Study the Behaviour of Water Flow over Different Stepped Spillway

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Abstract:- The flow over stepped spillways is a complex flowdue to the turbulence of water flow with different water flow aspects. for that, in this paper, the spillway effects have been investigated by various spillway design analysis using ANSYS CFD Fluent software. The slope of all the models is held constant for each case and two types of slops considered in this research. The inlet boundary condition of the stepped spillway model is represented by the discharge. The outlet boundary condition of the spillway is set by pressure, velocity and volume of friction. The results observed that it is feasible to improve the hydraulic behaviors of a pool configurations stepped spillway. the pools in this study present an overcome of the flow stability and energy dissipation issues. The pressure value at the beginning of the step in the pooled configuration was large, while for the notched pool the maximum pressure values decreased near the step pool. Pool configuration (simple or notched) did not have a significant influence on the location of air entrainment.Also, the air entrainment location (inception point) moves downward when increases the discharge rate. This result observes the importance of the spillway steps shape to generate the pressure force based on height of each step.

Keywords:- spillway slop design, and volume of friction, inception point,

INTRODUCTION

The flow characteristics over a stepped drain stream can be specified in three main systems: nape, skimming and moving. In the engineering consideration, limning flow represents more relevant condition than the other two types. For tit reason, stepped spillways are usually designed as slimming flow condition depending on the conditions of Mechanics of Fluid and hydrology of arranged stepped drain stream. The latest researches, several studies on non-uniform and uniform stepped spillways have been conducted. have investigated water flow characteristics such as flow regime, flow pattern, and velocity field. They founded the position at which the turbulent condition of boundary level specifies the free surface and determined the energy loss in these spillways. The previous studies also contain many modifications of spillways structural reinforcement, layouts and devise innovative solutions to enhance the hydraulic performance [1]. The next section will present briefly the main considerations and characteristics that can be utilized to investigate water flow behavior across a Stepped Spillway. Spillways design can consider it as a part of the dam or separate from it. Also, it can be designed as a controllable part or uncontrollable part. the spillway with control reliability is provided with gates to control the water level and flow. the spillway consists of a terminal structure, control structure and a unloading channel. in the present study, the Spillways shape and geometry are considered the main issue to investigate the flow characteristics.

Backflow, transition flow, and scraping flow systems with rising discharge for a particular waterfall dimension can all be classified as stepped drain flows [2]. The discharge channel setup, which comprises channel slope, step height, and discharge, determines how flow systems change. Finally, the flow system affects the amount of electricity dissipated. The waterfalls descend one by one on the steps at a laminar flow rate, and the rays fall one by one into the rear flow system. It can be divided into three types of breach flow subsystems. The transition flow regime in intermediate discharges exhibits perplexing behavior, with heavy scattering and start point. The present system of flow initially detected and investigated by Ohtsu & Yasuda in 1995, also it was explained by Elviro and Mateos in 1995 and Chanson in 1996 [3]. Limited investigational studies have been made to characterize particular transient flow characteristics. Chanson and Toombes defined two transient flow subsystems in 2004 that differed in empty fraction distribution profiles. Some researchers investigated the instability of the transient flow system for combined stepped spills. The energy of the water flow is wasted in the transmission of shear stress from the prevailing fluxes. In general, drains are intended for excessive discharge in a scraping flow system, which is why the majority of exploratory research for this system have been completed. The flow of air and water can be fully advanced at the lower end, and the concentration, speed, and depth of the air will attain a constant value in these uniform equilibrium settings [4].

