Numerical Simulation of Morning Glory Spillway at Various Discharge Capacity using Lattice Boltzmann Method

by

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17002838

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

Numerical Simulation of Morning Glory Spillway at Various Discharge Capacity using Lattice Boltzmann Method
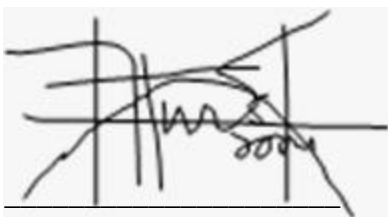

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A project dissertation submitted to the

Civil Engineering Programme

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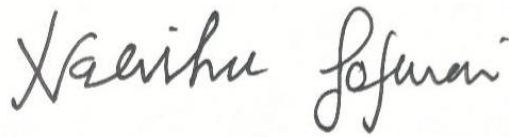BACHELOR OF CIVIL ENGINEERING WITH HONOURS

Approved by,

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(Dr. Siti Habibah Binti Shafiai)

UNIVERSITI TEKNOLOGI PETRONAS

SERI ISKANDAR, PERAK

January 2022

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

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NASIHA SOFWANI BINTI MOHAMAD SHIHAM

ABSTRACT

This research is focused on finding the discharge capacity of the morning glory spillway at the funnel of the pier structure. The software used for this numerical simulation study is MATLAB. Using MATLAB, the result can be guaranteed accurate is effective plus more control over the results compare to other software. Not to mention, MATLAB is a more friendly user for easy and normal simulation. The numerical simulation will be created using the Lattice Boltzmann Method and LABSWE^{TM} for the modeling. The parameters to create the model such as discharge rate, velocity, the lattice size, height of the water, density, and the dimension of vortex breaker are collected from previous research related to this project. The model was calibrated through the validation the of model for flow around a cylinder in 2D using LBM. To reduce the vortex formation and the decrease in discharge capacity, two models of piers have been created; piers at 45-degree and 90-degree. The flows around the piers are analyzed and tested in the software. As a result, the graph discharge coefficient against the height of the water is plotted to determine the flow rate increment and decide the best design for the spillway structure.

Keywords: Lattice Boltzmann method, Spillway Morning Glory, Piers, MATLAB, LABSWE^{TM}

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CHAPTER 1 INTRODUCTION

This chapter highlights the explanation of the project title and provides clarification on the expected outcome of the project that comprises the background of the study, problem statement, objectives, and scope of the project research study. The background of the study discusses the purpose of the Morning Glory Spillway for dam operation. The problem involved with the current situation and condition of the study will be discussed further. The objectives and scope of the project are laid out as the guideline to complete the project

1.1 BACKGROUND OF STUDY

The Morning Glory Spillway is a roofed conduit that conveys flow from one level to another rapidly. Although this sort of spillway is comparable to a siphon spillway, it behaves differently. These spillways are used to manage erosion of structures and highway culverts in addition to dams. In dams with steep abutments across narrow valleys or a diversion tunnel to transfer water flow downstream of the dam, this form of the spillway is economically efficient. Furthermore, morning glory spillways in stormwater drainage systems or water conveyance systems convey flows from upstream to downstream (from the catchment basin to the tunnel drainage system in hilly places). Morning glory spillways are used in these situations, together with "vortex basins," which give the flow an angular velocity, resulting in a circling flow in the glory hole. Morning-glory spillways are standing structures within the dam reservoir that play a critical role in the dam's operation. During a flood, the continual weight and hydrodynamic loading on the body of the spillway concrete structure complicate the structure-fluid interaction study.

A fluid-structure interaction analysis with coupled computational fluid dynamics and structural analysis can accurately simulate the performance of these spillways during overflow. Therefore, the preferable method of understanding and designing would be analysis through the hydraulic model for the structure.

1.2 PROBLEM STATEMENT

The study of fluids in motion or at rest is known as hydraulics. The study of fluids in motion is known as hydrodynamics, while fluid properties in static equilibrium are known as hydrostatics (motionless). In designing hydraulic structures, it is important to fully understand and analyze the flow characteristics passing through these structures. For instance, spillways are provided for storage, multipurpose, and detention dams to release excess water or flood water that cannot be contained in the designated storage space, as well as diversion dams to bypass flows that have been turned (redirected) into the diversion system. The significance of a safe, reliable spillway cannot be overstated; many dam catastrophes have been driven by spillways that were inadequately built and/or constructed or spillways with insufficient discharge capacity. Vortices can occur at many types of hydraulic structures, such as hydropower intakes, spillway intakes, or pump sumps which can hurt the structure's operation. A vortex is a turbulent flow of fluid that is spinning and has a closed streamline. In particular, the morning glory spillway operates in a free mode with radial and axial velocity, allowing water to flow directly into the spillway. However, during the vortex phenomenon, incidence and tangential velocity cause the flow path to diverge from the direct mode and travel a longer path, resulting in energy loss and a reduction in discharge capacity.

1.3 OBJECTIVES

- To develop and model the simulation using the Lattice Boltzmann Method.
- To analyze and test the discharge capacity of swirling flow at the intake funnel of Morning Glory Shaft Spillway at various data.
- To propose the design of a compatible spillway with suitable discharge capacity

1.4 SCOPE OF STUDY

The scope of the study for this project will focus on the various discharge capacity at the intake funnel of Morning Glory Spillways. As for the design of the spillway rotational flow, the numerical simulation will be created using the Lattice Boltzmann Method and LABSWE^{TM} for the modeling. After the hydrodynamic flow has been determined, the data will be analyzed to recommend the best structure design for the shaft spillway which can avoid the formation of the vortex and maintain the discharge capacity.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will describe the literature collected that is related to the project matter. The topic that will include in this chapter is Hydrodynamics, Hydraulic facilities such as dams, reservoirs, and spillways. More detailed information will be enlightened on the spillway's topic about the project's main chosen structure which is Morning Glory Shaft Spillway. Not forgetting the Lattice Boltzmann method and its components, the backbone of this whole trial.

2.2 HYDRODYNAMICS

Fluid mechanics is the study of science that deals with the mechanical properties of fluids when forces are exerted upon them. It's a field of classical physics with practical uses in hydraulics and aeronautics, chemical engineering, meteorology, and zoology. Water is recognized as the most familiar fluid and the study regarding it is widely known as hydrostatics, the science of water at rest, and hydrodynamics, the science of water in motion. According to McGraw-Hill (2005), Hydrodynamics is the study of a fluid and the interaction of the fluid with its boundaries, especially in the incompressible inviscid case.

The study of hydrodynamics is concerned with the physical conservation laws of mass, momentum, and energy. These principles can be expressed mathematically in either integral or differential form. The integral form is beneficial for large-scale investigations because it delivers solutions that are sometimes excellent and sometimes not but are always valuable, especially in engineering applications. For small-scale analysis, the differential form of the equations is preferred.

Although differential forms can theoretically be utilized for any issue, exact solutions are only available for a restricted number of various flows. The majority of problems require the use of numerical methods to solve. Hydrodynamics is used to examine closed-conduit and open-channel flow, as well as to calculate forces on submerged bodies. Experimental and theoretical research on flow in closed conduits, or pipes, has been substantial.

$$\text{Renold Number} = \frac{VD\rho}{\mu}$$

Equation 1: Renold number

Based on the Reynolds number given by the equation, where V is the average velocity and D is the pipe diameter, is less than about 2000, the flow in the pipe is laminar. In this case, the solution to the continuity, momentum, and energy equations is readily obtained, particularly in the case of steady flows. If ReD is greater than about 4000, the flow in the pipe is turbulent, and the solution to the continuity, momentum, and energy equations can be obtained only by employing empirical correlations and other approximate modeling tools. The ReD region between 2000 and 4000 is the transition region in which the flow is intermittently laminar and turbulent.

Figure 2: Laminar Flow
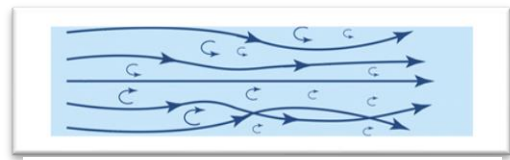
Figure 1: Turbulent flow

The bottom slope and water depth change with position in most open-channel flows, and the free surface is not parallel to the channel bottom. The flow is called a gently varied flow when the slopes are small and the variations aren't too abrupt. A differential equation for the rate of change of the water depth concerning distance along the channel is derived from an energy balance between two portions of the channel. The shape of the water surface is determined by solving this equation, which can be done using any of the many numerical approaches available.

Rapidly fluctuating flows include flow over spillways and weirs, as well as flow over a hydraulic jump. The fluctuations in water depth with distance along the channel are substantial in these circumstances. The pressure distribution with depth may not be hydrostatic in this situation due to the enormous accelerations, as it is in the case of progressively varying and homogeneous flows. Approximation techniques are used to solve problems with rapidly varying flows.
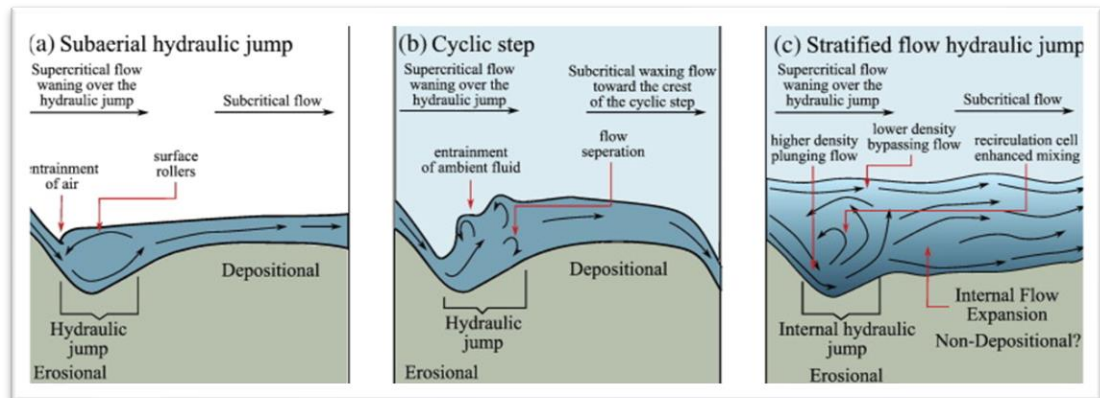
Figure 3: Various conditions of
hydraulic jump

2.4 HYDRAULIC FACILITY: DAM

A dam is a structure that is built to store water across a stream, a river, or an estuary. They are built for drinking water, irrigation scorched, and semiarid lands, or industrial developments. The huge amount of water retained in the reservoir would be used to generate hydroelectric power, to lower the peak discharge of floodwater during heavy storms or snowmelt, or to upsurge the water depth in the river for navigation of ships and barges to transport more easily. Dams can help in recreating a lake for activities like swimming, boating, and fishing. The dam is usually built for more than one purpose and they were helping to properly function by spillways, movable gates, and valves that navigate the release of surplus water downstream of the dam. There are also intake structures that help in conveying the water to the far-distant place from the dam's location through the designated canals, tunnels, or pipelines.

