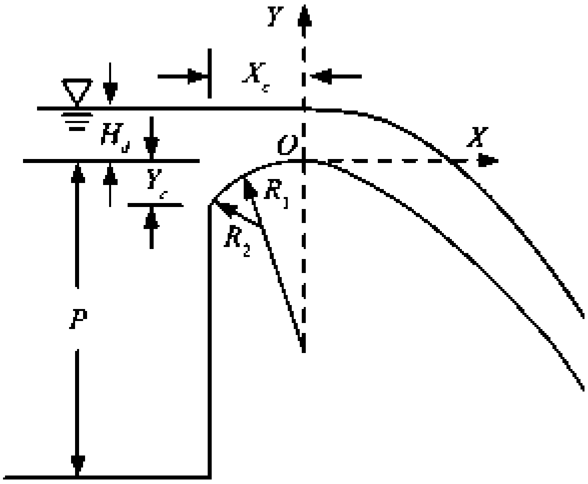

Figure 2.1: Ogee spillway (Source: Chen, 2015)

Channel type spillways are usually designed and built isolated from the dam structure. Some of these spillways are chute and side channel spillways. A chute spillway as in Figure 2.2, which has a crest and a sloping discharge outlet, is a critical facility used to avoid overtopping and release flood surge. (Hien, 2020). It also consists of a reinforced concrete slab open channel at a steeper gradient. Generally, the chute spillway is very economically sound since it adapts the existing ground slope to safely negotiate the discharge. Side channel spillway as illustrated in Figure 2.3 has a control weir placed parallel to discharge channel. However, the flow of water above the crest follows a narrowed trough, directed to a right angle to be discharged at the main channel.

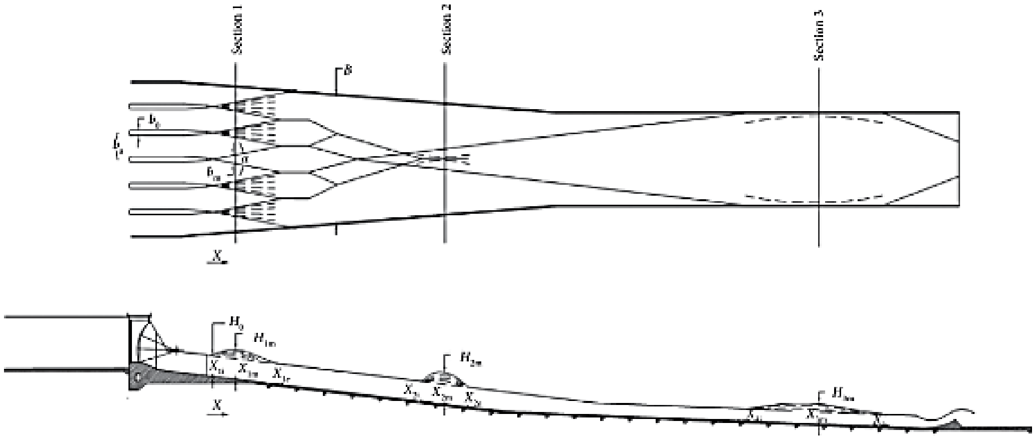

Figure 2.2: Chute spillway (Source: Mousavimehr et al., 2021)