TYPE OF FLOW IN SPILLWAYS

Spillways are structures that can be used to evacuate overflowing of water flow dams. the high velocity represents the main important hydraulic problem in the field of water flow in spillways which causes cavitation at its downstream. For that, the flows along stepped spillways considered an interesting concern in the previous studies. The researchers found that the napped regime in the flow over spillways observes three sub-kinds categorized by the creation of hydraulic jumps on the bottom of the stairs. The parameters of the three standards flow conditions may vary based on the geometric conditions of entry into the channel, the steps size and conditions, the length of the channel based on region steps and finally the flow rates. It occurs by considering specific conditions such as the variations in steps length in relation to their height and bottom flows (related to scrape flow) [5]. The “transitional flow” between the backflow flows and the scrape flows is also known as the area among these two “extreme” flows. Numerical modeling such as computational fluid dynamic (CFD) can apply the specific related equations which are usually Naiver-Stokes equations. These equations can be solved along the turbulence models. the watercourse design will observe the stream height, width, step height and slope. likelihood of estimating the power dissipation along the gradient stream and determining the remaining head at the stream's end for an acceptable pour-sump design is based on this data [6]. The safety factor can also be used to determine the size of the graded drainage sidewall. Several principles have been proposed based on various experimental results that provide adequate clues for graded channels in a scarping flow system for a specific set of slopes. The high number of design criteria limits the accuracy of pre-design calculations, and a practical trial in a massive size specimen yields more precise results for the entire design[7]. Furthermore, the design standards only apply to flat steps, and varied step layouts necessitate further testing. In the current study, several configurations of uniform steps, irregular steps, and varied configurations of mixed steps are discussed for graded spillways. Spillways are normally classified according to their geometrical layouts (ogee, chute, stepped, shaft, etc.), functions (service, auxiliary and emergency) and control structures (gated, ungated and sluice). Vischer and Rutschmann develop a systematic classification approach considering all the essential elements of the channel, such as entrance, regulation or control, discharge transporter, and opening. According to Vischer and Hager, spillways are classified in a simple way: frontal spillway, side spillway and shaft spillway [8].

i. Chute spillway

A chute is a discharge channel downstream of a control structure. Typically, a chute spillway is composed of an approach channel, a chute, and a tail water section. The dimension and profile of the chute are mainly dependent on the hydraulic requirements. The geological and topographical features also have an impact on their selection. A chute spillway can be either straight or curved. Its cross-sectional profile can be a rectangular or trapezoidal shape. Ideally, it should be straight, as the flow in it is usually supercritical. Any constriction, expansion, or curvature would lead to unfavorable flow behaviors, such as shock waves. Nevertheless, owing to geographical restrictions or for energy dissipation purposes, contractions or expansions in width might be applied to a chute spillway [9].

ii. Shaft spillway

A shaft spillway is a closed conduit transferring water from a high to low elevation. A water drainage canal can be constructed in several methods. It usually consists of a vertical shaft or, in some situations, an inclined shaft. The drain duct is very useful when discharging a large amount of water from high tanks [10]. It is widely used in dam engineering, erosion-control structures, and highway culverts. Due to its vertical arrangement, this type of spillway is advantageous in narrow canyons with steep abutments. In addition, a shaft spillway is capable of operating at its near-maximum capacity even at low heads, resulting in a significant attenuation of floods. Air entrainment is the most important and complex issue in a drop shaft. It occurs when the flow from the intake hits the water column in the shaft. Its occurrence is closely linked to the flow regimes explained above. With the increase in water head, the air discharge first climbs and then drops to zero when it is submerged [11].

iii. Labyrinth spillway

A labyrinth spillway features a number of slender walls. Its crest is prolonged with a weir in triangular, trapezoidal or rectangular shape in plan. It is designed particularly for conveying large floods at low heads, as the water can still flow over the entire crest length even at a low head. The stepped drainage has some long length steps comparing to the regular graded fall and also has a wider effective width [12]. The proof of the numerical prototypes is founded on investigational outcomes of water surface, compression measurements and relative power waste. Simulations extend the understanding of flow phenomena over normal fall cycles and graded fall and make the flow performance more explicit [13]. For instance, if a higher design flood is introduced, a labyrinth structure is an effective measure to upgrade the existing spillway in a narrow waterway. Recent successful applications of labyrinth spillways show their potential in improving discharge characteristics. However, as the water level increases, a labyrinth spillway suffers from limited discharge, which is due to the interactions of the flows from the upstream apex and the sidewalls. If the head is large enough, its discharge capacity will further drop close to that of a straight weir with a same channel width. Depending on the head, the flow patterns are classified as fully aerated, partially aerated, transitional, and suppressed flow [14;15].