In a multipurpose scheme designed, a dam acts as the central structure to retain the water resource on a provincial origin. For the developing countries, the multipurpose dams play a critical role in the operation while a single purpose dams give benefits to the industries such as agriculture development, hydroelectric power production, and general industrial growth. Regrettably, the construction of these

hydraulic structures become a debate in the environmental concern due to the impact of migrating fish and riparian ecosystems, especially the large reservoir which can overwhelm a vast land that homes many living creatures and plants.

In Engineering terms, dams are classified based on their structural types and construction materials. The conclusion in determining the type of dam built mostly depends on the foundation characteristic of the valley, the availability of building materials, the limitation of transporting network from the site, and the experiences of the engineers respond to the project. Nowadays, the common materials usually in between of concrete, earth fill, and rockfill. While in the past, few numbers of dams were created by joined masonry which in the present-day exchanged to the concrete materials. Example of concrete dams is massive gravity dams, thin arch dams, and buttress dams. Embankment dams are including then rockfill and earth-fill dams due to the forms of huge mounds of earth and rock imprinted in the man-made embankments.

2.5 AUXILIARY STRUCTURES

2.5.1 RESERVOIR

Modern engineers have realized the importance of addressing possible reservoir maintenance issues early on. Sediment in rivers has a significant impact on the reservoir's useful life and, as a result, the dam's financing. Because the reservoir has filled with silt, some contemporary dams have become worthless for storing water. Many others have seen significant reductions ineffective storage capacity. The heavy silt-laden floodwater is permitted to pass through the sluices at the Nile barrages, allowing only the cleaner water to be held at the end of the flood season.

2.5.2 GATES

The opening through dams is needed for the irrigation and water supply, which can maintain the minimum flow in the river for the riverbank interests downstream, electricity generation, and water and silt removal from the reservoir. The gates are

constructed by filling the coarse screens at the upstream ends to avoid the incoming of floating and submerged debris. Gates come in a variety of shapes and sizes. The most basic and oldest type is a vertical-lift gate, which may be raised by sliding or rolling against guides and allowing water to pass underneath. The mechanism of radial or tainted gates is similar, but the vertical part is curved to better resist water pressure. Tilting gates have flaps on their lower edges that are held in place by hinges, allowing water to pour over the top when they are lowered.

Drum gates can autonomously manage the reservoir level upstream to precise levels without the use of mechanical motion. A molded caisson is kept in place by hinges installed on the dam's crest and anchored in a flotation chamber built directly downstream of the crest in one drum gate design. The rotational equilibrium of the caisson is sustained by water pressure in the reservoir and buoyancy in the flotation chamber. The caisson rotates in the same direction as the water level in the flotation chamber, reducing or increasing the flow from the reservoir over the gate. The float controller in the reservoir can be linked to this action and operated automatically.

2.5.4 SPILLWAYS

Spillways are constructed either within a dam or in the side-line of the reservoir to properly release the excess floodwater during flood flows from the reservoir before it overtops the dams. In normal conditions, excess water is reserved from the top of the reservoir and conveyed back into the river through an artificially designed waterway. However, there is some consideration taken where the water may be diverted to an adjacent river valley. The spillway must be hydraulically adequate and structurally safe, as well as placed such that out-falling flows into the river do not damage or undermine the dam's downstream toe. The spillway's surface should also be able to withstand erosion or scouring caused by the extremely high velocities created during a flood's passage through the spillway.

Flood water discharged over the spillway must flow down a channel from a higher elevation at the reservoir surface level to a lower elevation at the natural river level downstream. An energy dissipation mechanism is normally installed near the bottom of the channel, where the water rushes out to meet the natural river, to eliminate the majority of the energy of the flowing water. These devices, also known as Energy

Dissipators, are necessary to prevent the river surface from being dangerously scraped by the out falling water's impact. Some projects, such as the Indira Sagar Dam on the Narmada River, include two sets of spillways: main and auxiliary. The main spillway, often referred to as the service spillway, is the one that is used to pass the bulk of the design flood. The auxiliary spillways' crest levels are usually higher, and thus their discharge capacities are smaller. They are activated when the river discharge exceeds the main spillway's capacity.

The capacity of a spillway is usually worked out based on a flood routing study. As such, the capacity of a spillway is seen to depend upon the following major factors:

- The inflow floods
- The volume of storage provided by the reservoir
- Crest height of the spillway
- Gated or ungated

The volume of the reservoir at various elevation heights, as well as the level of the crest, has an impact on the spillway capacity. The discharging water (Q) is determined by the gate opening if the spillway is gated; thus, the relationship between Q and reservoir water level is different if the spillway is not gated. In most practical situations, however, spillways are equipped with gates, which operate according to a pre-programmed sequence based on the inflow discharge. As a result, when planning a spillway capacity, not only the inflow hydrograph but also the gate operation sequence must be taken into account.

Spillways are typically categorized based on their most noticeable feature, whether that feature is related to the control, the discharge channel, or another component. The following are the most prevalent types of spillways:

- Free Overfall (Straight Drop) Spillway
- Overflow (Ogee) Spillway
- Chute (Open Channel/Trough) Spillway
- Side Channel Spillway
- Shaft (Drop Inlet/Morning Glory) spillway
- Tunnel (Conduit) spillway
- Siphon spillway

2.6 SHAFT SPILLWAYS

Water enters a Shaft Spillway through a horizontally positioned lip, drops through a vertical or sloping shaft, and then flows to the downstream river channel through a horizontal or nearly horizontal conduit or tunnel. An overflow control weir, a vertical transition, and a closed discharge channel are the three elements that make up the construction.

2.6.1 MORNING GLORY SHAFT SPILLWAY

The structure is known as a Morning Glory Spillway when the intake is funnel-shaped. The name comes from the same-named flower, which it resembles quite similarly, especially when fitted with antivortex piers. These piers or guiding vanes are frequently required to reduce vortex action in the reservoir; nevertheless, if the air is permitted to the shaft or bend, it may generate explosive violence in the discharge tunnel unless it is well built for free flow.

The drop intake spillway's discharge characteristics may change depending on the head range. The flow pattern would shift as the head increased, from weir flow over a crest to tube flow, and finally to pipe flow in the tunnel. At relatively low heads, this style of spillway achieves maximum discharging capacity. Should a flood bigger than the selected inflow design flood occur, however, there is little gain in capacity above the intended head? A drop intake spillway can be beneficial at dam sites that are located in narrow gorges with steeply rising abutments. It could also be used in situations where a diversion tunnel or conduit is available.
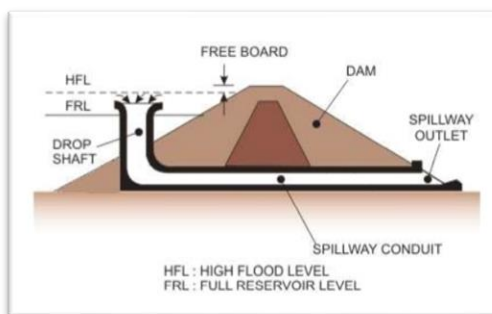
Figure 5: Structure of Morning Glory Spillway
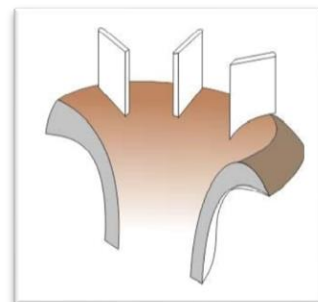
Figure 4: Cross-section of Morning Glory Spillway at the intake funnel.

2.7 FREE VORTEX AT INTAKES

Vortices that occur at many types of hydraulic structures, such as hydropower intakes, spillway intakes, or pump sumps, can harm the structure's operation. Vortices arise at the hydraulic intake structure due to their location relative to surrounding boundaries and geometric qualities, and they originate in a whirling flow. A swirl is a tendency for water at the intake to twist or spin in a twisted or whirling motion. The swirl motion isn't a problem in and of itself. The degree of swirl motion, on the other hand, is what defines the adverse effect and tendency of vortex formation. A vortex is a spinning turbulent flow or fluid with a closed streamline, according to the definition. These two concepts (swirl and vortex) are connected, and a vortex is a fluid swirling rapidly around a central point.

2.8 LATTICE BOLTZMANN METHOD

The lattice Boltzmann method (LBM) is a new numerical methodology that is particularly efficient and versatile for simulating various flows within complex/varying geometries. It is derived from the lattice gas automata (LGA) to overcome the shortcomings of the LGA. The LBM's fundamental equation turns out to be a discrete variation of the continuum Boltzmann equation in statistical physics, making it self-explanatory. On a macroscopic level, the approach provides a proper average description of fluid while giving the microscopic picture of particle movement in an extremely simplified manner. There are only 3 tasks involved, which are the Lattice Boltzmann equation, lattice pattern, and local equilibrium distribution function.

2.8.1 LATTICE BOLTZMANN EQUATION

The Lattice Boltzmann Equation (LBE) applies to a wide range of fluid flows, including shallow water flows. There are two steps involved in the origin of the Lattice Boltzmann Method (LBM), which are a collision step and a streaming step. During the streaming steps, in the direction of their velocities, the particles migrate to the neighbouring lattice points which are conducted by

$$f_\alpha(x + e_\alpha \Delta t, \, t + \Delta t) = f'_\alpha(x, t) + \frac{\Delta t}{N_\alpha e^2} e_{\alpha i} F_i(x, t)$$

Equation 2: Streaming step

Formula	Descriptions
f_α	Distribution function of particles
f'_α	Value of f_α
$e = \Delta x / \Delta x$	Lattice size
Δx	Time step
F_i	Force component in the i-direction
e_α	velocity vector of a particle in the α link
$N_\alpha = \frac{1}{e^2} \sum_\alpha e_{\alpha i} e_{\alpha i}$	Constant

Table 1: The parameter for streaming step

While in the collision step, according to scattering laws, the arriving particles at the sites interact with one another and change their velocity directions which govern by

$$f'\alpha(x, t) = f_\alpha(x, t) + \Omega_\alpha[f(x, t)]$$

Equation 3: Collision Step

Collision operators control the speed of changes in distribution function particles during the collision. After expanding into the equilibrium state and implying the local equilibrium distribution function to approximate zero, Linear Collision Operator is obtained.

$$\Omega_\alpha(f) \approx \frac{\partial \Omega_\alpha(f^{eq})}{\partial f_\beta} (f_\beta - f_\beta^{eq})$$

Equation 4: Linear Collision Operator

Assume local equilibrium distribution function to an equilibrium state at a single rate.

$$\frac{\partial \Omega_\alpha(f^{eq})}{\partial f_\beta} = -\frac{1}{\tau}\delta_{\alpha\beta}$$

Equation 5: Equilibrium distribution function at single state

and the range value of $\delta_{\alpha\beta}$ is taken from:

$$\delta_{\alpha\beta} = \begin{cases} 0, & \alpha \neq \beta, \\ 1, & \alpha = \beta, \end{cases}$$

Equation 6: Kronecker delta function

Using the range, input back the value into linear collision operator and become the BGK Collision equation.

$$\Omega_\alpha = -\frac{1}{\tau}\left(f_\alpha - f_\alpha^{eq}\right)$$

Equation 7:BGK collision operator

Finally, the combined equation of streaming and collision steps. Thus, Lattice Boltzmann Equation (LBE) is produced.

$$f_\alpha(x + e_\alpha \Delta t, t + \Delta t) - f_\alpha(x,t) = -\frac{1}{\tau_t}\left(f_\alpha - f_\alpha^{eq}\right) + \frac{\Delta t}{N_\alpha e^2}e_{\alpha i}F_i$$