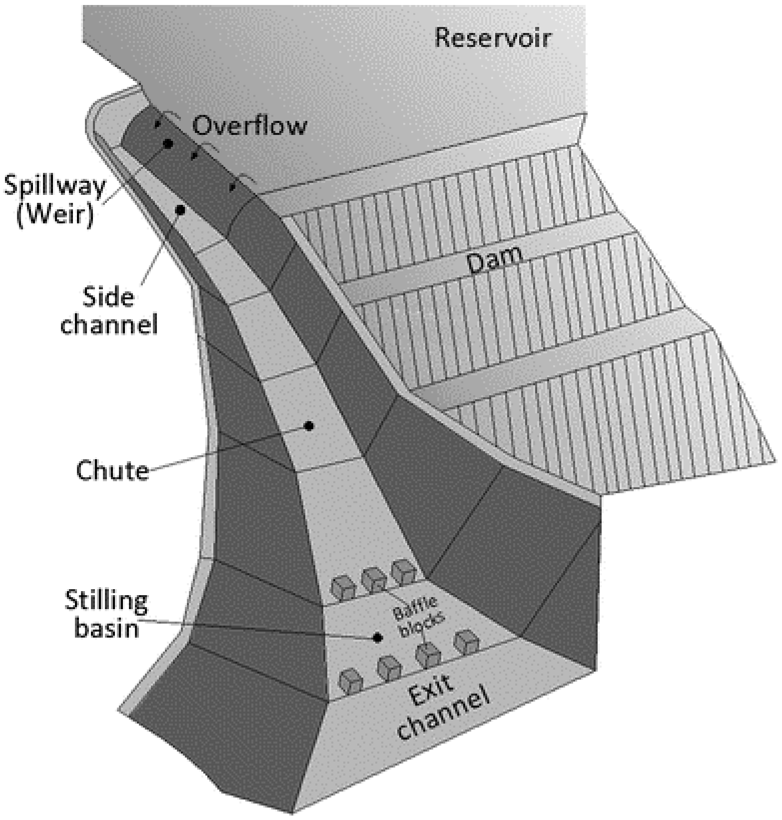

Figure 2.3: Side channel spillway (Source: Seo, Il et al., 2019)

2.2.2 Energy dissipation below spillway

Spillway flows typically associated with the energy dissipations since a number of hydraulic processes take place such as the presence of friction along the spillway which then substantially upsets the flow energy in the form of flow turbulence and interactions (Gu et al., 2017). Dissipation of the energy in the flow is caused by the formation of vortex where the regime changes due to jet intrusion in the interfacing device when coming in contact with a solid body hydrodynamically (Orekhov, 2018).

Water level at the crest of the spillway tend to have potential energy proportional to rising crest height above spillway floor. The potential energy then transforms into kinetic energy when the water pass through the crest and reaches the bottom of the spillway with high velocity. The high kinetic energy is able to cause deep erosions and etc. For a higher energy dissipation at the spillway, several factors should be taken into consideration such as flow velocity and its orientation, jump height (JHC), tailwater elevation (TW) at different discharge rate as well as the design of dam and its spillway type.

Hence, a suitable energy dissipater is necessary to be implemented because it can diminish the high energy entering the downstream channel as well reducing its velocity (Hayder and Jafar, 2015). Thus, reduction in velocities and kinetic energy with high air entrainment will reduce the risk of cavitation in these hydraulic structures (Nouri et al., 2020).

2.2.3 Importance of spillway

Spillways are crucial since it has the adequate capacity to act as a temperance of floods because it has to be sized hydraulically to ensure that the flood safely passes through equivalent or less than the Probable Maximum Flood (PMF) required (Kamel and Abdulhameed, 2016). It also maintains the tailwater while directing the excess downstream flow such that the dam and other appurtenant work are well protected.

It also regulates the surplus water to be released safely when the reservoir capacity is exceeded. Since the downstream down the channel generates immense scouring velocity, the spillway is hydraulically and structurally adequate and erosion resistant to withstand those velocities and secure the base of the downstream and the dam floor from severe scouring and erosion (Abdel Aal et al., 2018).

The position or location of the spillway structure plays an important role for an efficient operation to pass the designed flood without overtopping the dam and also provide structural integrity throughout the design life of the dam (Abdel Aal et al., 2018). The suitable location of the spillway is usually within the dam structure itself or sides of the dam. Some of the spillway structures are placed away from the dam structure. Moreover, there is a high probability of dam failure to occur when the spillway fails to operate due to misplacement of the structure.

2.3 Hydraulic Jump

Hydraulic jump is understood for its convoluted nature of intense turbulence, recurrent fluctuations in velocity and pressure as well as its implication of the entrainment of air flow (Macián-Pérez *et al.*, 2020). In theory, hydraulic jump is an event when the river flow drastically changes from the supercritical flow (>1) to subcritical flow (<1). (Anggraheni *et al.*, 2017). Prior to the event, hydraulic jump is the utmost mutual way for dissipating energy from the spillway to the downstream (Eltoukhy, 2016). An effective hydraulic jump is described as non-submerged and non-swept which occurs at the front of the stilling basin at the toe of the spillway (Sonaje, 2017).