MODEL DEVELOPMENT

This section will present the model implementation procedure. The ANSYS FLUENT software is used to solve CFD problems based on the selected model. In this section, the researcher designs the steps to create the simulation model based on the three spillway shape design. The symmetric type will be used as a baseline to investigate the water over stepped spillway behavior of the other two types. The present steps contain the tasks of preparing the geometrical shape by sequins of operations starting with pre-processing step which is constructing to generate the mesh, followed by the physical model fix, boundary conditions, initial conditions, and additional suitable parameters that are defined in the modelling and solving step, and finally and post-processing step. The experiments can be used to obtain outcomes through the computational range in the post-processing step. The fluid flow analysis system consists of different cells (geometry, mesh, etc.) that characterize the workflow for accomplishment of the analysis. ANSYS Workbench consists of numerous data-combined and native uses in a single, seamless project process, where each cell can retrieve data from other cells and offer data to additional cells. Next step concern with creating the geometry [16].

When the geometrical dimensions uploaded to the ANSYS Design Modeler, the spillway dimensions have specified [17]. It is seen in Figure 1 the dimensions specified in two various spillway models. These dimensions represent the boundary conditions of the water over stepped spillway.

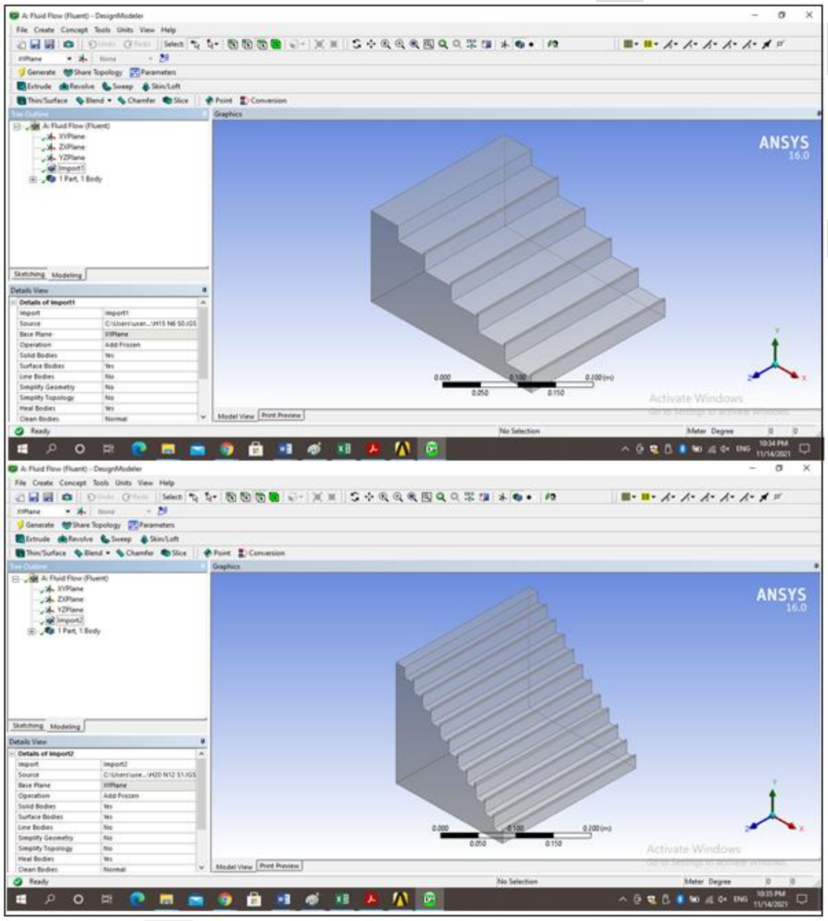


Figure 1: the case study shape geometry

The hydraulic characteristic changes in the spillway effects have been investigated by various spillway design analysis. It typically requires understanding the spillway specific shape design to find the water behavior moving on the spillway surface which produces the traditional responses. The present work produces a set of simulation tests using various spillway and velocities. Numerical simulations are performed to study the influences of the step edges and cavities on the water flow features. The parameters affecting the mixture flows include step edge and cavity shape. The simulation applied by ANSYS CFD Fluent software which is validating by the baseline [18]. This step is essential to consider the correctness of the CFD technique. Validation testing is a way to reduce and estimate modeling errors and to confirm that the CFD model being resolved is a respectable demonstration of actuality. For examine the effect of the difference of any given variable in the simulation. The CFD simulation outcomes achieve the purpose of this study and offer brief discussion depended on spillway geometries [19]. The first section presents the results of ANSYS and plots its own numerical outcomes, while the second section presents an analysis of the comparative study among the two existing types of spillway and looks at the variances [20].

STEPPED SPILLWAY RESULTS

Numerical modelling is an extensively applied computer-aided technique the Navier-Stokes equation, which is based on the preservation of collective power, mass, and momentum The stepped spillway prototypes are modeled using CFD software. The Navier-Stokes equation is estimated by Fluent software using the Finite Element Method (FEM). In CFD, the FEM methodology is the most extensively used method for preserving the dynamic equations. Instead of solving equations numerically, volume control technology converts the governing equation into algebraic equations. The volume control integration equations are solved in an embedded form, and the numerical simulation uses seven distinct types of spillway models with varied step sizes and configurations, as indicated in Table 4.1. For each example, the slope of all models is kept constant, and there are two types of slops investigated in this study. The discharge characterizes the stepped spillway model's entrance of boundary condition. Pressure, velocity, and friction volume are used to determine the spillway's opening boundary condition.

Table 1: Design parameters for numerical simulation of several tiered spillways

model	Step shape	slop
M1	Triangle step	Type 1
M2	Triangle step	Type 2
M3	Rectangle step	Type 1
M4	Rectangle step	Type 2

The first step, the researcher validates the ANSYS software model by comparing the results with previous studies. The selected study was an experimental and numerical modelling of flows over stepped spillways presented by Van Alwon et al, in 2017. The comparison was by measuring the pressure on the spillway steps and the results shown in the figures below:

Figure 2: pressure distribution on spillway steps

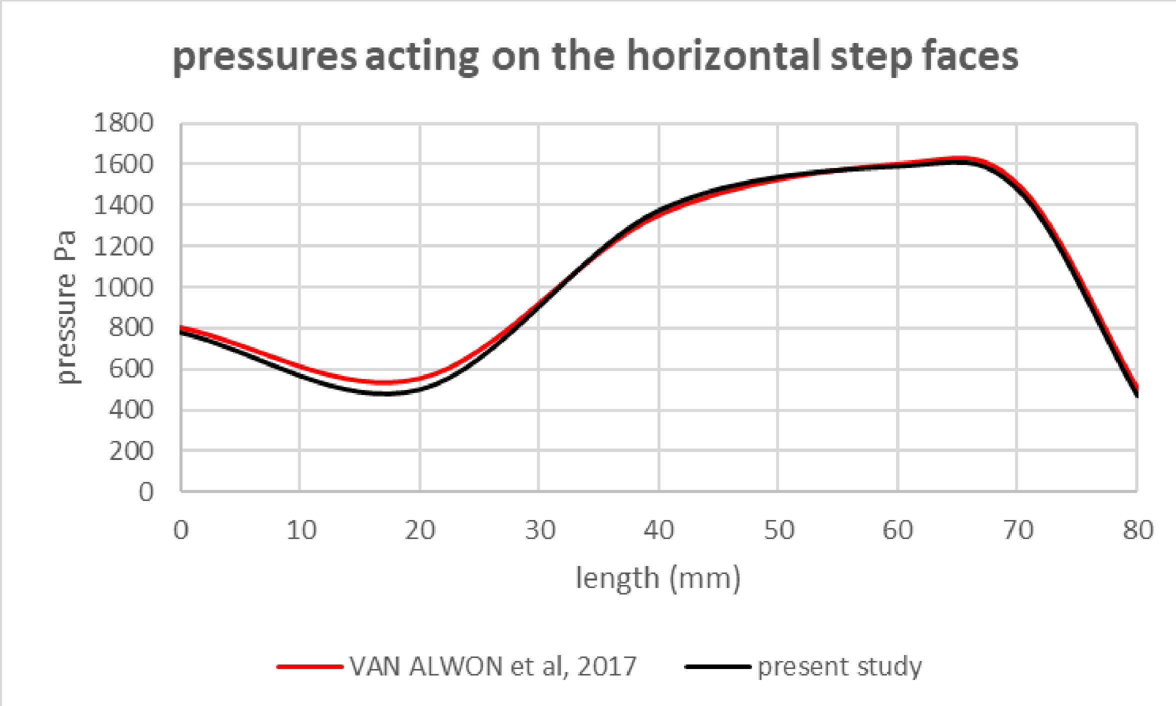


Figure 3: comparison the pressure on the spillway steps

The results were significant the researcher continue to next simulation step.

ANSYS EVALUATION OF TRIANGLE STEPS (CASE 1)

The Stepped Spillway is the most crucial component in the dams. For that, this study aims to investigate the aerodynamic characteristic in dam Stepped Spillway. The flow characteristic can be recognized by observing the water flow behavior in various types of Stepped Spillways and water velocity. Various shape of the dam Stepped Spillways produces various flow behavior This creates a difference in velocity based on the physical law recognized as Bernoulli's Principle. While this velocity is trying to balance, the water flow is trying to move in the direction of the lower level. In order to characterize the aerodynamic forces acting on the dam Stepped Spillway. Current study observes the aerodynamic behavior around the darn Stepped Spillway by using CFD ANSYS. The part of