Equation 8: Lattice Boltzmann Equation

2.8.2 LATTICE PATTERN

The lattice pattern provides 2 functions for the LBE which are to illustrate the grid points and to govern the movement of the particles. For 2D dimension. the lattice pattern has been classified into two types; square lattice (Figure 14) and hexagon lattice (Figure 15). The models are determined by the number of particles speed at the lattice nodes such as 4-speed, 5-speed, 8-speed, or 9-speed model for square lattice while 6-speed or 7-speed model for hexagon lattice. In every lattice pattern model,

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lattice symmetry is essential for the repossession of the correct flow equation which can be proven via theoretical analysis and numerical study.
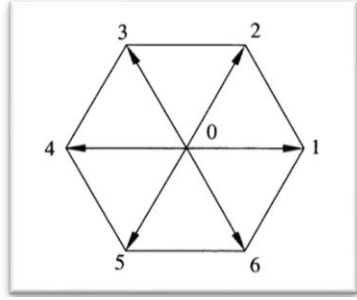
Figure 7: Hexagon Lattice
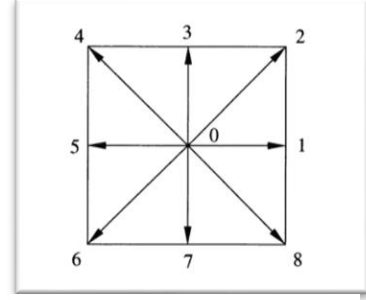
Figure 6:Square Lattice

After numerous recent studies and trials, 9-speed square lattice had chosen as the best lattice pattern as it provides accurate results compared to based hexagon in numerical simulations. Figure 16 shows the velocity vector for a 9-speed square lattice. Nodes 1-8 indicate the movement of the particles at one lattice unit on its velocity while Node 0 represents the rest particle at zero speed.

$$e_\alpha = \begin{cases} (0,0), & \alpha = 0, \\ e\left[\cos\dfrac{(\alpha-1)\pi}{4}, \sin\dfrac{(\alpha-1)\pi}{4}\right], & \alpha = 1,3,5,7, \\ \sqrt{2}e\left[\cos\dfrac{(\alpha-1)\pi}{4}, \sin\dfrac{(\alpha-1)\pi}{4}\right], & \alpha = 2,4,6,8. \end{cases}$$

Equation 9: velocity vector

As mentioned in the LBE before, N_α is the constant in Lattice Pattern and when the velocity value is applied into the equation, and the new LBE equation is;

$$N_\alpha = \frac{1}{e^2}\sum_\alpha e_{\alpha x}\, e_{\alpha x} = \frac{1}{e^2}\sum_\alpha e_{\alpha y}\, e_{\alpha y} = 6$$

Equation 10: Na constant after Velocity vector value applied

$$f_\alpha(x + e_\alpha\Delta t,\, t + \Delta t) - f_\alpha(x,t) = -\frac{1}{\tau_t}\left(f_\alpha - f_\alpha^{eq}\right) + \frac{\Delta t}{6e^2}e_{\alpha i}F_i$$

Equation 11: LBE for fluid flow simulation

2.8.3 LOCAL EQUILIBRIUM DISTRIBUTION FUNCTION

This task is considered the most substantial in the lattice Boltzmann method. It is used to solve the flow equation using lattice Boltzmann equations. The solution to the 2D shallow water equation can be completed by deriving the correct lattice equilibrium distribution function. However, the preceding flow equation has a few restrictions, therefore another option is to suppose that the equilibrium function can be expressed as a power series in macroscopic velocity.

$$f_\alpha^{eq} = A_\alpha + B_\alpha e_{\alpha i} u_i + C_\alpha e_{\alpha i} e_{\alpha j} u_i u_j + D_\alpha u_i u_i$$

Equation 12: Equilibrium function

Nevertheless, there are 3 conditions for the LED function must obey for the shallow water equation, which are

$$\sum_\alpha f_\alpha^{eq}(x,t) = h(x,t),$$

$$\sum_\alpha e_{\alpha i} f_\alpha^{eq}(x,t) = h(x,t) u_i(x,t),$$

$$\sum_\alpha e_{\alpha i} e_{\alpha j} f_\alpha^{eq}(x,t) = \frac{1}{2} g h^2(x,t) \delta_{ij} + h(x,t) u_i(x,t) j(x,t).$$

Equation 13: Condition must be followed in shallow water simulation.

By substituting the preceding equations, the following local equilibrium function is obtained:

$$f_\alpha^{eq} = \begin{cases} h - \dfrac{5gh^2}{6e^2} - \dfrac{2h}{3e^2} u_i u_j, & \alpha = 0, \\[2mm] \dfrac{gh^2}{6e^2} + \dfrac{h}{3e^2} e_{\alpha i} u_i + \dfrac{h}{4e^4} e_{\alpha i} e_{\alpha j} u_i u_j - \dfrac{h}{6e^2} u_i u_j, & \alpha = 1,3,5,7, \\[2mm] & \alpha = 2,4,6,8, \\[2mm] \dfrac{gh^2}{24e^2} + \dfrac{h}{12e^2} e_{\alpha i} u_i + \dfrac{h}{8e^4} e_{\alpha i} e_{\alpha j} u_i u_j - \dfrac{h}{24e^2} u_i u_j, & \end{cases}$$

Equation 14:Local equilibrium function

2.8.4 SGS FOR SHALLOW WATER EQUATIONS

Sub grid-scale stress model is used for turbulence flow. The effect of flow turbulence must be taken into consideration in the flow equations to include turbulence in shallow water flows. Therefore, the equation for the shallow water equation with the effect of turbulent is as derived below;

$$\frac{\partial h}{\partial t} + \frac{\partial (hu_j)}{\partial x_j} = 0,$$

$$\frac{\partial (hu_i)}{\partial t} + \frac{\partial (hu_j u_j)}{\partial x_j} = -g\frac{\partial}{\partial x_i}\left(\frac{h^2}{2}\right) + (v + v_e)\frac{\partial^2 (hu_i)}{\partial x_j \partial x_j} + F_i.$$

Equation 15: Turbulence equation for shallow water condition

2.8.5 LABSWE^{TM}

To describe the Lattice Boltzmann model for shallow water equation with the turbulent modeling (LABSWE^{TM}), the momentum equation must consider using the eddy viscosity. Kinematic viscosity can be determined by the relaxation time. If defined the relaxation time (Eq. 16), the total viscosity would also be altered as in Equation 17.

$$\boldsymbol{\tau_t = \tau + \tau_e}$$

Equation 16: Relaxation Time

$$\boldsymbol{v_t = v + v_e}$$

Equation 17: Total Viscosity equation

Thus, the solution to the lattice Boltzmann equation will be mention before in Eq. 8. However, the strain-rate sensor must be known and can be calculated in terms of the distribution function. It can be discovered to be connected to the non-equilibrium momentum flux tensor via the Chapman-Enskog expansion.

$$S_{ij} = -\frac{3}{2e^2 h\tau_t \, \Delta t} \sum_\alpha e_{\alpha i} e_{\alpha j}(f_\alpha - f_\alpha^{eq})$$

Equation 18: Strain-rate Sensor

Then, the finalized equations after some improvement and derivation.

$$\tau_t = \frac{\tau + \sqrt{\tau^2 + 18C_s^2/(e^2h)\sqrt{\prod ij \prod ij}}}{2}$$

Equation 19: Total Relaxation Time

$$\tau_e = \frac{-\tau + \sqrt{\tau^2 + 18C_s^2/(e^2h)\sqrt{\prod ij \prod ij}}}{2}$$

Equation 20: Eddy Relaxation Time

CHAPTER 3 METHODOLOGY

3.1 PROJECT WORKFLOW

```
                    ┌──────────┐
                    │  Start   │
                    └──────────┘
                         │
                         ▼
        ┌────────────────────────────────────┐
        │ Objective Analysis and Literature Review │
        └────────────────────────────────────┘
                         │
                         ▼
        ┌────────────────────────────────────┐
        │   Develop the LABSWE^TM Model      │◄──────┐
        └────────────────────────────────────┘       │
                         │                            │
                         ▼                            │
                    ◇ Model Testing                   │
                        and          ──── No ─────────┘
                    Validation ◇
                         │
                        Yes
                         ▼
            ┌─────────────────────┐
            │  Run the simulation │
            └─────────────────────┘
                         │
                         ▼
    ┌────────────────────────────────────────┐
    │ Application of Vortex Action at the Intake │
    │   Funnel of Morning Glory Spillway       │
    └────────────────────────────────────────┘
                         │
                         ▼
        ┌─────────────────────────────┐
        │  Data Analysis and Discussion │
        └─────────────────────────────┘
                         │
                         ▼
        ┌─────────────────────────────┐
        │ Conclusion and Recommendation │
        └─────────────────────────────┘
                         │
                         ▼
                    ┌──────────┐
                    │   End    │
                    └──────────┘
```
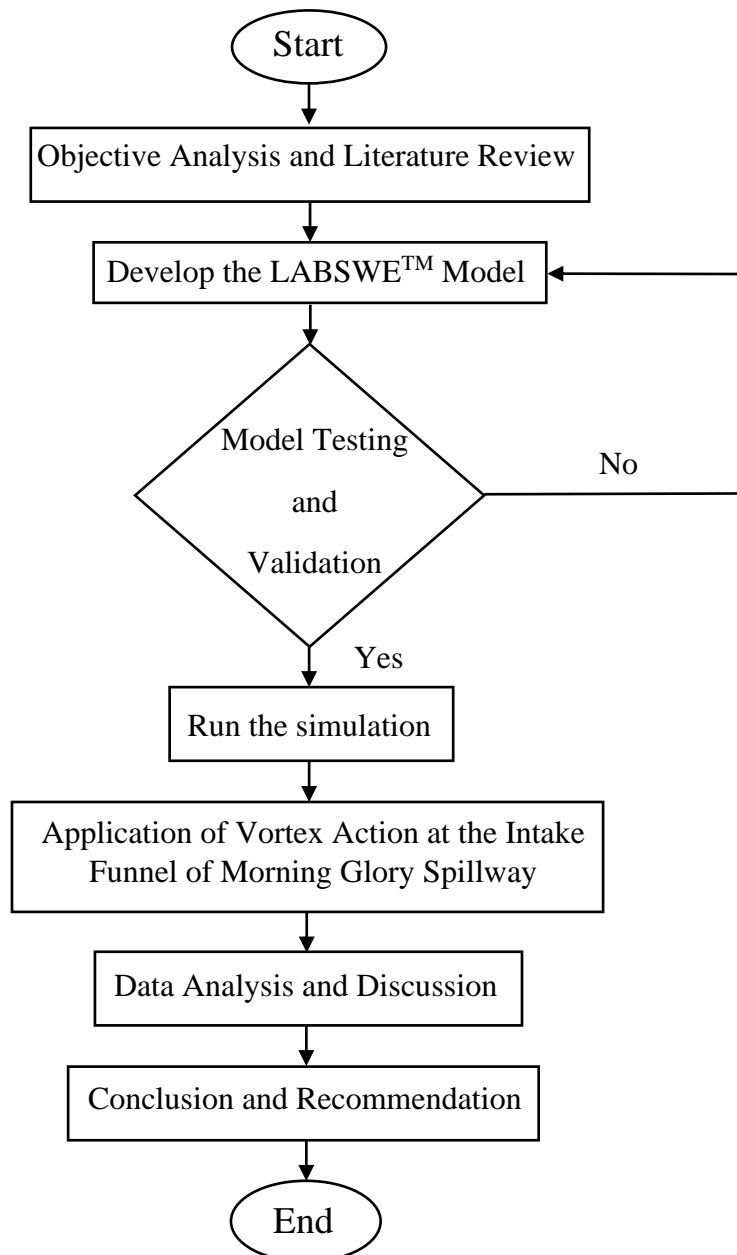
Figure 8: Methodology of flow chart

3.2 TOOLS

Figure 9: MATLAB logo

MATLAB is a programming language created by MathWorks. It was originally integrated from a matrix programming language like linear algebra programming and known as matrix laboratory. MATLAB can apply a collaborative setting for numerical computation, visualization, and programming. It made for matrix manipulation; plotting of function and data; implementation of algorithms; creating user interfaces; analyzing data and creating models and applications. MATLAB comes with numerous built-in commands and math functions that benefit mathematical calculation, generating plots, and performing the numerical method.