In addition, hydraulic jump is categorised using inflow Froude Number where optimum value ($4.5< Fr< 9$) of Froude number will tend to have a stable hydraulic jump at the stilling basin with an even energy dissipation. However, lower Froude Number ($4.5< Fr$) in hydraulic jumps is most likely to cause undulant jumps which is exemplified by wave-like formation. Hydraulic jump with high Froude Number ($Fr>9$) tends to be unstable and described to have forceful spray and bubble formation (Macián-Pérez *et al.*, 2020). Figure 2.4 below shows the hydraulic jump formations based on the Froude Number.

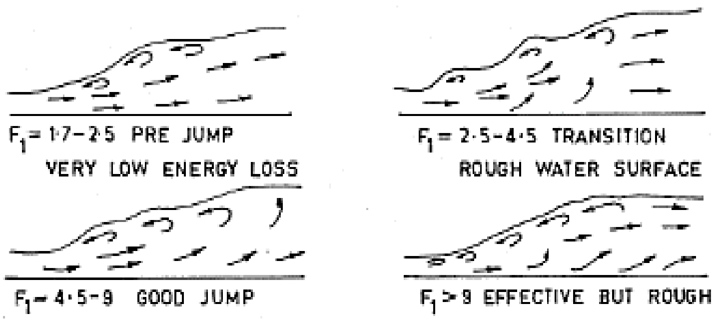

Figure 2.4: The hydraulic jump formations based on Froude Number.
(Source: Nigam et al., 2016)

In addition, hydraulic jump is influenced by several factors such as pre-jump depth (y1), post jump depth (y2), crest height (y’) and tail water depth (yt). Usually the pre-jump depth (y1) and velocity (V) can be determined when the discharge per unit width (Q) is provided and the total energy from the spillway to the starting point of the jump formation is assumed to be constant. The apron length is also influenced by the length and the location of the jump formation which is directly proportional to the pre-jump depth (y1), magnitudes of the post-jump depth (y2), and tail water depth (Sonaje, 2017). The energy loss in hydraulic jump is derived as in equation 2.1 as below:

$$\mathbf{EL = E1 - E2 = \frac{(y2 - y1)^3}{4(y1)(y2)}} \qquad \textbf{(2.1)}$$

Where:

EL = Loss of energy

E1 = Specific energy before the hydraulic jump

E2 = Specific energy after the hydraulic jump

2.3.1 Location of hydraulic jumps

The position of the hydraulic jump is influenced by the tailwater level in the stilling basin. An increase in the tailwater level ensures that the position of the hydraulic jump is maintained within the length of the stilling basin so that more floodwaters can flow through safely. Moreover, the risk of scouring and cavitation in the stilling basin can be also reduced when the hydraulic jump is stabilised and confined within the structure (Mahtabi et al., 2020).

Besides, the location of the jump is mainly dependent on the magnitudes of two components which are jump height (JHC) and tailwater rating curve (TWRC) against the discharge per unit (Q). Figure 2.5 shows the possible position of jump height and tailwater rating curves during the hydraulic jump phenomenon. There are five possible cases of relative positions of jump height (JHC) and tailwater rating curve (TWRC):

