DEVELOPMENT OF SULTAN ABU BAKAR SPILLWAY DAM RATING CURVES FOR FLOOD MITIGATION STRATEGIES

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DEVELOPMENT OF SULTAN ABU BAKAR SPILLWAY RATING CURVE FOR FLOOD REDUCTION STRATEGIES

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ABSTRAK

Empangan mempunyai pelbagai fungsi, ia bukan sahaja dibina untuk penjanaan kuasa tetapi juga sebagai mitigasi banjir. Bagaimanapun, air yang dikeluarkan perlu dikawal supaya ia boleh mengurangkan kesan ke kawasan hiliran. Objektif utama kajian ini adalah untuk membangunkan lengkung pengkadaran yang dilepaskan untuk pintu 'tilting', satu pintu, gabungan dua pintu dan semua pintu radial dari model Empangan Sultan Abu Bakar, Cameron Highland, Pahang. Model fizikal Empangan Sultan Abu Bakar dihasilkan sebagai model biasa dengan skala 1:25. Peralatan yang digunakan semasa proses ujian ialah 'Nixon Streamflo Velocity Meter' dan 'Ultrasonic Flow Meter'. 'Nixon Streamflow Meter Velocity' digunakan untuk mengukur halaju air pada pembukaan pintu sementara Ultrasonic Flow Meter digunakan untuk mengukur kadar alir daripada paip semasa model sedang beroperasi. Untuk mengetahui ketepatan peralatan ujian, penentukuran telah dilakukan menggunakan eksperimen'flume'. Hasil daripada proses pengujian menunjukkan hubungan kadar alir (l/s) dan takungan kepala hulu (mm) di bukaan pintu radial. Untuk model fizikal skala penuh, pada bukaan 0.75m untuk semua pintu radial menunjukkan pelepasan tertinggi iaitu 214.5754m^3/s. Ini akan membantu TNB dalam proses untuk melepaskan air dari Empangan SAB untuk mengelakkan berlakunya banjir.

ABSTRACT

Dam has multiple functions, it is not only built for power generation but also as flood mitigation purposes. However, the discharge off the dam has to be managed properly so that it can act as the final line of defence in order to mitigate the flood impact to downstream areas. The main objective of this study is to develop discharge rating curve for tilting gate, radial gates and the combination of both gates through a hydraulic physical model of Sultan Abu Bakar Dam, Cameron Highland, Pahang. The hydraulic physical model of Sultan Abu Bakar Dam was produced as a non-distorted model scale of 1/25. Equipment was utilized during the testing process was Nixon Streamflo Velocity Meter and Ultrasonic Flow Meter. Nixon Streamflo Velocity Meter is used to measure the velocity of water at the opening of the gate while Ultrasonic Flow Meter used to measure the overall discharge of the piping system during the physical simulation of the model. In order to ensure the accuracy of the testing equipment, a calibration process of this equipment was conducted using a hydraulic flume experimental in the Hydraulics Laboratory, PPKA. The result from the calibration processes showed the relationship of discharge (l/s) with the upstream head (mm) of reservoir at different opening of the gate. For the full scale hydraulic physical model, opening of three radial gates and a full opening of tilting gate gave the highest discharge which is 214.5m^3/s. This constructed mono-chart of gates discharge released helps TNB in decision process of gate opening in order to mitigate the downstream flooding due to unscheduled water released from the SAB Dam.

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LIST OF ABBREVIATIONS

HPG	**H**ydraulic **P**erformance **G**raph
TNB	**T**enaga **N**asional **B**erhad
USM	**U**niversiti **S**ains **M**alaysia

NOMENCLATURES

A	Area
Fr	Froude number
g	Gravitational constant
h_1	Upstream head
h_2	Gate opening
k	Kinematic viscosity
L_r	Length scale
L_m	Length prototype
L	Characteristic length
Q	Discharge
V_p	Velocity of prototype
V_m	Velocity of model

Chapter 1

INTRODUCTION

1.1 Background of the study

A dam is a barrier that is constructed to hold back or restricts the flow of water from a specific catchment. A reservoir that created by a dam is used to control the amount of water flow into a stream and regulate the water levels and flooding downstream of the dam. Dam has multiple functions, such as power hydro, irrigation, flood mitigation and others.