3.3 DATA COLLECTION

Vortex-breaker is one of the effective methods to control vortex which is used in many dams in order to increase the discharge and discharge coefficient. In the Morning glory spillways, the vortex flow can reduce discharge, discharge coefficient and the performance of spillway. Based on the research done by Kamanbedest. A (2014), the effect angle of vortex breaker and different modes of anti-vortex piers (160 experiments were performed) on discharge coefficient were studied.

$$Y = \left(\frac{H}{D}\right) \times 10^3$$

$$I = \left(\frac{Q}{D^{\frac{5}{2}}\sqrt{2g}}\right) \times 10^3$$

$$Y = \left(\frac{H}{D}\right) \times 10^3$$

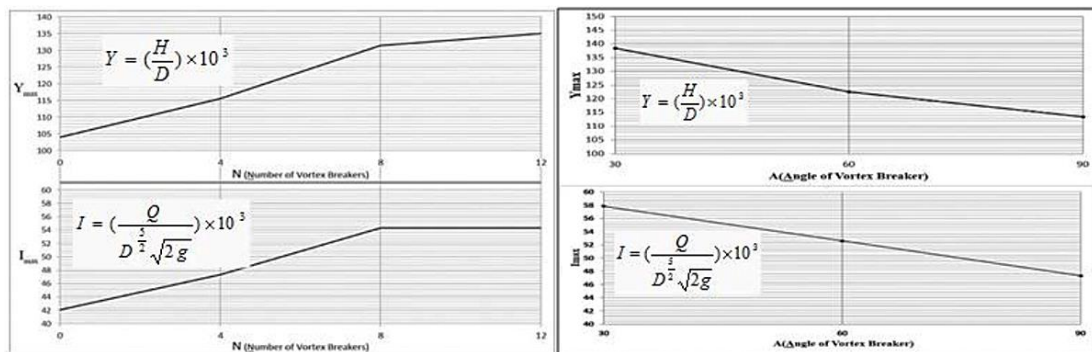$$I = \left(\frac{Q}{D^{\frac{5}{2}}\sqrt{2g}}\right) \times 10^3$$

Figure 10: The effect of number (left) and angle (right) of Anti-vortex piers in square spillway

According to Kamanbedest. A (2014), Figure 10 indicate that by iincreasing the number of anti-vortex piers increases the inflow and height of water before spillway submerging (increases submergence threshold) and increasing the angle of vortex breaker decreased the passing flow. This represents an increase in the spillway capacity, which increases the risk of severe and dangerous vortexes.

parameters	without piers	with best number of piers	with best angle of piers	Increase percentage for best number of piers	Increase Percentage for best angle of piers
Y_{max}	104.0	135.0	138.4	29.8%	33.1%
I_{max}	42.1	54.3	57.8	29.2%	37.3%

Figure 11: The effect of Anti-vortex piers on flow parameters in submergence threshold

The rise in water height and inflow in the square spillway is 29.8% for water height and 29.2% for inflow in the best mode of utilizing anti-vortex piers, 33.1 percent for water height, and 37.3 percent for inflow in the optimal angle of piers. The results also reveal that in a square spillway without a vortex breaker, the influence of pier

20

angle is greater than the number of piers as shown in Figure 11.. The reason for this is that by deploying a large number of anti-vortex piers as a flow-blocking barrier, the values of Imax and Ymax will be reduced.

In the Figure 12, Cd and (H/D) values for different modes of number and angle of anti-vortex piers used in square and circular spillways are displayed. For the influence of the number of anti-vortex piers, the maximum discharge coefficient was observed when 12 vortex breakers were placed, and varied patterns of the angle of piers discharge were observed for the influence of the angle of piers.
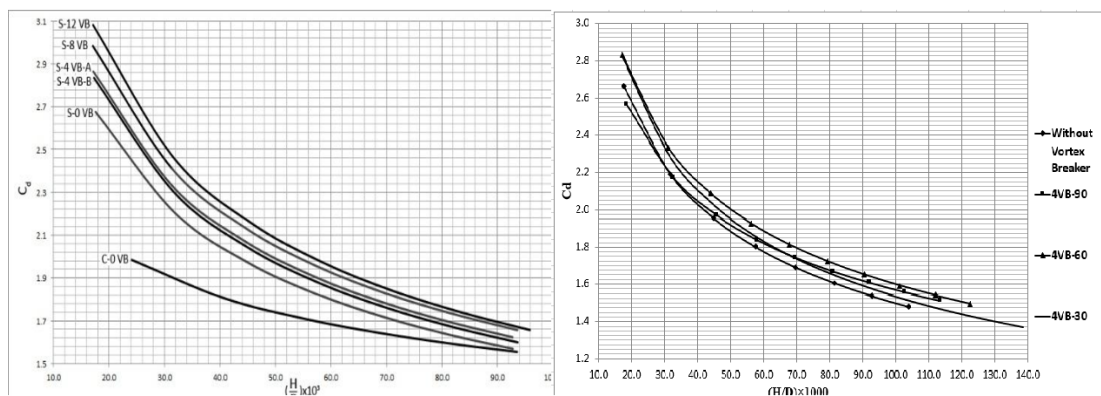

Figure 12: Comparison Chart of Discharge coefficient and Depth of submergence.

3.4 MODEL VALIDATION

3.4.1 2D FLOW AROUND A CYLINDER

In fluvial hydraulics, flow around a cylinder is a classic problem. It is also a proper test because it reflects a class of flow problems in coastal engineering, such as flow around an island. Referring to (Yulistiyanto 1998), a cylinder with a radius of 0.11m is placed at the center of the channel with the dimension of 4m long and 2m width. The discharge is $Q = 0.248$ m^3/s; outflow depth is h0 = 0.185 m; the bed slope is zb = -6.25 X 10- 4 in the flow direction; and the Manning's coefficient is nb = 0.012.

600 x 300 square lattices were employed in the numerical simulation. T = 1.982, $\Delta x = \Delta y = 0.00667$ m, $\Delta t = 0.00145$ s, and $\tau = 0.00145$ s. Along the cylinder's wall, no-slip boundary conditions are used; slip boundary conditions are used for the side walls; the depth at the outflow is set to h = h0; at the inflow boundary, zero gradients for the depth is specified; the inflow velocity u is determined by the discharge; and v = 0 at the inflow boundary. A steady-state solution was found after 40,000 steps. As a result, LABSWE^{TM} is utilized to forecast the water surface profile as well as the riverbed topography. Figure 34 shows the lattice solid for the solid profile of 2D flow around the cylinder.
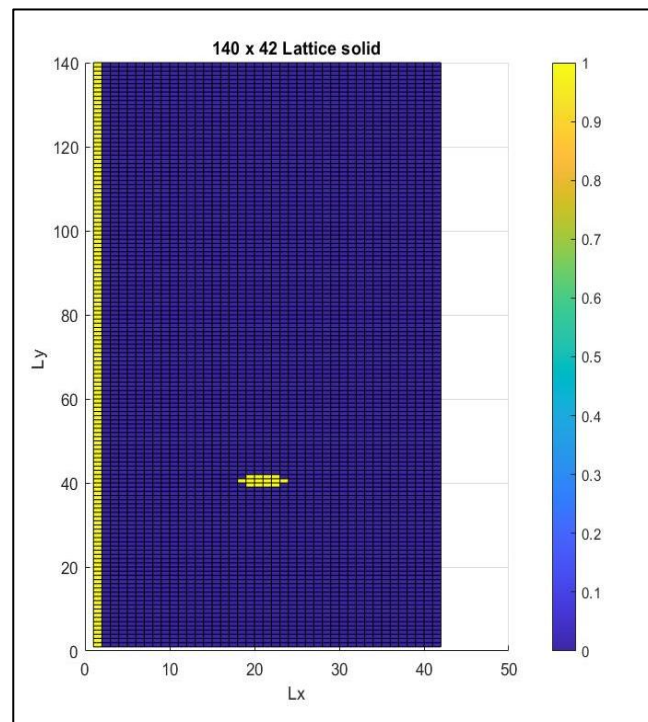

Figure 13: The Lattice of 140x42 solid

For this section, to describe the numerical results from this project, the following observation is a measured to determine the accuracy and capability of the central scheme. To illustrate them, all subsequent numerical tests include a force term associated with a bed slope such as flow over a bump and flow around a cylinder. Analytical answers are compared to numerical predictions. Figures 34, 35, and 36 indicate the analysis that is suitable for shallow water equations.
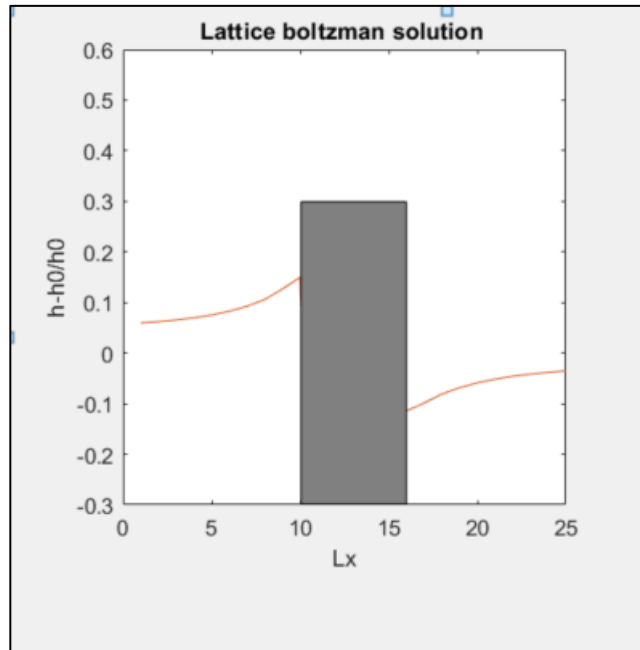