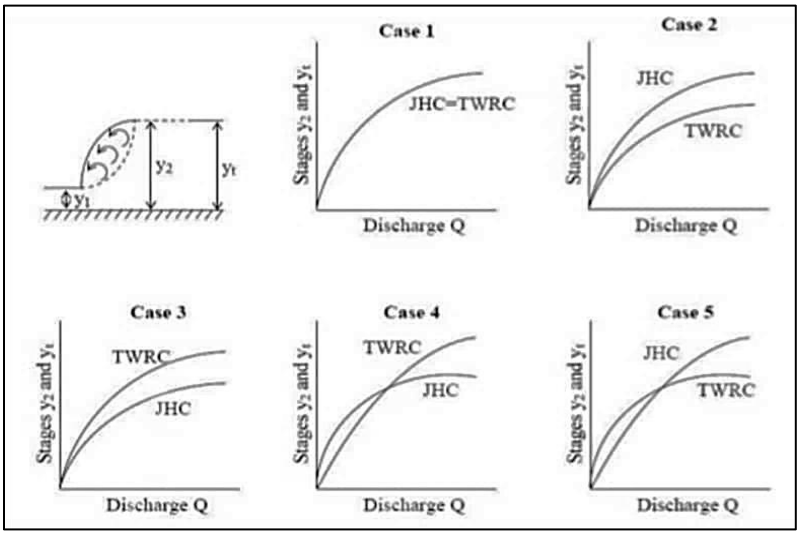

Figure 2.5: The jump height and tail water rating curves
(Source: Rahul Gupta, 2015)

Case 1 is where the JHC and TWRC coincides throughout the discharges. The tailwater depth is equal to the subsequent depth needed for the hydraulic jump. The jump is described to a perfect jump exactly at the toe of the spillway in an idealised condition.

Case 2 is where the TWRC is lower than JHC throughout the discharges. This case condition is very dangerous since the tailwater is elevated rapidly due to rapid downstream. The jump formation is exactly at the downstream of the spillway toe. This generates high velocity can cause severe erosion and scouring of the riverbed.

Case 3 is where TWRC exceeds JHC throughout the discharges. This occurs when the downstream of the spillway is narrowed down causing the tailwater to snarl. The formation of the hydraulic jump is at the spillway face. The jump is described to be submerged and drowned which is not suitable in the aspect of energy dissipation.

Case 4 is where TWRC is lower than JHC at low discharges but exceeds at high discharges. This is an amalgamation of case 2 and 3 where the tailwater discharge is lower than jump height but then gradually increase and exceed the JHC at a significant point of the discharge. The jump formation is further at the toe of the spillway during low discharge point and drowned at high discharge point.

Case 5 is where TWRC exceeds JHC at low discharges, but lesser than JHC at high discharges. It is similar to the combination of case 2 and 3 but the formation of jump is further along the downstream and described to be drowned at low point of discharge.

2.4 Froude Number

Froude number (Fr) is a dimensionless quantity or number which signifies the gravitational impact within the hydrodynamic system. It is expressed in the form of ratio between gravitational and inertial forces of the fluid. The Froude number is important to provide an efficient energy dissipation rate in the stilling basin (Ljubičić et al., 2018). Froude number is also essential for the classification of jumps occurs in the channels such as rectangular, horizontal, and smooth channels (Mahtabi et al., 2020). The Froude number value is derived as in equation 2.2 below:

$$\mathbf{Fr} = \frac{\mathbf{V}}{(\mathbf{gD})^{\mathbf{1/2}}} \tag{2.2}$$

Where:

Fr = Froude number

V = Average velocity of liquid (ft/ sec^2 or m/ sec^2)

g = Gravitational acceleration (32.17 ft/ sec^2 or 9.81 m/ sec^2)

D = Characteristic length

Froude number less than one **(Fr<1)** is known as subcritical flow. It occurs when the real water depth reaches the critical depth. Subcritical flow is governed by gravitational forces and exhibits sluggish or steady behaviour. Froude number less than one **(Fr =1)** is known as critical flow. The movement or control flow for the flowrate possesses minimal amount of energy.

Froude number less than one **(Fr>1)** is known as supercritical flow. Inertial forces dominate supercritical flow, which manifests as fast or turbulent flow. The transition from supercritical to subcritical flow occurs through a hydraulic jump, which reflects a high energy loss with erosive potential. When the real depth is smaller than the critical depth, the condition is referred to as supercritical.