CFD in design changes field of relies on the phase of study. Computational fluid dynamics in the shape of a two-dimensional structured mesh flow analyzer by using the Navier-Stokes equations averaging Euler and Reynolds. The numerical model is prepared and run with CAD software that creates boundary conditions for the analysis. Outcomes of analysis act a very significant part in optimizing design components so that there is a smallest velocity on the Stepped Spillway surface and swirl of water flow.

i. Triangle Steps

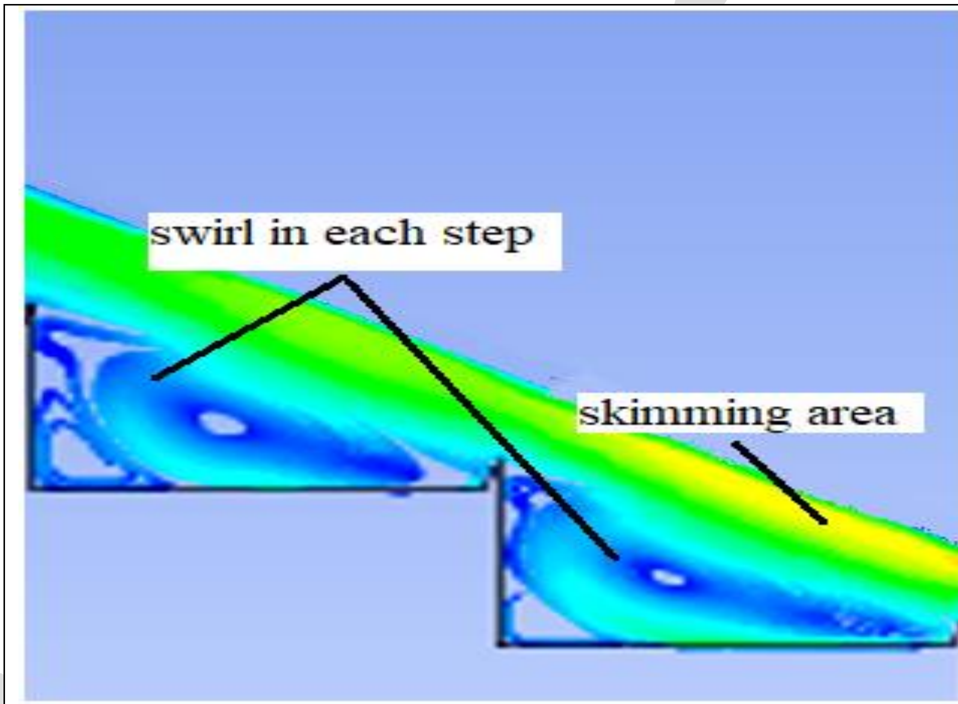
Flow Pattern Vector plots and the stream line plots for the triangle steps case clearly represent the flow patterns over dam Stepped Spillway. The ANSYS software simulated the chosen cases by defining them according to boundary conditions. There are five basic properties employed in the CFD-ANSIS simulation process which are given in Table 4.2. Numerous situations are produced by means of the behavior of the velocity and speed in different dam Stepped Spillway subjected to water motion.