Figure 14: Comparison of depth over channel
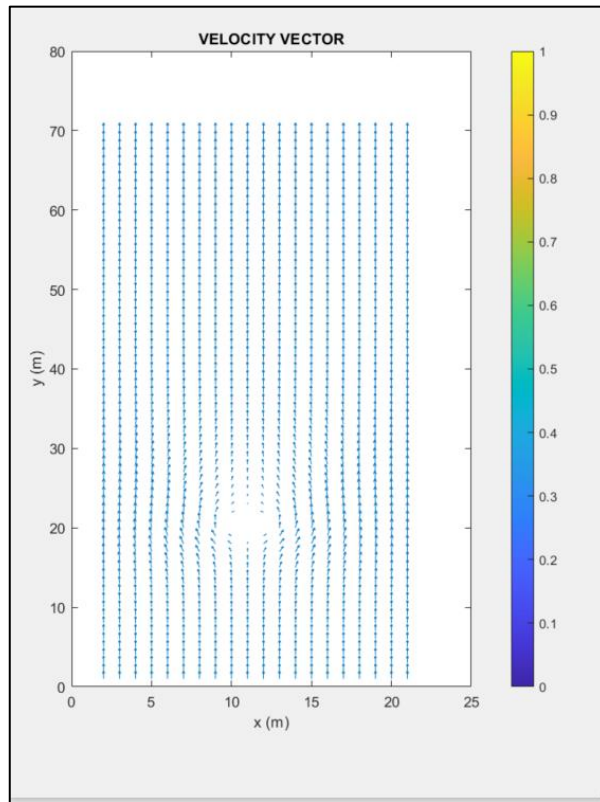along the centreline for flow around cylinder
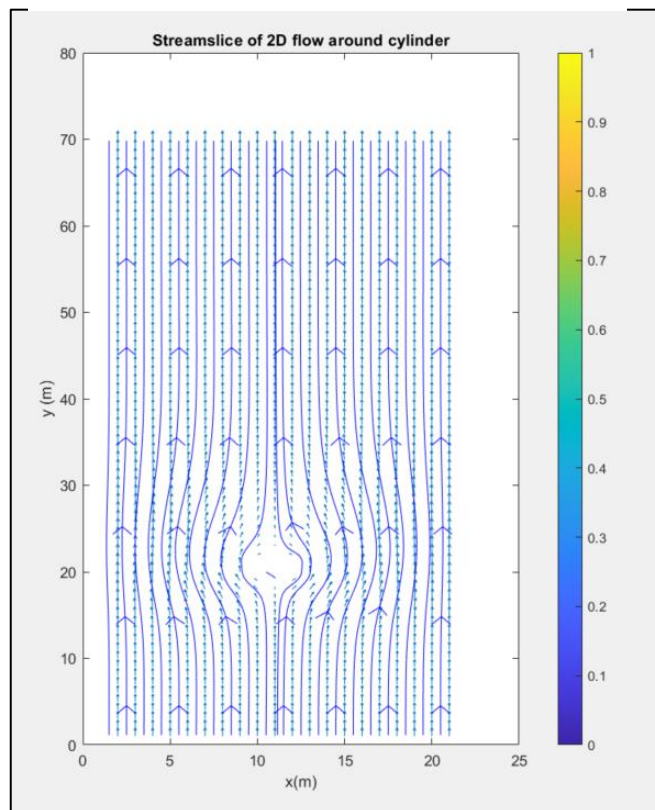
Figure 16:Velocity Vector for flow around cylinder

Figure 15: Streamline of 2D flow around cylinder

3.4.2 THE MATLAB CODING FOR 2D FLOW AROUND CYLINDER

```
clear
%    main program
%    !Input parameters!
length=4;width=2;
h0=0.185;he=0.185;v0=0;QinM=0.248;QinT=0.043;
Lx=600;
dt=0.00145;max_t=1;
tau=1.982;gacl=9.81; rou=1000; % fb=0;
 tau=1.1; % test laminar flow
Cs=0.4;
%    !Calculation of parameters!
dx=length/Lx; dy=dx;Ly=width/dy;
e=dx/dt;
%u0=Qin/(h0*(Ly-1)*dy);  % h0 should be changed to net h
nu_m=(2*tau-1)/6; % molecular viscosity
nu=e^2*dt*(2*tau-1)/6; % kinematic viscosity
mu=nu*1000;  % dynamic viscosity of water
nermax=(Lx-1)*(Ly-1);
Ly=Ly+2;
Xs=1;Xe=Lx;Ys=1;Ye=Ly;
    !determine solid values!
% load 'vortex.mat';
% load 'a.mat';

solid=solid_values(Lx,Ly);

%    bed data and slope calculation
[zb]=bed_data(Lx,Ly,dx,dy);
[Sx,Sy]=bed_slope(zb,Lx,Ly,dx,dy);
%    !initialize the depth and velocity field!
for y=1:Ly
    for x=1:Lx
        if solid(x,y)==0
          h(x,y) = 0.185;
          u(x,y)=0.43; v(x,y) = 0;
        else
          h(x,y) = 0; u(x,y) = 0; v(x,y) = 0;
        end
    end
end
ui=u;vi=v;hi=h;
[fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
area0=0;
for y = 1:Ly-1
```

```matlab
    area0 =area0+0.5*(h(1,y)+h(1,y+1))*dy;
end
[ex,ey]=setup(e); % calculate ex and ey
feq = compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);   %
initial feq
f=feq; % set initial feq to f
fcon=feq;
iteration=0;

%      main loop
time=0;
for time=0:dt:400*dt;
    iteration=iteration+1;
    h_bf=h;
    feq = compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);   %
update feq
    [taut,taue,nue] =
compute_taut(Lx,Ly,solid,tau,Cs,h,e,ex,ey,f,feq,dt);   %
Large eddy simulation
    [fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
    ftemp =
collide_stream(Xs,Xe,Ys,Ye,solid,taut,gacl,dt,Sx,Sy,u,v,e,e
x,ey,feq,f,h,fb); %collide_stream

ftemp=BC_Body_slip(Xs,Xe,Ys,Ye,solid,ftemp,Lx,Ly,fcon,ui,vi
,hi,e);

%       calculate h,u,v results
    [h,u,v,f]=solution(Xs,Xe,Ys,Ye,solid,ftemp,ex,ey);

iteration
c = u(50,37)

 end

%     continuity test
    [Q]=continuity(Xs,Xe,Ys,Ye,h,u,dy);

u0=u(50,37);
Fr=u0/sqrt(gacl*he);  % Froud Number
Re=u0*width/nu;        % Renold Number


 %     !determine solid values!

% function solid=solid_values(Lx,Ly,a)
function solid=solid_values(Lx,Ly)

for i=1:Lx
    for j=1:Ly
         if (i-40)^2+(j-21)^2<2.5^2
             solid(i,j)=1;
        else
%            solid(i,j)= a;
            solid(i,j)=0;
        end
    end
end

solid(1:81,1:23)=1; solid(100:Lx,1:23)=1;
% solid(1:Lx,Ly)=1;solid(1:Lx,1)=1;


return
```

3.5 PROJECT GANTT CHART

FYP I														
TASK	**WEEK**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Discussion on the project title	█	█												
Identify the problem		█												
Identify the objectives		█	█											
Study on the LBM			█	█	█	█	█							
Study on the MATLAB coding.				█	█	█	█							
Literature review				█	█	█	█	█	█	█	█	█		
Submit extended proposal						█								
Research on the discharge capacity of morning glory spillway						█	█	█	█	█				
Proposal defense							█							
Review on the research data collection.							█	█	█	█	█			
Prepared simulation							█	█	█	█	█	█	█	
Interim report draft submission													█	
Final submission of the interim report														█

Table 2: FYP I Gantt chart

FYP II														
TASK	**WEEK**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Literature review	■	■	■	■	■	■	■	■						
Design numerical model for morning glory spillway		■	■	■	■									
Prepare the simulation			■	■	■	■								
Run the simulation and observe the rotational flow				■	■	■	■							
Progress report submission							■							
Analyses the result and chooses the best hydraulic design of the shaft spillway.							■	■	■	■				
Submission of final report draft										■				
Submission of the final report												■		
Submission of technical report												■		
Prepared dissertation												■	■	■
Viva presentation														■

Table 3: FYP II Gantt chart

CHAPTER 4: RESULTS AND DISCUSSION

4.1 NUMERICAL STUDY OF 2D FLOW OF THE ANTI-VORTEX PIERS AT MORNING GLORY SPILLWAY

4.1.1 MEASURED DATA

In a numerical model study, the first step is to calibrated the model. It can be done by consider the external factors and the model conditions were taken into observation with regard to the real studies. This research numerical model is performed based on the previous experimental data. The numerical model needs to be calibrated in terms of boundary conditions and simulation. It is vital to acquire steady state in order to get the right and exact data from a numerical model. After examining numerous numerical models, the optimal duration for extracting findings from the model was determined to be 40 seconds in the analyzed numerical model. In the figure below, lattice solid 140x42 is developed as the model for the simulation of piers at the funnel of the morning glory spillway.

In this research, two models of piers at the funnel of the morning glory spillway have been created to find a suitable design for the effective discharge capacity. The limit of the method is restricted to the x-axis and y-axis only. The model of piers was created with the references from circular piano-key Inlet in Shaft Spillways according to the research by Z. Kashkaki, 2018. According to Kam R. Eslinger, 2022, Piano key weirs are straightforward solutions that are as safe and simple to use as standard free-flow spillways while being far more efficient. They have the potential to double the specific flow, significantly lower the cost of most new dams while ensuring their safety, enhance the storage capacity of many existing reservoirs, improve flood management at many existing dams, and raise the overflowing capacity of many existing dams.

The channel dimension for the research is; Length (4m), width (0.75m), density is $\rho = 1000 kg/m^3$, Renold number, $Re_D = 3.2 \, x \, 10^4$ and the time interval of 20sec. the two angles that were consider in this research are: angle of 45° and 90° .
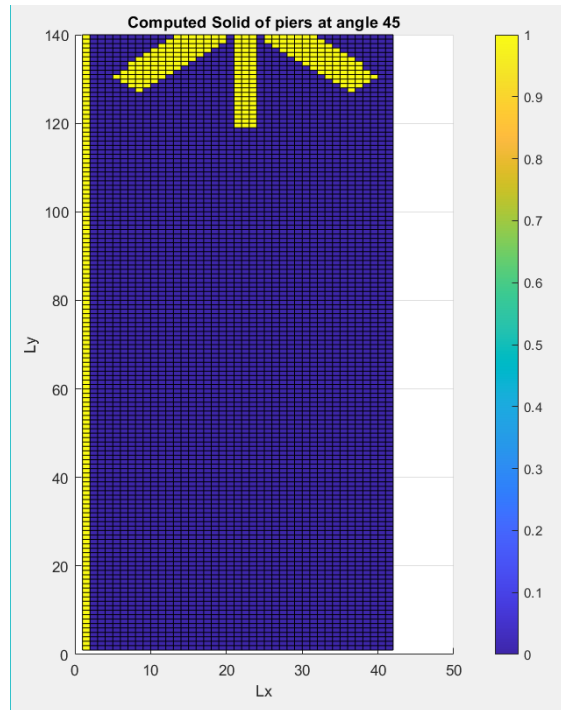

Figure 17: Lattice solid for pier at angle 45.