2.5 Reynold Number

The Reynold Number (Re) is a dimensionless quantity used in fluid dynamics to model flow patterns and represent whether the fluid flow in a system is laminar or turbulent. Laminar flow dominates flows at low Reynolds numbers. At large Reynolds numbers, turbulence is caused by changes in the fluid's speed and direction, which may result in cross flow, cavitation, and eddy current phenomena. The form of flow is defined by the value of Re. If Re 2000, the flow is referred to as Laminar. If Re > 4000, the flow is said to be turbulent. The flow is known as transformation if the Re ranges from 2000 to 4000 (Prasetyorini et al., 2020). The Reynolds number formula is expressed by equation 2.3 below.

$$\mathbf{Re} = \frac{\boldsymbol{\rho}.\mathbf{V}.\mathbf{L}}{\boldsymbol{\mu}} = \frac{\boldsymbol{inertial\,forces}}{\boldsymbol{viscous\,forces}} \qquad \textbf{(2.3)}$$

Where:

ρ = density of the fluid

V = velocity of the fluid

μ = viscosity of fluid

L = length or diameter of the fluid

2.6 Stilling basin

In dam engineering, stilling basin as illustrated in Figure 2.6 is a commonly used transitional hydraulic structure primarily for energy dissipation process at the downstream. It also reduces the velocity and the high energy of the downstream as well. The stilling basin also reduces the sequential depth and avoids submerged jumps and prevents potential hydraulic jumps. Since erosion and scouring are a major problem, stilling basin will protect the downstream of the riverbed to be less affected (Ghamari, et al., 2015). Design of the stilling basin must be adequate in order to shorten the length and maintain the position of the hydraulic jumps so that it is not vulnerable to tailwater fluctuations.

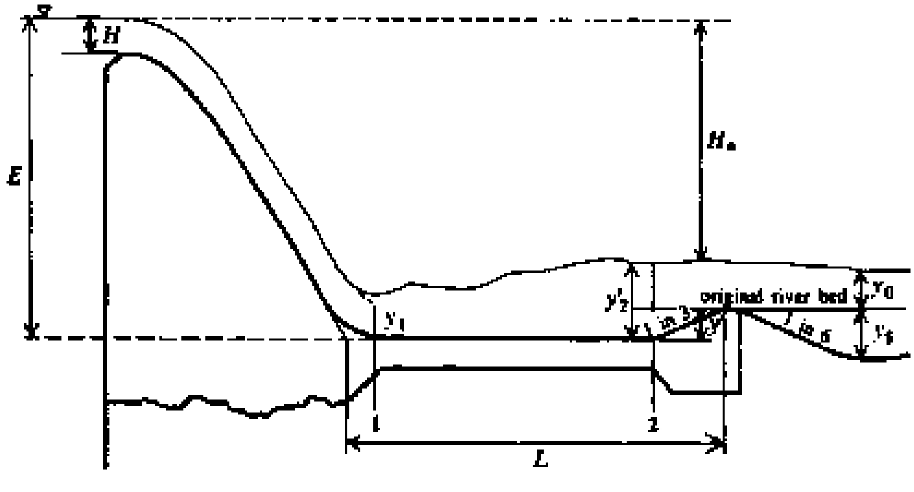

Figure 2.6: Schematic diagram of stilling basin
(Source: Chen, 2015)

Since there are uncertainties within the design of the stilling basins, four types of stilling basins are developed by USBR which are Type I, Type II, kind III and Type IV (Ghamari, et al., 2015).

2.6.1 Configuration of stilling basin

The configuration of the stilling basin consists of three components which are chute blocks, baffle blocks and end sill or dentated sill. Figure 2.7 below shows the configuration of the stilling basin.

Chute blocks are used as a mounting device at the entrance to the stilling basin. The block narrows down the incoming downstream and lift a portion of it from the floor for a shorter jumping distance. The block design must be carefully adapted to the specific conditions of the dam to achieve maximum efficiency. If the block is used for excessively high flow induced velocities or improperly designed, the risk of damage due to cavitation is high (Dahl and Lönn, 2016).