Table 2: Operating Parameters

	parameter	input value
1	Water flow speed	0.2, 0.8, 1.2 m/s
2	Operating temperature	288.16 K
3	Density	1016 Kg/m3
4	Model	Realizable k-ε Model
5	Fluid	Water

The flow characteristic can be recognized by observing the water flow behavior in various kinds of Stepped Spillways. The influence of velocity variation on the dam Stepped Spillway indicates the variances. The flow speed water of is crucial because it control the effect of water movement which changes the surface velocity on Stepped Spillways.

It is observed that the maximum velocity affects in the down of the dam Stepped Spillway as shown in the red color of the velocity profile. This observation approved that there is a high down force in this point, the affected force component will have applied perpendicularly on the longitudinal axis of the dam Stepped Spillway section. But with the increase of water velocity, the vortex appears as shown in Figure 3 in the velocity profile. The vortex will increase the drag force which cause several aerodynamic problems. Due to boundary layer separation at the suction side of the dam Stepped Spillway stationed below the critical edge vortex which broke down that resulted in loss of velocity. It is seen that the water characteristics have been changed by the changes of water velocity; therefore, the speed forms detect a rise in the water velocity at the side of surfaces of the dam Stepped Spillway and reduction in the upper surface as revealed in the red area. In current case, the force will increase because there is an inverse relationship between the pressure and the water speed.



Velocity Flow Pattern of 0.2 mps

Figure 3: velocity profile of the triangle spillway simulation results

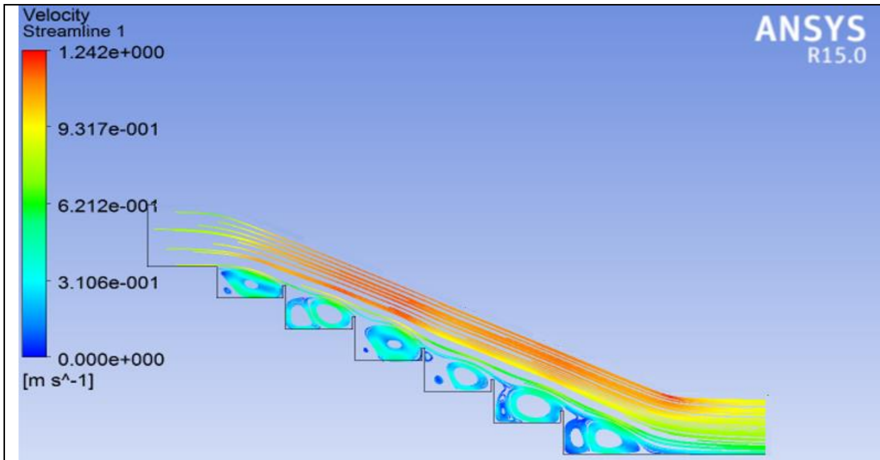
The velocity contours observe a rising in force surface of the dam Stepped Spillway and step pole surface reduction. This result indicates that the resistance counter to the flow course will create a negative force which means that the force will increase because there is a positive relationship between the force and the water velocity in the dam Stepped Spillway surfaces.