Based on figure 16 and figure 17, the water level near the piers of angle 45 is overflowing the structure and thus velocity is depth on the side channel rather than on the centerline of the path. When comparing to the piers at an angle of 90, the velocity shows only a few higher flows at the structure of piers due to the impact of water when reflected a solid wall but goes to a calm state directly after the collision area. These results can be explained more in the next subtopic: Velocity Vector.
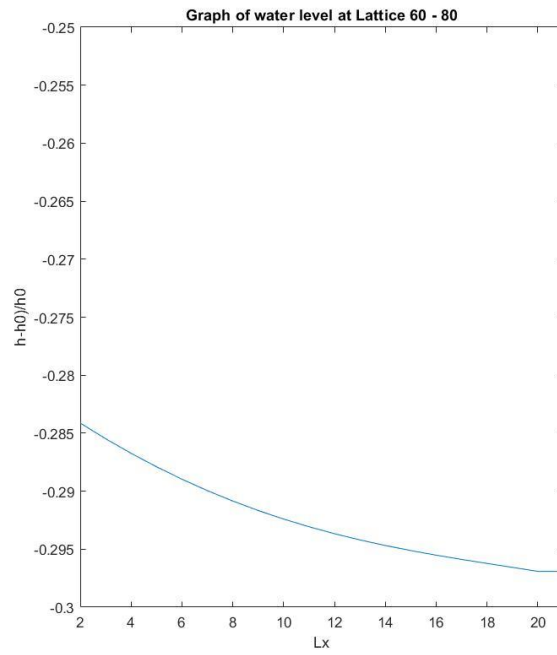
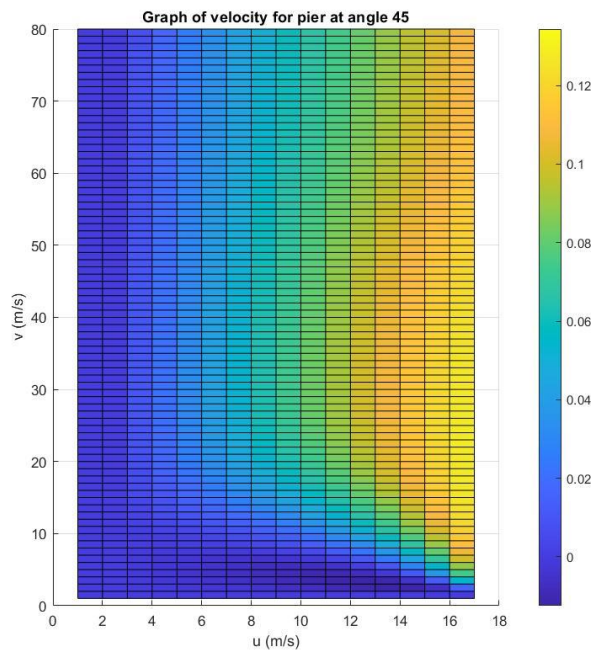Figure 18:Graph of water level at piers of angle 45
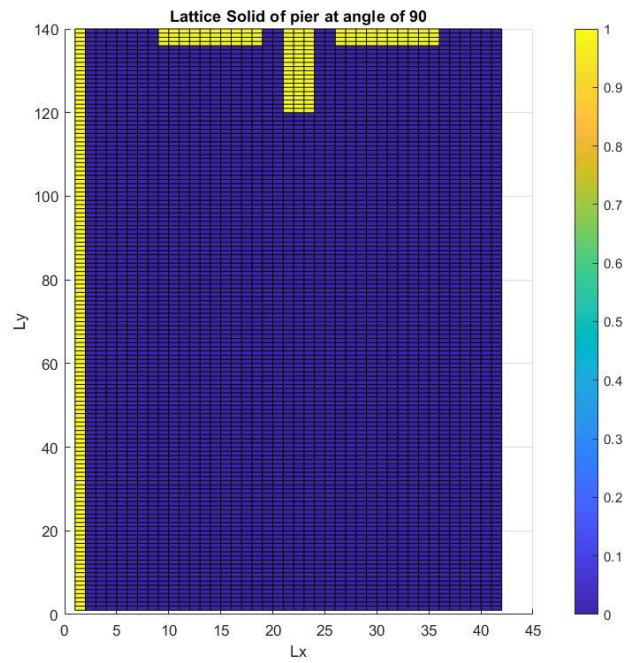

Figure 19: Graph of velocity for piers at angle of 45

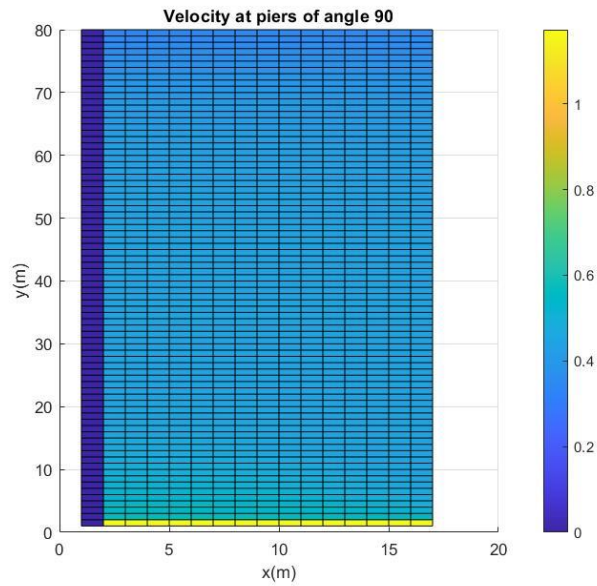Figure 20: The Lattice solid for piers at an angle of 90

Figure 21: Velocity of piers at an angle of 90

4.1.2 VELOCITY VECTOR

The rate of change of an object's position is represented by a velocity vector. The magnitude of a velocity vector indicates an object's speed, whereas the vector direction indicates the object's direction. The principles of vector addition can be used to add or subtract velocity vectors. It also known as the position function's derivative with regard to time. More in-depth velocity field can be observed from Figure 18 and the clear numerical result of streamline can be proved by Figure 19. The velocity vector for both angles shows that the water is drawn to the right-side wall of channel. It can be assumed as the magnitude of water is lower, the direction of water is dispersed to the side of path due to the little force attraction in the originated path and after a while, the flow of water returns to steady state again.
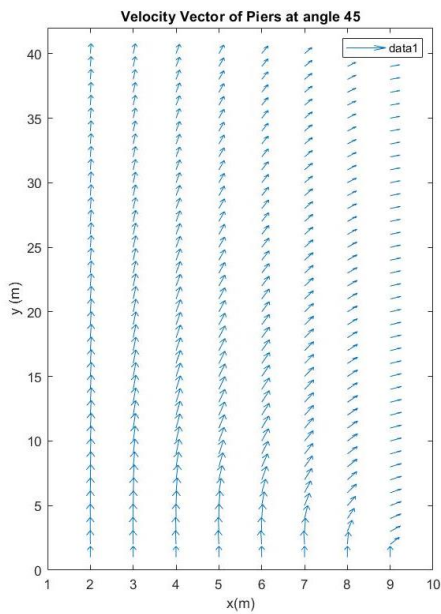

Figure 23: Velocity vector for piers at an angle of 45
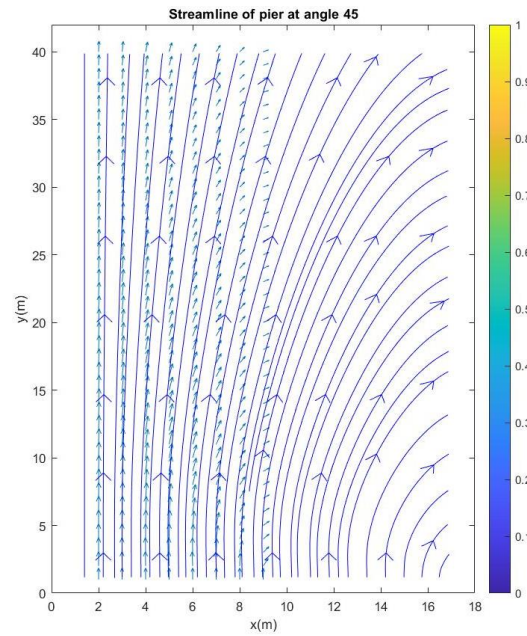
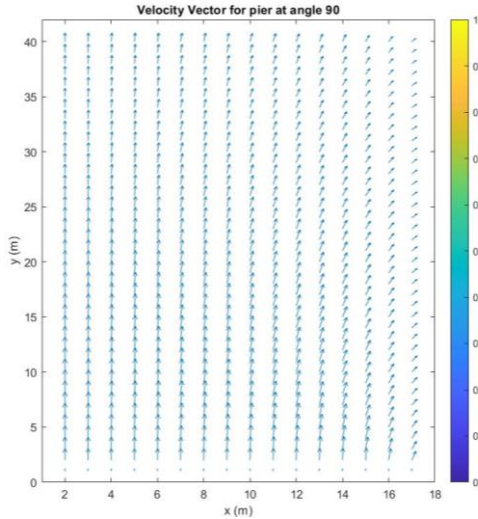Figure 22: Streamline of piers at angle 45

Figure 24: Velocity vector for piers at an angle of 90
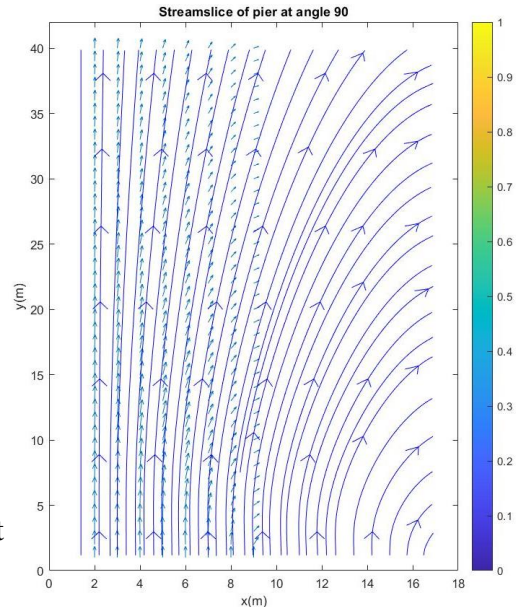
Figure 25: Streamline of piers at an angle of 90

According to A. Barati (2014), increasing the angle of piers can leads to the decreasing the inflow and height of water which also indicate that the flow will discharge greater capacity and no risky problems such as decreasing the discharge coefficient and huge swirling vortex will take place. This also produces a good performance of spillway capacity. Table 4 shows the relation between the discharge rate, height of water and the discharge coefficient that calculate using the following equation.

$$C_d = \frac{Q}{L \; x \; H^{\frac{3}{2}}}$$

Equation 21 : Discharge coefficient

In order to get more accurate numerical results, the data for Discharge, height of water and the discharge coefficient of Piers at angle-90 degree are analyze with the same parameters of Piers at angle-45 degree.

no.	Q (m3/s)	H (cm)	Cd
1	0.480	0.428	0.428
2	0.473	0.426	0.425
3	0.466	0.424	0.421
4	0.459	0.422	0.419
5	0.452	0.419	0.416
6	0.446	0.417	0.414
7	0.439	0.414	0.413
8	0.433	0.410	0.412
9	0.426	0.407	0.411
10	0.420	0.403	0.411
11	0.414	0.398	0.412
12	0.409	0.394	0.413
13	0.403	0.389	0.415
14	0.397	0.384	0.418
15	0.392	0.379	0.421
16	0.386	0.373	0.424
17	0.381	0.367	0.429
18	0.376	0.361	0.434
19	0.371	0.354	0.441
20	0.367	0.346	0.450
21	0.367	0.346	0.450