Baffle blocks or baffle piers, one of the components used to stabilise the jump and dissipate energy from the impact action. Baffle block consists of different shapes, but the common shapes are cubic and trapezoidal. Generally, cubic shape is quite effective where the appropriate dimensions and location of the blocks in the basin have been used. Besides, United States Department of the Interior Bureau of Reclamation (USBR) recommends that baffle block vertices not be curved since it is critical in eddy current generation for dissipate energy effectively (Abbas et al., 2018).

End sills are usually constructed at the end of the basin, where the shape is designed in two forms which are solid and dentated. The end sill is a terminal component of the basin which contributes to the downstream energy reduction as well as enhancing the flow pattern downstream of the channel, indirectly reducing the span of the stilling basin. Sill height, configuration and positioning have a major influence on the dissipation of flowing water energy (H. L. T. ,2015). The end sill also incorporates artificial roughness, which increases the resistance of the riverbed to maintain the stability of the jump (Abbas et al., 2018).

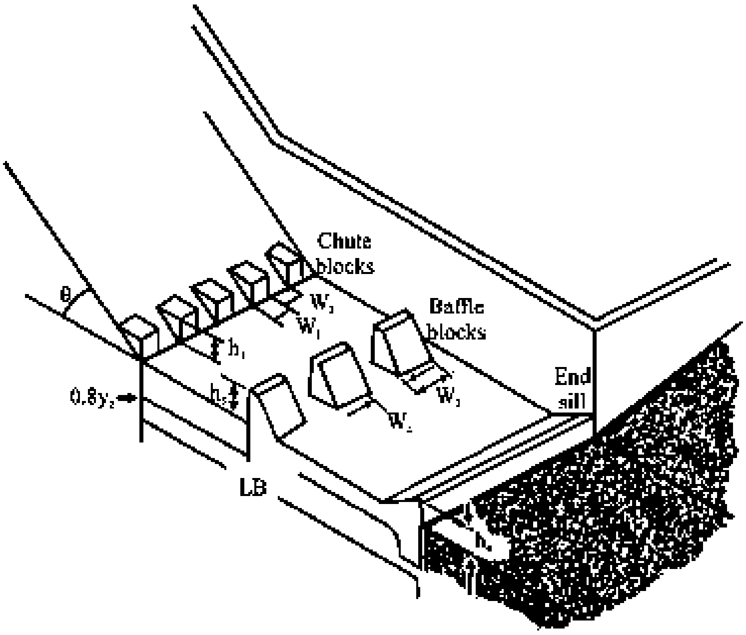

Figure 2.7: Components of stilling basin
(Source: Dahl and Lönn, 2016)

2.6.2 Types of stilling basin

The hydraulic jump stilling basin is a common energy dissipating structures widely used in dams. The design of these structure is simple and effective since the design of these structures especially the apron length depends on the hydraulic jump properties and the tailwater depth. The upstream Froude Number (Fr) will be determining the amount of energy dissipation at the stilling basin (Anderson, et al., 2017). However, there are certain limitations when the discharges vary. The sudden change in discharge can affect the hydraulic jump location on the apron. This subsequently will jeopardise the energy dissipation rate and create severe structural damages (Sonaje, 2017). Thus, four types of stilling basins have been developed by the United States Department of the Interior Bureau of Reclamation (USBR) such as Type I, Type II, Type III and Type IV. Figure 2.8 below shows the Type I stilling basin which has a plain basin without any appurtenances such as chute blocks, buffer blocks or end still. According to Ghamari, A., & Nekoufa (2015), this type of stilling basin has limited Froude Number (1.7 <Fr <2.5) and maximum capacity at Froude number of 3. Due to the large basin, the hydraulic jump is very sensitive to the downstream fluctuation which bring uncertainties in the aspect of safety.