ANSYS EVALUATION OF RECTANGLE DAM (CASE 2)

The present case observes the aerodynamic behavior around rectangular dam Stepped Spillway by using CFD ANSI'S. The numerical model is also prepared and run with CAD software which creates a boundary conditions for the analysis. This analysis outcome acts a very significant part in optirni7ing design components so there must be a minimum velocity on the Stepped Spillway surface and swirl of water flow.

i. Rectangle Spillway

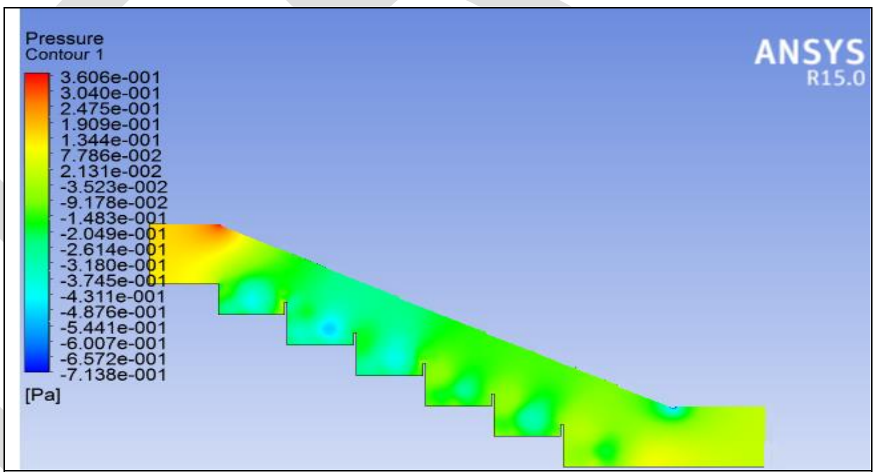
Flow Pattern Vector plots and the stream line plots as shown in Figure 5 for the single column case clearly represent the flow patterns around the rectangular dam Stepped Spillway. The ANSYS software simulated the chosen cases with meaning of boundary conditions. There are five basic properties employed in the CFD-ANSYS simulation process are the same in the first case flow characteristic can be recognized by observing the water flow behavior in this type of Stepped Spillways. The influence of velocity variation on the dam Stepped Spillway indicates the variances. The water flow speed is crucial because it control the effect of water movement which changes the surface velocity on Stepped Spillways.



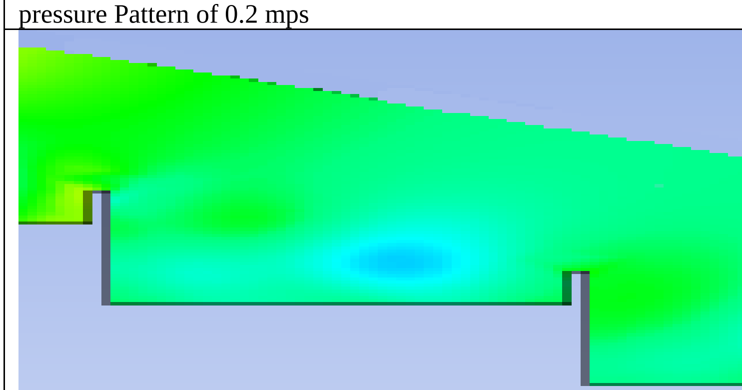
Velocity Flow Pattern of 0.2 mps

Figure 5: Velocity flow pattern of the rectangle spillway Dam simulation results,