Table 4: Piers at angle 90-degree

Piers at angle 45			
no.	Q (m3/s)	H (cm)	Cd
1	0.031	0.117	0.192
2	0.030	0.116	0.191
3	0.030	0.116	0.190
4	0.030	0.116	0.189
5	0.030	0.116	0.188
6	0.029	0.116	0.187
7	0.029	0.115	0.186
8	0.029	0.115	0.185
9	0.029	0.115	0.184
10	0.029	0.115	0.183
11	0.028	0.115	0.183
12	0.028	0.115	0.182
13	0.028	0.115	0.182
14	0.028	0.115	0.181
15	0.028	0.115	0.181
16	0.028	0.115	0.181
17	0.028	0.114	0.180
18	0.028	0.114	0.180
19	0.028	0.114	0.180
20	0.028	0.114	0.180
21	0.028	0.114	0.180

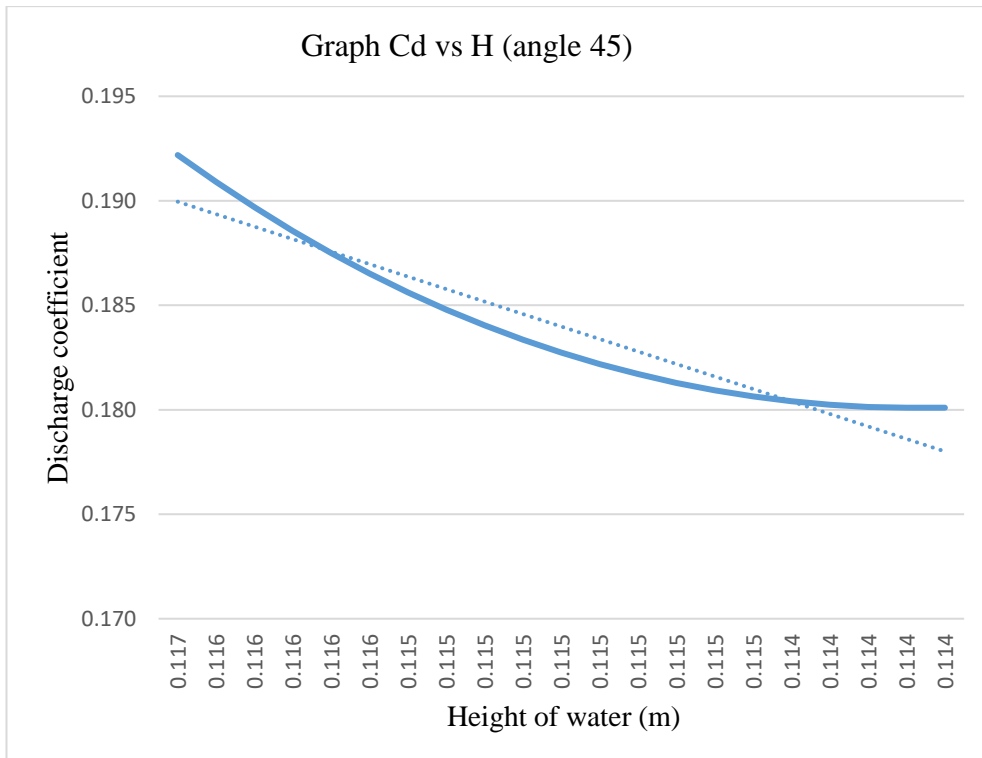Table 5. Piers at angle 45-degree

Figure 26: Graph height of water versus discharge coefficient
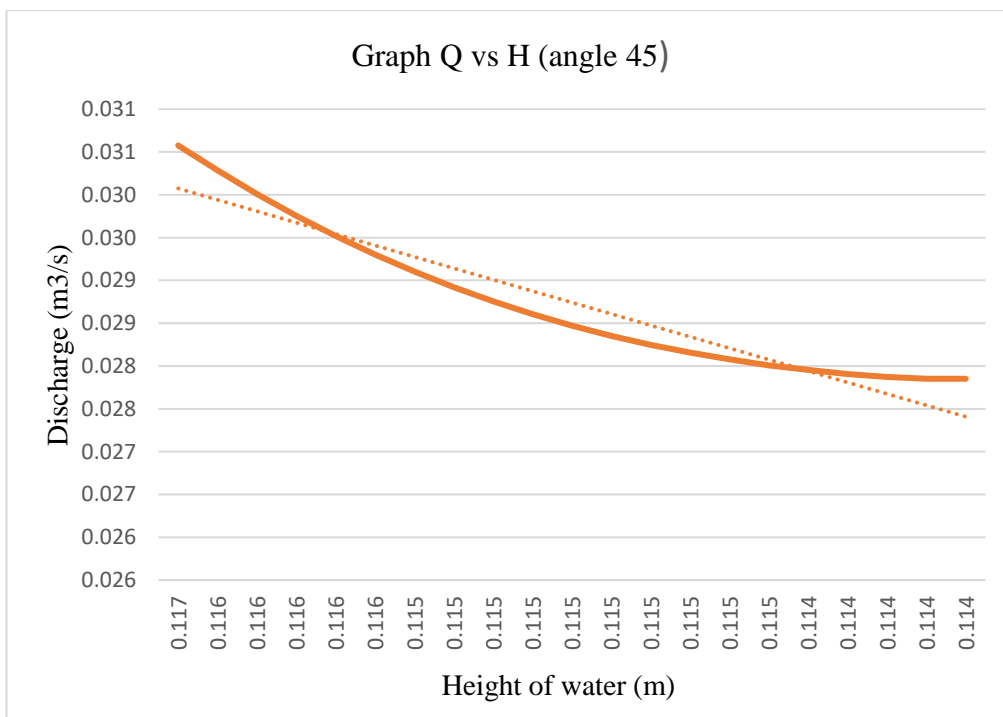
for angle 45-degree

Figure 27: Graph height of water versus rate of flow for angle 45-degree
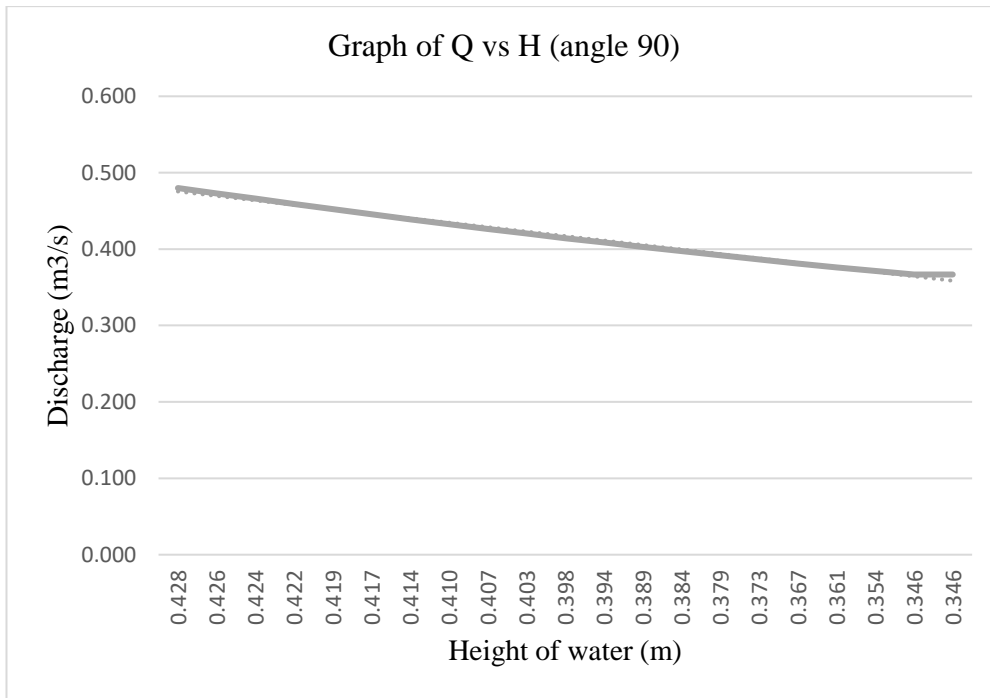
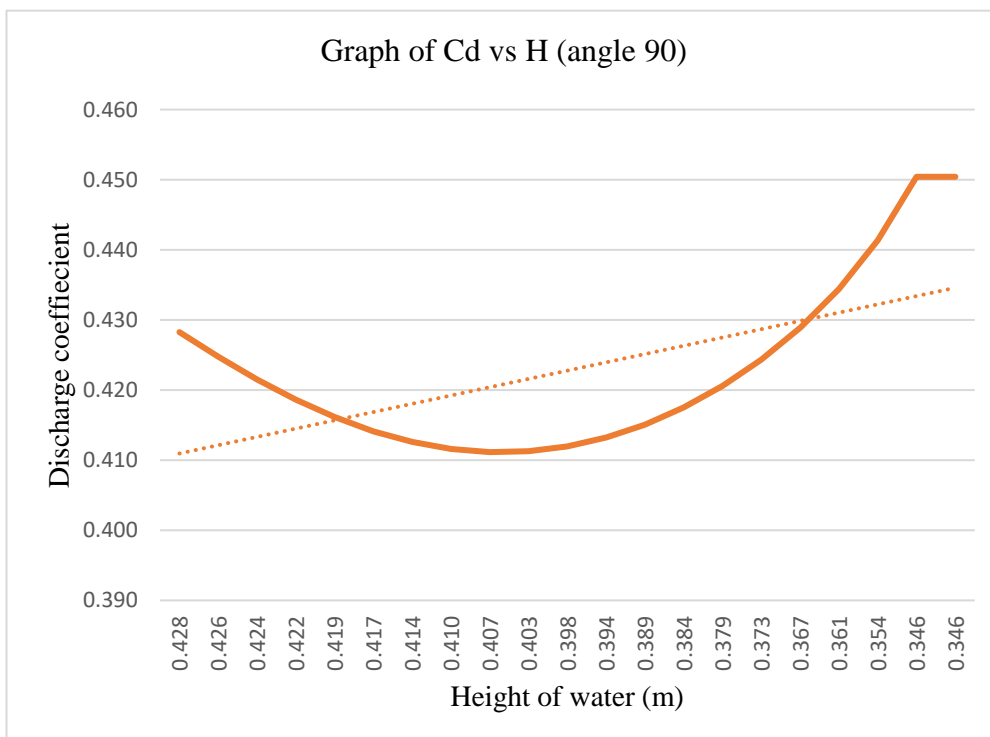Figure 28: Graph height of water versus rate of flow for angle 90-degree