Sultan Abu Bakar Dam is located at Ringlet-Bertam Valley Road, Cameron Highland that creates a man-made lake called Ringlet reservoir on the upstream of the dam. Ringlet reservoir is situated on the Sungai Bertam in the mukim of Ringlet in the Cameron Highlands district (Sidek et al., 2011) as shown in Figure 1.1.

Figure 1.1: Sultan Abu Bakar Dam in Ringlet, Cameron Highlands

Hydropower reservoir typically requires water level to be kept at maximum design level to store as much energy as possible for daily hydropower generation as well as to prevent any spillage at dam (Luis et al., 2013). The Star Online (2011), stated that any spillage become non-renewed energy for the hydro operational. The Ringlet reservoir receives waters from the rivers namely Sg. Habu, Sg. Bertam, Sg. Ringlet and other minor tributaries as shown in Figure 1.2. The Sultan Abu Bakar dam impounds water of Bertam River and diverts the water from Telom River, creating the Ringlet Reservoir. The Ringlet Reservoir holds 6.7 million m^3 in which 4.7 million m^3 of it is the live storage with a surface area totalling 60 ha with a "full supply level" (FSL) at EL 1071.71 m (Teh, 2011). It impounds the water from the Bertam River, Telom River, Plau'ur River and Kodol River (Teh, 2011).

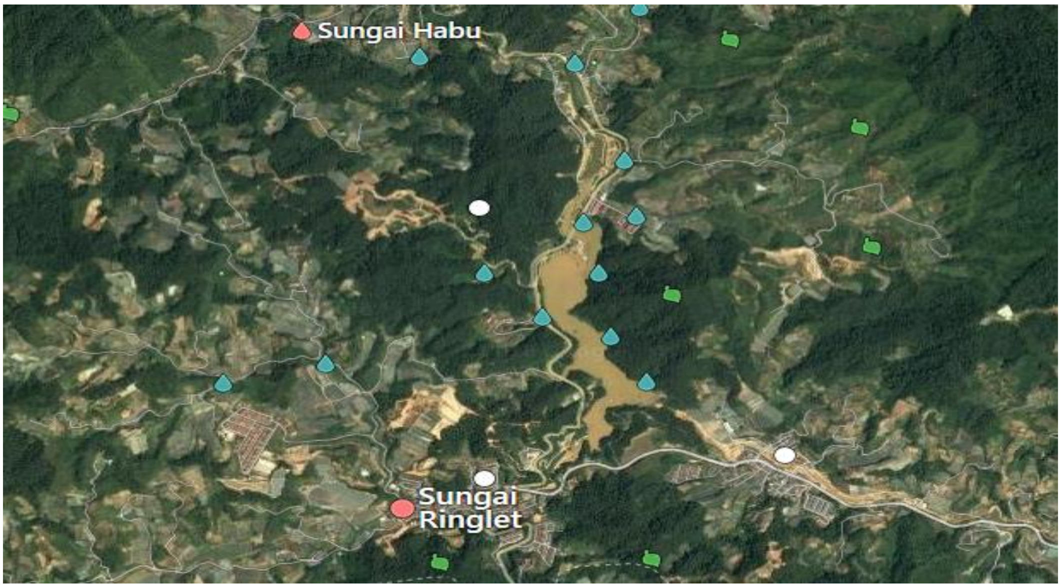

Figure 1.2: Location of the river.

The spillway gates used in SAB dam are a tilting gate and three (3) radial gates. The water will flow to the downstream over a spillway when the water level of the reservoir is high enough to spill over the tilting gate. Then, the radial gates will be operated. The spillways gates is used to control amount of water let out into the river downstream where they can be fully or partially open. Tilting gate has bottom hinged at 1068.0 m (3504.0 ft) EL and this gate will open when reservoir level at is 1070.7 m (3513.0 ft) and fully opened when reservoir level is at 1071.0 m (3514.0 ft). The gate of the radial gate will open when the reservoir level at 1071.1 m (3514.08 ft) and fully open at 1071.4 m (3515.00 ft) of reservoir level (Teh, 2011). The Specifications of Sultan Abu Bakar Dam as shown in Table 1.1.