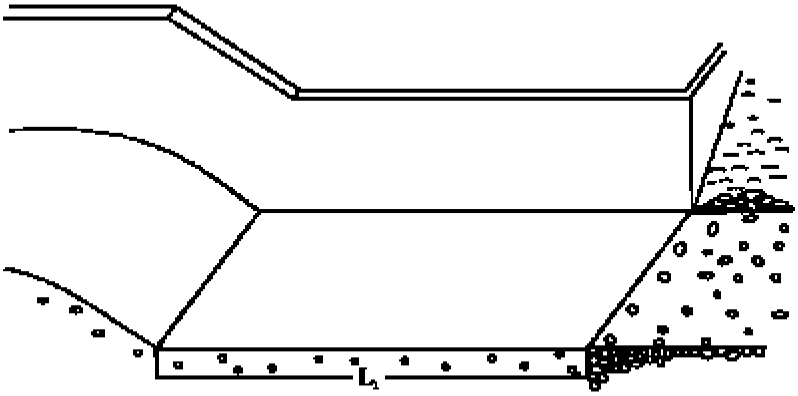

Figure 2.8: Type I stilling basin.
(Source: Bejestan and Neisi, 2009)

Figure 2.9 below shows Type II stilling basin, which is distinguished by blocks at the end of the fall and a dentated sill at the end of the basin. For this basin, USBR just points out the overall design requirements for the length of the basin and the sizes of the block on the basis that the hydraulic jump maintains confined to the sill for dissipation purposes (Padulano et al., 2017). Type II basin is suitable for high dams, land dam spillways with Froude numbers greater than 4.5 and flow velocity greater than 18 m/s.

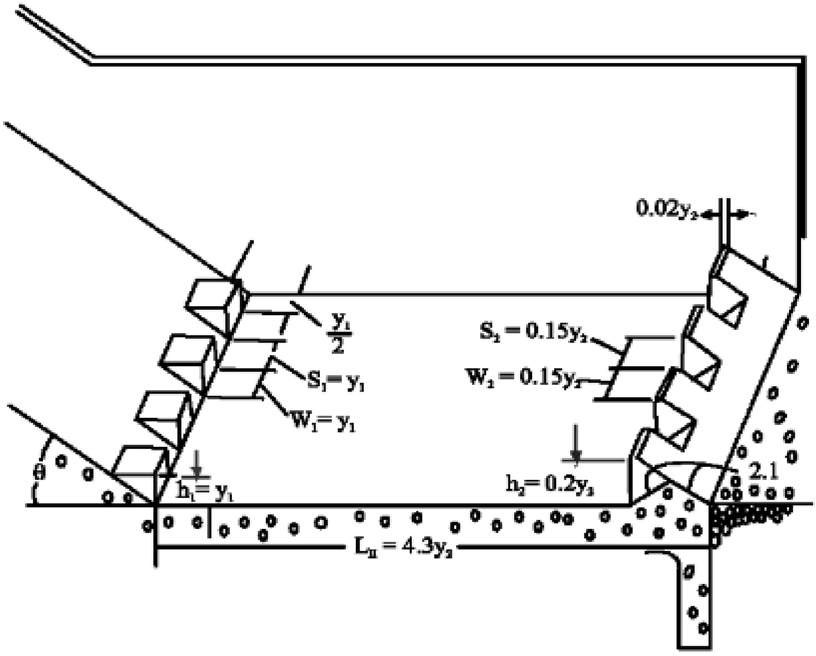

Figure 2.9: Type II stilling basin.
(Source: Padulano et al., 2017)

Figure 2.10 below shows the Type III stilling basin, another kind of energy dissipator produced by the United States Bureau of Reclamation (USBR). Based on USBR analysis, the USBR Type III stilling basin was planned to determine the acceptable tailwater depth. Based on studies conducted by the United States Office of Reclamation (USBR), the USBR Type III stilling basin is ideal for the reduction of hydrostatic pressure and energy of discharge (q < 18,6 m3/sec/m; v < 18 m/sec and

Froude > 4.5). From the studies conducted by Ulfiana and Wardoyo (2019), the basic principle of this stilling basin is to reduce the energy flow by creating friction between water molecules and blocks. One kind of block widely used is a baffled block with a certain pattern installation.