Figure 29: Graph height of water versus discharge coefficient

for angle 90-degree

Based on Figure (26) to Figure (29), the discharge coefficient for angle 90-degree has greater values compared to angle-45 degree and the spillway produce bigger inflow capacity for 90-degree angle of anti-vortex piers than for 45-degree angle. In simpler words, increasing the angle of anti-vortex pier will increase the inflow capacity and the discharge coefficient values. According to Figure 30, for the constant head, a circular piano key inlet with an angle of 90 degrees overflows a greater quantity of discharge than models with angles of 60 and 45 degrees. When compared to a circular piano key inlet, a shaft spillway with no reformed inlet spills a smaller quantity of discharge. In conclusion, comparison to the shaft spillway, the circular piano key intake performs better. According to the research done by Z. Kashkaki (2019), results showed in Figure 31, that in a constant head, the greater amounts of discharge coefficient have been measured for the circular piano key inlet model with a 90 degrees angle by 15.16%.
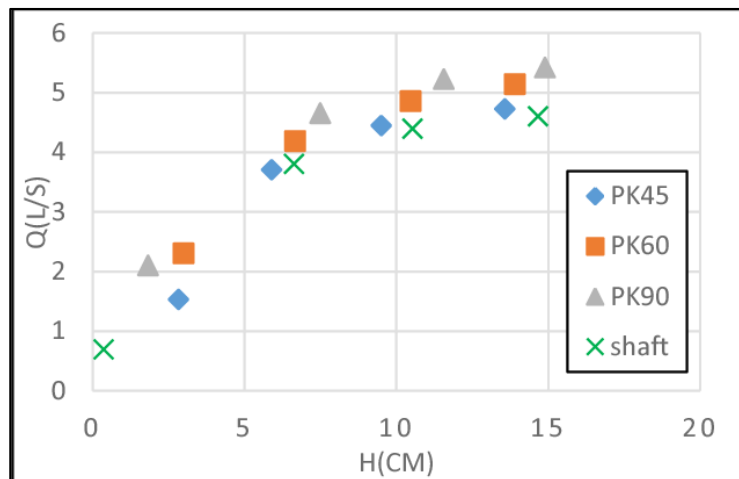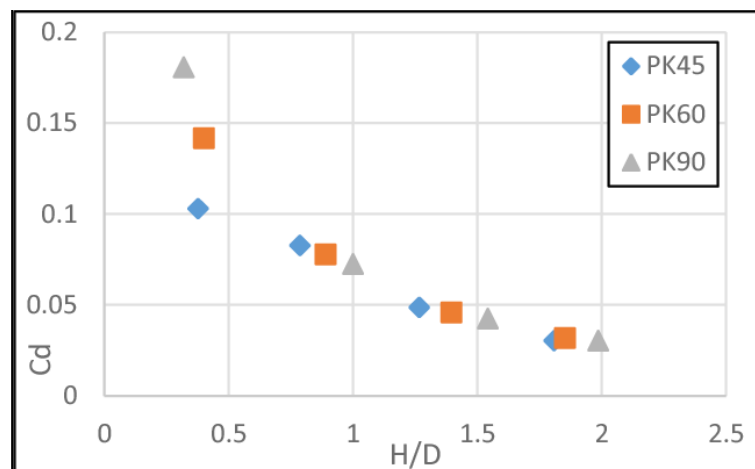

Figure 31: Rating curve for different models.

Figure 30: Discharge coefficient vs H/D for different models

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4.1.3 MATLAB CODING

```
clear
%    main program
%    !Input parameters!
length=4;width=0.75;
h0=1.173;he=1.173;v0=0;QinM=1.127;QinT=0.043;
Lx=80;
dt=0.01;max_t=1;
tau=0.500012;gacl=9.81; rou=1000; % fb=0;
 tau=1.1; % test laminar flow
Cs=0.4;
%    !Calculation of parameters!
dx=length/Lx; dy=dx;Ly=width/dy;
e=dx/dt;
%u0=Qin/(h0*(Ly-1)*dy);  % h0 should be changed to net h
nu_m=(2*tau-1)/6; % molecular viscosity
nu=e^2*dt*(2*tau-1)/6; % kinematic viscosity
mu=nu*1000;  % dynamic viscosity of water
nermax=(Lx-1)*(Ly-1);
Ly=Ly+2;
Xs=1;Xe=Lx;Ys=1;Ye=Ly;
    !determine solid values!
% load 'vortex1.mat';
load 'vortex2.mat';
% solid=solid_values(Lx,Ly,a);

%    bed data and slope calculation
[zb]=bed_data(Lx,Ly,dx,dy);
[Sx,Sy]=bed_slope(zb,Lx,Ly,dx,dy);
%    !initialize the depth and velocity field!
for y=1:Ly
    for x=1:Lx
        if solid(x,y)==0
          h(x,y) =1.173;
          u(x,y)=0.43; v(x,y) = 0;
        else
          h(x,y) = 0; u(x,y) = 0; v(x,y) = 0;
        end
    end
end
ui=u;vi=v;hi=h;
[fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
area0=0;
for y = 1:Ly-1
   area0 =area0+0.5*(h(1,y)+h(1,y+1))*dy;
end
[ex,ey]=setup(e); % calculate ex and ey
feq = compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);  % initial feq
f=feq; % set initial feq to f
fcon=feq;
iteration=0;

%     main loop
time=0;
for time=0:dt:200*dt;
    iteration=iteration+1;
    h_bf=h;
    feq = compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);  % update feq
```

40

```matlab
    [taut,taue,nue]                                               =
compute_taut(Lx,Ly,solid,tau,Cs,h,e,ex,ey,f,feq,dt);    % Large eddy
simulation
    [fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
    ftemp                                                         =
collide_stream(Xs,Xe,Ys,Ye,solid,taut,gacl,dt,Sx,Sy,u,v,e,ex,ey,feq,
f,h,fb); %collide_stream

ftemp=BC_Body_slip(Xs,Xe,Ys,Ye,solid,ftemp,Lx,Ly,fcon,ui,vi,hi,e);

%     calculate h,u,v results
    [h,u,v,f]=solution(Xs,Xe,Ys,Ye,solid,ftemp,ex,ey);

iteration
c = u(50,17)

 end

%     continuity test
    [Q]=continuity(Xs,Xe,Ys,Ye,h,u,dy);

u0=u(50,17);
Fr=u0/sqrt(gacl*he);  % Froud Number
Re=u0*width/nu;       % Renold Number




%     !determine solid values!

% function solid=solid_values(Lx,Ly,a)
function solid=solid_values(Lx,Ly)

for i=1:Lx
    for j=1:Ly
        if (i-40)^2+(j-21)^2<2.5^2
            solid(i,j)=1;
        else
%             solid(i,j)= a;
            solid(i,j)=0;
        end
    end
end

% solid(1:81,1:23)=1; solid(100:Lx,1:23)=1;
solid(1:Lx,Ly)=1;solid(1:Lx,1)=1;


return
```

CHAPTER 5: CONCLUSION AND RECOMMENDATION

As a conclusion, the objective of the research is obtained. The model was able to develop and run the simulation using Lattice Boltzmann method in shallow water. In the result also mention that the model is tested and able to analyses the discharge capacity of the channel. Among the two proposed piers' angle, the most suitable angle that proven by this research is piers at angle 90-degree. The real-life case also help this research in properly determining the compatible design for the effective discharge capacity as mention in the scope of this study.

Physical models were used to test an innovative approach named "circular piano-key spillway," which combined the piano-key weir idea with a morning glory spillway. The hydraulic performance of the shaft spillway with no repaired inflow was compared. A Circular piano key spillway with a 90-degree angle demonstrated a higher discharge coefficient than the other models examined in this study. In a geometric comparison of three circular piano-key spillway models, the circular piano-key spillway with a 90-degree angle has the best performance. As a result, increasing their dimension to a certain point improves the discharge coefficient and spillway flow discharge.

For this research, MATLAB was chosen as the software to develop the model. However, they are more out there that can create better models than these models. MATLAB was purposely used to develop the lattice Boltzmann models for the shallow water equations (LABSWE and LABSWETM). Based on the simulation done, it suggests that the LABSWETM is accurate and conservative to be used, develop and model the flow of water. However, further study is recommended for this research as the result obtained is little compared to other research regarding the use of LBE in the simulation of shallow flow for the 2D axis.

CHAPTER 6: REFERENCE

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CHAPTER 7: APPENDIX

```
clear
%     main program
%    !Input parameters!
length=7;width=2;
h0=0.173;he=0.173;v0=0;QinM=0.127;QinT=0.043;
Lx=140;
dt=0.01;max_t=1;
tau=0.500012;gacl=9.81; rou=1000; % fb=0;
 tau=1.1; % test laminar flow
Cs=0.4;
%     !Calculation of parameters!
dx=length/Lx; dy=dx;Ly=width/dy;
e=dx/dt;
%u0=Qin/(h0*(Ly-1)*dy);  % h0 should be changed to net h
nu_m=(2*tau-1)/6; % molecular viscosity
nu=e^2*dt*(2*tau-1)/6; % kinematic viscosity
mu=nu*1000;  % dynamic viscosity of water
nermax=(Lx-1)*(Ly-1);
Ly=Ly+2;
Xs=1;Xe=Lx;Ys=1;Ye=Ly;
    !determine solid values!
load 'vortex.mat';

% solid=solid_values(Lx,Ly,a);

%     bed data and slope calculation
[zb]=bed_data(Lx,Ly,dx,dy);
[Sx,Sy]=bed_slope(zb,Lx,Ly,dx,dy);
%     !initialize the depth and velocity field!
for y=1:Ly
    for x=1:Lx
        if solid(x,y)==0
          h(x,y) = 0.173;
          u(x,y)=0.43; v(x,y) = 0;
        else
          h(x,y) = 0; u(x,y) = 0; v(x,y) = 0;
        end
    end
end
ui=u;vi=v;hi=h;
[fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
area0=0;
for y = 1:Ly-1
   area0 =area0+0.5*(h(1,y)+h(1,y+1))*dy;
end
[ex,ey]=setup(e); % calculate ex and ey
feq = compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);   % initial
feq
f=feq; % set initial feq to f
fcon=feq;
iteration=0;

%     main loop
time=0;
```

```
for time=0:dt:200*dt;
    iteration=iteration+1;
    h_bf=h;
    feq  =  compute_feq(Lx,Ly,h,u,v,e,ex,ey,gacl,solid);    %
update feq
    [taut,taue,nue]                                         =
compute_taut(Lx,Ly,solid,tau,Cs,h,e,ex,ey,f,feq,dt);   % Large
eddy simulation
    [fb]=fb_distribution(Lx,Ly,dx,dy,h,gacl);
    ftemp                                                  =
collide_stream(Xs,Xe,Ys,Ye,solid,taut,gacl,dt,Sx,Sy,u,v,e,ex,e
y,feq,f,h,fb);  %collide_stream

ftemp=BC_Body_slip(Xs,Xe,Ys,Ye,solid,ftemp,Lx,Ly,fcon,ui,vi,hi
,e);

%     calculate h,u,v results
    [h,u,v,f]=solution(Xs,Xe,Ys,Ye,solid,ftemp,ex,ey);

iteration
c = u(50,37)

 end

%     continuity test
    [Q]=continuity(Xs,Xe,Ys,Ye,h,u,dy);

u0=u(50,37);
Fr=u0/sqrt(gacl*he);  % Froud Number
Re=u0*width/nu;       % Renold Number




 %     !determine solid values!

% function solid=solid_values(Lx,Ly,a)
function solid=solid_values(Lx,Ly)

for i=1:Lx
    for j=1:Ly
        if (i-40)^2+(j-21)^2<2.5^2
            solid(i,j)=1;
        else
%            solid(i,j)= a;
            solid(i,j)=0;
        end
    end
end

% solid(1:81,1:23)=1; solid(100:Lx,1:23)=1;
solid(1:Lx,Ly)=1;solid(1:Lx,1)=1;


return
```