Table 1.1: Specifications of Sultan Abu Bakar Dam (Source: Teh, 2011)

Dam Type	[m]	Concrete (52000 m^3) and Rockfill (19000 m^3)
Crest Level	[EL. m]	EL. 1074.42 m
Dam Height	[m]	40
Length of Dam	[m]	140
Gross Storage	[MCM]	6.7
Usable Storage	[MCM]	4.7
Surface area at FSL	[km^2]	60 ha at EL 1071.71 m
Catchment area	[km^2]	183.4
Normal operating level	[EL. m]	EL. 1068.3 m
Min. operating level	[EL. m]	EL. 1065.2 m
Max. operating level	[EL. m]	EL. 1070.4 m
<u>Spillway</u> Type No. of spillway gates		 Controlled gated spillway 3 radial gates, 1 tilting gate
<u>Spillway Gates</u> Titling Gate		6.1 m. wide x 3.3m. Height (20 ft.x 11 ft.) • Bottom hinged at EL. 1068.0 m (EL. 3504.0 ft.) • Opens at reservoir level EL. 1070.7 m • (EL. 3513.0 ft) • Fully open at reservoir level EL. 1071.0 m. • (EL. 3514.0 ft) ≈ 65.1 m^3/s (2,300 cusecs)
Radial Gates		12.2 m. wide x 5.0m. Height (40 ft. x 16 ft.-6 in.) • Open at reservoir level level EL. 1071.1 m. • (EL. 3514.08 ft) • Fully open at reservoir level EL. 1071.4 m. • (EL. 3515.00 ft) ≈ 300.2 m^3/s per gate (10,600 cusecs) or 900.5 m^3/s for 3 gates (31,800 cusecs)

The main proposed of this project is to develop rating curve for the different opening of the tilting gate and the radial gates.

1.2 Problem Statement

The unusually intense downpour on October 22 and 23, 2014 had brought huge volume of water to Ringlet reservoir together with debris and siltation from the massive land clearing and agricultural activities in the upstream catchment. The rubbish clogged up the Bertam Water Intake as shown in Figure 1.3, an outlet where water from the Ringlet Reservoir normally flows before entering the Bertam tunnel to an underground power generation units. The accumulation of siltation and sediment had reduced the reservoir's holding water capacity. As a result, for the first time in the history of the 50 year old SAB dam, water level surged at a rate of 1.5 ft per hour, in which is three times more than the normal monsoon rain condition (TNB, 2013). The result caused a disastrous flood especially at the New Village of Bertam Valley.

Figure 1.3: The mud flood in Bertam Valley in Cameron Highlands (Source: Sagayam, 2013).

The discharge of the dam has to control, so that it can prevent the negative impact to downstream areas. "Once the water level at the Sultan Abu Bakar dam hits 3,513 feet, the dam gates automatically open, but the danger was that releasing so much water at once endangered valley residents" (Shagar, 2016). Residents in the surrounding areas at Bertam Valley would be evacuated if the dam's water level exceeded 1069.8 metres (The Star Online, 2016). The Star Online, (26 December 2016) also reported the flash flooding occurred most probably due to uncontrolled of water releases from SAB dam. Therefore, TNB as dam operator was advised by local authority to develop these gates rating curves for their own consumption. So, TNB appointed USM to deliver the discharge-upstream head rating curves for SAB Dam release for TNB operational guide.

1.3 Objectives

The objectives in this study are as follow:

1. To estimate flow for existing tilting gate (5 windows) and a fully open tilting gate from a hydraulic physical model.
2. To develop discharge rating curves for three (3) radial gates in operation from the physical model.
3. To analysis the combination operational a tilting gate and radial gates for the maximum available released.

1.4 Scope of Work

The scope of works for the hydraulic model includes the data collection from the physical model of Sultan Abu Bakar (SAB) dam. The design scaled for this hydraulic physical model of Sultan Abu Bakar Dam according to the actual dimension is 1:25 (model: prototype). There are nine cases in order to construct the stage-discharge rating curves. The openings of the radial gates are 10mm, 15mm, 20mm, 25mm, and 30mm.

In the result observation process, flows and upstream head at each gate was measured using a miniature Nixon Streamflow Velocity Meter. Finally, the rating curves of all the cases are developing using Microsoft Excel. The upstream head against the total of the discharge is the data used in order to develop rating curve. The testing cases of the gates are shown in Table 1.2.