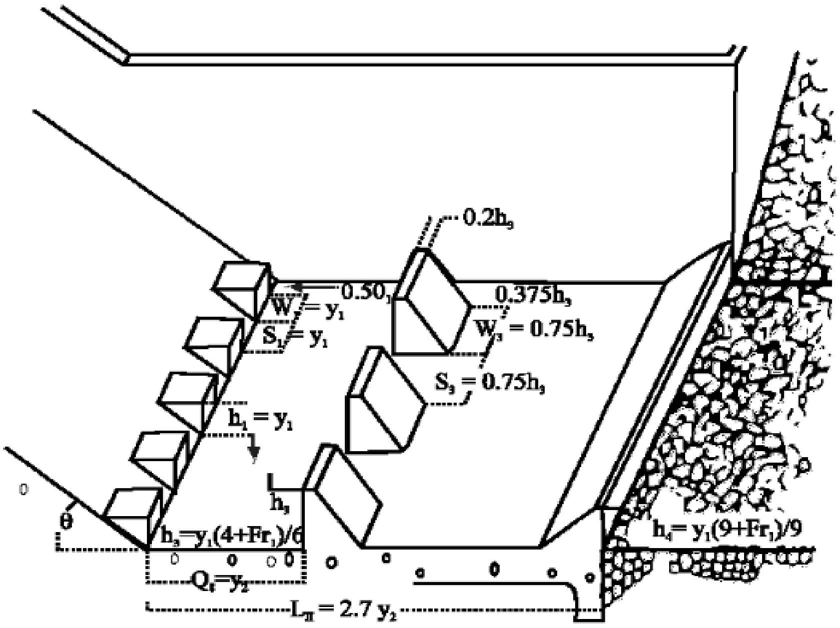

Figure 2.10: Type III stilling basin.
(Source: Chen, 2015)

Figure 2.11 below illustrates another variant of the stilling basin, the most widely built stage outlet of stepped chute, the Type IV stilling basin. USBR Type IV stilling basins are recommended for use in $2.5 \leq Fr \leq 4.5$. The hydraulic jump in the USBR Type IV stilling basin is defined as being at a transitional stage in such a way that the jump appears to be oscillatory in nature. To fix the propagating waves produced by the oscillatory transition, the Type IV USBR stilling basin is a lengthier basin than the Type III USBR. The optional end sill and greater tailwater depth of the USBR Type IV relative to the tailwater depth of the USBR Type III keep the formation of jump from flowing out of the basin (Hunt and Kadavy, 2018)

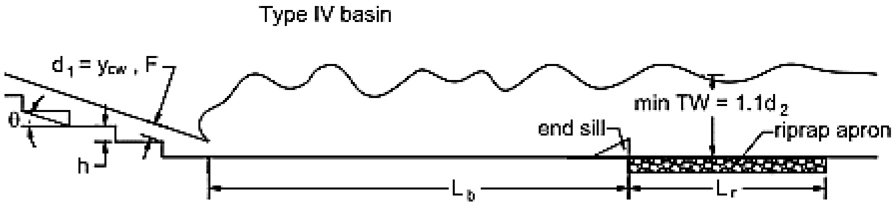

Figure 2.11: Type IV stilling basin.
(Source: Hunt and Kadavy, 2018)

2.7 Physical modelling

In hydraulic engineering simulation studies may assist in the proper understanding of physical phenomena in laboratories. These models are usually referred to as physically based and data-driven models. In theory, physically based models (knowledge-driven models) can be applied to almost every form of hydraulic problem. These models are focused on our knowledge of the dynamics of hydraulic phenomena, which are defined using physical equations. While physically based models are more commonly available, they necessitate a considerable amount of data and computing information (Mahtabi et al., 2020).

According to Kamel, A. H. (2015), physical modelling is undoubtedly applicable by using distorted small scales which is represents the full-scale prototype or structure for localised flow pattern simulation for design principles which cannot be done mathematically or numerically under controlled flow conditions. Physical modelling specifically in hydraulic engineering are widely used to evaluate the energy dissipation performances in hydraulic structures such as dams, spillway, stilling basin etc (Macián-Pérez et al., 2020). Hence, physical models must be designed and built with précised accuracy ascertain the hydraulic factors of the flow and field of flow in spillways (Enjilzadeh and Nohani, 2016).