Table 1.2: Testing case of gates

Cases	Radial gate			Tilting gate	
	1	2	3	Window flow	Full flow
1					
2					
3					
4					
5					
6					
7					
8					
9					

1.5 Justification of research

The hydraulic physical model testing in this study is essential to ensure the safe operational of the SAB dam discharge release especially during heavy downpour in the upper stream catchment. Hydraulic physical model allows visualization observation in order to ensure the model replicates the prototype. From these observations, the spillway maximum discharge can be estimated and finally determined. Besides that, the hydraulic model is intended to provide the solution for a very complex problem when the manual calculation and even computer simulation could not provide the 'true' answers. Finally, all these information are essential for TNB operational teams to estimate the amount of discharge released from SAB dam so that the negative impact of flash flood in Bertam Valley and surrounding can be mitigated.

1.6 Limitation of the study

There are several limitations of this study. Firstly, the scale effect is the main limitation of this study. Scale effects not possible to simulate to all relevant variables in correct relationship between the model and the prototype. A smaller prototype-to-model scale ratio L_r should be considered to minimize the scale effects. Secondly, the human error could be occurred because the model can create artificial situations that do not always represent in real-life situations. Human error also plays a key role in the validity of the project during data collections. Next, the opening of the gates study is depends on the amount of the pump used. In order to increase the height of the opening, the pump used also need to increase. It is because the pump used to control the discharge of the model. Lastly, the number of cases is depends on the time. Only 9 cases used for this study because of the time constraint.

1.7 Dissertation Outline

The thesis has been sub-divided into specific chapters for better understanding of the study. This dissertation consists of five chapters such as follow:

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

Chapter 2: Literature Review – This chapter include the substantive findings that have been done in previous study for the physical model. The development of the rating curve for tilting gate and the radial gates has also discussed in this chapter.

Chapter 3: Methodology – This chapter discussed about the overall sequence of work for this project. The method, equipment and the procedure to develop rating curve has been stated.

Chapter 4: Results and Discussion – The result of the calibration test had presented in this chapter. The result of discharge of the various opening of the gates also presented. The rating curves of the gates are developed.

Chapter 5: Conclusions and Recommendations – Conclusion is drawn based on the result from experiment work.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter have been discussing the study of the hydraulic physical modelling, spillway, and development of discharge rating curve. For the hydraulic physical modelling, the main concept, scale effect, model similarities such as geometric similarity, kinematic similarity and dynamic similarity are presented in this chapter. For the spillway, the controlled and uncontrolled gate of the spillway such as radial gate and tilting gate are presented in this chapter. The equipment used in the experiment such as an ultrasonic flow meter and a Nixon velocity meter are also being described in this chapter.

2.2 Physical Hydraulic Model of Spillway

A hydraulic physical model is built by reducing or enlarging the size of the prototype system in correct proportion to the actual size. The main purpose of hydraulic physical model is to emphasise the observed data for a better overview and understanding the overall system (Hughes, 1993). The physical model is being widely used in hydraulic structure is spillway. The example of spillway has shown in Figure 2.1.

Figure 2.1: Paradise dam (Australia) stepped spillway operation. (Source: Zhang and Chanson, 2016)

The hydraulic physical modelling studies ultimately ensure the safety of the hydraulic structures is not compromised by identifying and eliminating potential problems, and also will reduce construction and maintenance costs. They are particularly useful where hydraulic structures and systems are of unusual design or configured further boundary layers of several hydraulic parameters cannot be adequately evaluated by state-of-the-art analytical or computational methods. Furthermore, hydraulic physical models are also incorporated with the appropriate governing equations without the simplifying assumptions that are often necessary conducted in analytical or numerical models. Hydraulic physical models may also be used to establish conservative and reasonable designs or operating bases for specific sites, structures, or systems involving thermal and erosional problems (Burke, 2008). The advantages and disadvantages of the physical model are shown in Table 2.1.

Table 2.1: Advantage and disadvantage of physical model (Sources: Hughes, 1993)

Advantages	Disadvantages
• The physical model integrates the appropriate equations governing the process without simplifying assumptions that have to be made for analytical or numerical models. • The small size of the model permits easier data collection throughout the regime at a reduced cost. • The degree of experimental control that allows simulation of varied or sometimes rare environmental conditions at the convenience of the researcher. • The ability to get a visual feedback from the model.	• Scale effects occur in models that are smaller than prototype if it is not possible to simulate all relevant variables in correct relationship to each other. • Laboratory effects can influence the process being simulated to the extent that suitable approximation of the prototype is not possible. • Sometimes all forcing functions and boundary conditions acting in nature are not included in the physical model. • Except in rare instances, physical models are undeniably more expensive to operate that numerical model.

2.3 Basic principle of hydraulic physical model

In a hydraulic physical model, the flow condition is said to be similar to the prototype if the model displays similarity of form (geometric similarity), similarity of motion (kinematic similarity) and similarity of forces (dynamic similarity) (Chanson, 1999). The model is referred to as a distorted model if one or more of the established similitude criteria are not satisfied in a model. The definition of model distortion means that in an undistorted model all the dimensionless pi-terms determined from the important independent variables of the problem must be the same in the model as in the prototype. Model that maintains geometric similitude is referred to as undistorted model while distorted model is a hydraulic physical model in which the horizontal length scale and the vertical length scale are different in their linear scales. In other words, a distorted model is not geometrically similar to the prototype (Hughes, 1993).

A distorted model is said to be a distorted model only when it is not geometrically similar to prototype. The main reason for adopting distorted model is to maintain turbulent flow. It is also to minimize cost of model. Meanwhile, an undistorted model is geometrically similar to its prototype. The scale ratio for corresponding linear dimension of the model and its prototype are the same. The behaviour of the prototype can be easily predicted from the result of the undistorted type of model (Sajan, 2017). The Figure 2.2 shows the basic flow parameter of radial gate. The Table 2.2 and Table 2.3 shows the advantage and disadvantage of distorted model and undistorted model respectively.

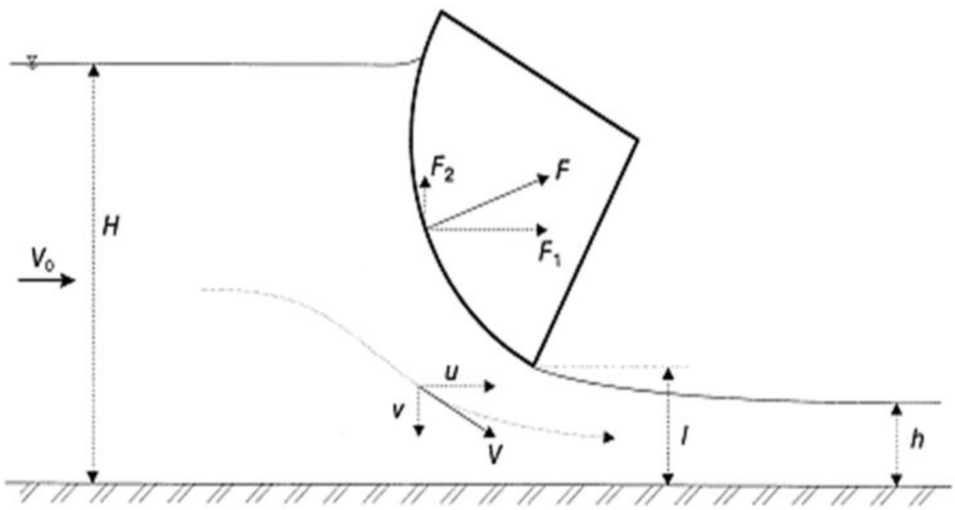

Figure 2.2: Basic flow parameter. (Source: Chanson, 1999)

Table 2.2: Advantage and disadvantage of distorted model (Sources: Sajan, 2017)

Advantages	Disadvantages
• Accurate and precise measurement is made possible due to increased vertical dimension of models. • Model size can be reduced so its operation is simplified and hence the cost of model is reduced.	• Depth or height distortion changed wave patterns. • Slopes bands and cuts may not be properly reproduced in model.

Table 2.3: Advantage and disadvantage of undistorted model (Sources: Sajan, 2017)

Advantages	Disadvantages
• The basic condition of perfect geometrical similarity is satisfied. • Predication of model is relatively easy. • Result obtained from the model tests can be transferred to directly to the prototype.	• The small vertical dimension of model cannot be measured accurately. • The costs of model may increase due to the long horizontal dimension to obtain geometric similarity.

2.4 Scale effect of a spillway model

Scale effects may be defined as the distortions introduced by effects (e.g. viscosity, surface tension) other than the dominant parameter (e.g. gravity in free-surface flows). They take place when one or more dimensionless parameters differ between model and prototype. Scale effects are often small but they are not always negligible altogether. Considering an overflow above a weir, the fluid is subjected to some viscous resistance along the invert section. However, the flow above the crest is not significantly affected by resistance, the viscous effects are small and the discharge-upstream head relationship and it can be deduced as an ideal fluid flow. In free-surface flows, the gravity effect is dominant. If the same fluid (i.e. water) is used in both the model and the prototype, it is impossible to keep both the Froude and Reynolds numbers in the model and full-scale (Chanson, 1999).

It is elementary to show that a Froude similitude implies $(Re)_r = L_r^{3/2}$, and the Reynolds number becomes much smaller in the model than in the prototype (if $L_r < 1$). Different fluids may be used in order to produce the same Reynolds and Froude numbers in both the model and prototype, but this experiment is often not practical nor economical (Chanson, 1999). Surface tension and viscous effects can also influence napped behavior with changing model scales (Erpicum et al., 2016). The main causes of scale effects are model roughness and model approach conditions associated with turbulent boundary layer development. Besides that, the surface tension effects, associated aeration, vortex-formation problem and cavitation phenomena also the main causes of the scale effects. Some of these scale effects can be overcome, or at least minimized by using model scales. It is giving sufficiently high model Reynolds number which is reduced against the prototype using the Froude scaling law and Weber numbers (Novak et al., 2007).

2.5 Similarity in hydraulic physical model

The conditions of the model where a phenomenon reproduces all aspects of behavior of a prototype represented are known as of similitude. A primary goal of any experiment is to provide the result as part of prototype. To achieve that end result, a concept of similitude is often used so that measurements made in one laboratory environment system can be used to describe the behavior of other similar system in real world (prototype) located outside of the laboratory. The laboratory built system is the first build of the similar system based on behavior its model, beyond laboratory frame called prototype (Zohuri, 2015).

Construction of a scale model, however, must be accompanied by an analysis to determine what conditions that the model will be tested under. While the geometry may be simple scaled, other parameters, such as pressure, temperature, velocity and type of fluid may need to be altered. Similitude is achieved when testing conditions are created such that the test results are applicable to the real design. Mechanical similarity requires three criteria (Zohuri, 2015):

1. Geometric similarity
2. Kinematic similarity
3. Dynamic similarity

2.5.1 Geometric similarities

Geometric similarity is a similarity in shape, i.e. all length dimensions in the model is λ times shorter than of its real-world prototype (Heller, 2011). The model is the same shape as the application however in the different scale. Basically it can be claimed as a geometric similitude when the model (m) and prototype (p) if the ratios of all corresponding dimensions in both model and prototype are equal and, mathematically can be presented as follows (Zohuri, 2015);

$$L_{model}/L_{prototype} = L_{ratio} \quad \text{or} \quad L_m/L_p = L_r \qquad (2.1)$$

Where:

L_r = Length scale

L_m = Model length

L_p = Prototype length

Geometric similarity implies the similarity of shape such that, the ratio of any length in one model system to the corresponding length in prototype system. This ratio is usually known as scale factor. Therefore, geometrically similar objects are similar in their shapes, i.e., proportionate in their physical dimensions, but differ in size (Zohuri, 2015).

Geometric similarity perhaps the most obvious requirement in a model system is designed to correspond to a given prototype system. A perfect geometric similarity is not always easy to attain. Problems in achieving perfect geometric similarity are as discussed by Zohuri (2015) are as follow:

For a small model, the surface roughness might not be reduced according to the scale factor (unless the model surfaces can be made very much smoother than those of the prototype). If for any reason, the scale factor is not the same throughout, it is advisable to construct a distorted model results. Sometimes it may be occurred that to have a perfect geometric similarity within the available laboratory space, the physicals of the problem should be changed. For example, in case of large prototypes, such as rivers, the size of the model is limited by the available floor space of the laboratory; a lower scale factor should be utilized.

2.5.2 Kinematic similarities

Kinematic similarity is when geometric similarity and similarity of motion between model and prototype particles is the same (Heller, 2011). Fluid flow of both the model and real application must undergo similar time rates of change motions (i.e. fluid streamlines are similar). Since motions are described by distance and time, it implies similarity of lengths (i.e., geometrical similarity) and, in addition, similarity of time intervals. If the corresponding lengths in the two systems are in a fixed ratio, the velocities of corresponding particles must be in a fixed ratio of magnitude of corresponding time intervals (Zohuri, 2015).

Velocity: $$\frac{V_m}{V_p} = \frac{L_m/T_m}{L_p/T_p} = \frac{L_m}{L_p} \div \frac{T_m}{T_p} = \frac{L_r}{T_r} = V_r \tag{2.2}$$

Where:

V_r = Velocity ratio

V_p = Velocity of prototype

V_m = Velocity of model

2.5.3 Dynamic similarities

Dynamic similarity exists when the model and the prototype have the same length scale ratio (i.e., geometric similarity), time scale ratio (i.e., kinematic similarity), and force scale (or mass scale) ratio (Yoon, 2014). Ratios of all forces acting on corresponding fluid particles and boundary surfaces in the two systems are constant. In other words, if the quantities refer to forces, then the similarity is termed as a dynamic similarity. In dynamically similar systems, the magnitudes of forces at correspondingly similar points in each system are in a fixed ratio (Zohuri, 2015). It requires geometric and kinematic similarity and in addition that all force ratios in the two systems are identical (Heller, 2011). Table 2.4 shows the relevant force ratio.

Most relevant forces in fluid dynamics are described by Heller (2011) as follows:

- **Inertial force**: It is equal to the mass and acceleration of the moving fluid.
- **Gravitational force**: Product of mass and acceleration due to gravity.
- **Viscous force**: It is equal to the shear stress due to viscosity and surface area of the flow. It presents in the flow problems where viscosity is having an important role to play.
- **Surface tension force**: Product of surface tension and the length of the surface of the flowing fluid.
- **Elastic compression force**: Product of elastic stress and area of the flow.
- **Pressure force**: Product of pressure intensity and flow area.

Table 2.4: Relevant force ratio (Sources: Heller, 2011)

Force ratio	Formula
Froude number F	(inertial force/gravity force)$^{1/2}$
Reynolds number R	inertial force/viscous force
Weber number W	inertial force/surface tension force
Cauchy number C	inertial force/elastic force
Euler number E	pressure force/inertial force

Note: Only the most relevant force ratio can be identical between model and its prototype, if identical fluid is used. The most relevant force ratio is selected and the remaining result in scale effects.

2.6 Spillway

In general, dams are equipped with spillway in order to avoid overtopping (Suprapto, 2013). When the water in the reservoir increases, the large accumulations of water endanger the stability of the dam structure. To avoid this problem, a spillway structure is provided in the body of a dam or near the dam or periphery of the reservoir. Hydraulic design of a spillway and a stilling basin has been one of the most studied subjects in hydraulic engineering (USBR, 1980). Properly designed approach flow conditions, spillways and stilling basins will be able to pass flood flows efficiently and safely to downstream of dams. A hydraulic physical scale model has been used in the design and investigation of spillway hydraulic structures for over 100 years. A hydraulic model is still a precision device for the experimental investigation of highly dynamics flow over a spillway structure, which can give reliable information only if it is, designed correctly (Willey et al., 2012).

The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess water or flood in a controlled or uncontrolled manner to ensure the safety of downstream areas. It is of paramount importance for the spillway facilities to be designed with sufficient capacity to avoid overtopping of the dam, especially when an earth fill or rock fill type of dam was selected for the project. In cases where safety of the inhabitants downstream is a key consideration during development of the project, the spillway should be designed to accommodate the probable maximum flood (PMF). Many types of spillways can be considered with respect to cost, topographic conditions, dam height, foundation geology, and hydrology (Coleman et al., 2004).

While the principal function of a spillway is to pass down the surplus water from reservoir into the downstream areas, there are precisely seven functions that can be assigned to spillway as suggested by (Khatsuria, 2004) :

1. Maintaining normal river function (compensation water supply).
2. Discharging water for utilization.
3. Maintaining initial water level in the flood-control operation.
4. Controlling floods.
5. Controlling additional floods.
6. Releasing surplus water (securing dam and reservoir safety).
7. Lowering water level (depleting water levels in an emergency).

2.6.1 Radial gate

The radial gate is a type of floodgate with arms used in dams and canal to control water flow. A side view of a radial gate resembles as a slice of circle. The curved part of the gate face the upper level of water and the tip pointing toward the lower level of pool. The curved portion or skin plate of the gate takes in the form of a triangular shaped section of cylinder. The straight sides, the trunnion arms, extend back from the ends of the cylinder sections and meet at a trunnion hub, which serves as a pivot point when the gate rotates. The pressure forces on a submerged body act perpendicular to the surface of body. The design of the radial gate results in every pressure force acting through the center of the imaginary circle, which the gate is a section of, so that all resulting pressure force acts through the pivot point of the gate. It makes construction and design easier (Sahu and Ajmera, 2017). The cross section of the radial gate is shown in Figure 2.3.

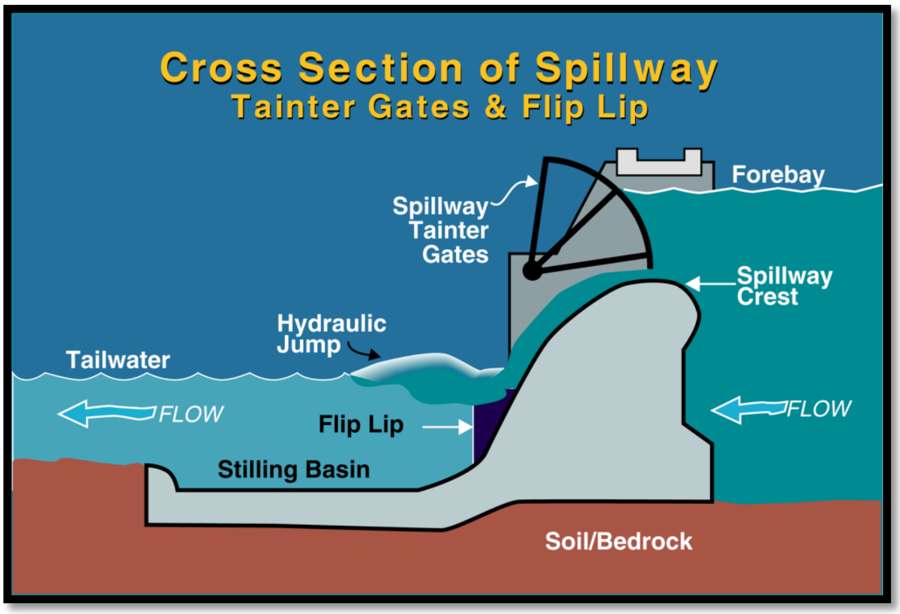

Figure 2.3: Cross section of spillway radial gate, (Virinchi, 2014)

The detail advantages and disadvantages of radial are discussed by Lewin et al. (2016) in Table 2.5 as follow:

Table 2.5: The advantages and disadvantages of the radial gate, (Sources: Lewin et al., 2016)

Advantages	Disadvantages
1. Absence of gate slots. This benefits pier structural design and hydraulic flow. Pier slots can produce cavitation and at low flows collect silt. 2. Gate thrust is transmitted to two bearings only. 3. They are stiffer structurally. 4. Less hoisting capacity is required than for a vertical-lift gate. 5. It is mechanically simpler and mechanical equipment usually costs less. 6. There is no possibility of trash jamming in the wheels. 7. They have a better appearance.	1. The flume walls must extend downstream at a sufficient height to provide attachment for the gate trunnions. 2. The gate water load is taken by the piers as concentrated loads at the gate anchorages. Because of this, integrity of the anchorages and distribution of the load into the piers require special consideration. 3. Increased fabrication complexity.

2.6.2 Tilting gate

Flap gates are commonly used at the ends of pipe drains and pump outlets to prevent backflows of water and entry of small animals. Large sizes are frequently found in tidal areas to reduce inflows during high tides and permit outflows during low tides. Other uses are to prevent flood flows from an upstream storm from backing into lowlands during the passing of the flood flow. Under these conditions, the gate closes under the influence of its own weight and the hydrostatic pressure from the downstream side. When the water levels on the downstream side recede, the gate reopens and flow can again drain to the lowered receiving waters. These installations are relatively inexpensive, and maintenance costs are low. Malfunctions can occur when debris lodges in the gate opening or in the pinned hinges that are common to many types of flap gates, requiring regular inspections (Replogle and Wahlin, 2003). The example of the tilting gate has shown in Figure 2.4.

Figure 2.4: Example of tilting gate, (Vortex Hydra)