It is observed that the maximum velocity affects in the downstream of the dam Stepped Spillway as shown in the red color of the velocity profile. This observation approved that there is a high down force in this point, the affected force component will have applied perpendicularly on the longitudinal axis of the dam Stepped Spillway section. But with the increase of water velocity, the vortex appears which will increase the drag force and that causes several aerodynamic problems. Due to boundary layer separation at the suction of the dam Stepped Spillway. It is seen that the water characteristics have been changed by the changes of water velocity; therefore, the velocity contours observe an increase in the water speed of the dam Stepped Spillway. In this case, the force will increase because there is an inverse relationship between the force and the water speed as shown in pressure plots



pressure Pattern of 0.2 mps



pressure Pattern on step

Figure 6: Pressure profile of rectangular spillway Dam simulation results

In Figure 6, compression shapes in the horizontal surfaces of the three stages are correspondingly, visible for the three flow rates. At both extreme and normal flow rates, the compression on the horizontal surface of the steps firstly reductions and then rises, and again at the edge of the step, decreases. At the lower bound of the flow rate, the upward trend observed in the previous cases occurred less so that the trend of decreasing compression distribution was roughly noticed.
The minimum pressure obtained from the simulation is a significant component of continuous compression, and the lowest average compression is wanted to evaluate the potential creation of cavitation. The pressure contours observe a rise in the head surface of the dam Stepped Spillway and reduction in the downstream surface.

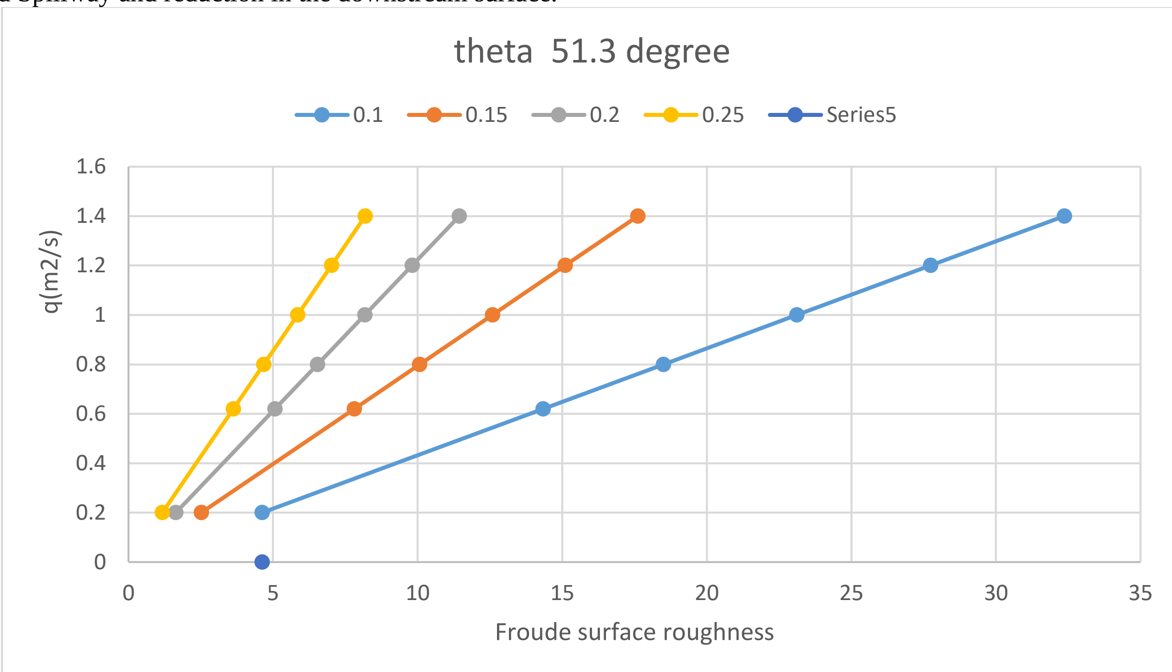


Figure 7: The relationship between Froude surface roughness and discharge with slope 51.3°

This result indicates that the resistance counter to the flow course will create a negative force which means that the force will increase because there is a positive relationship between the force and the water velocity in the dam Stepped Spillway surfaces. Based on the specific water discharge. The initial length climbs in the same number of steps as the discharge rises. The Froude surface roughness, identified by the meaning of surface roughness, increases as the number of steps increases.

($k_s = h\cos\Theta$), which is based on unit discharge (q) and step height.

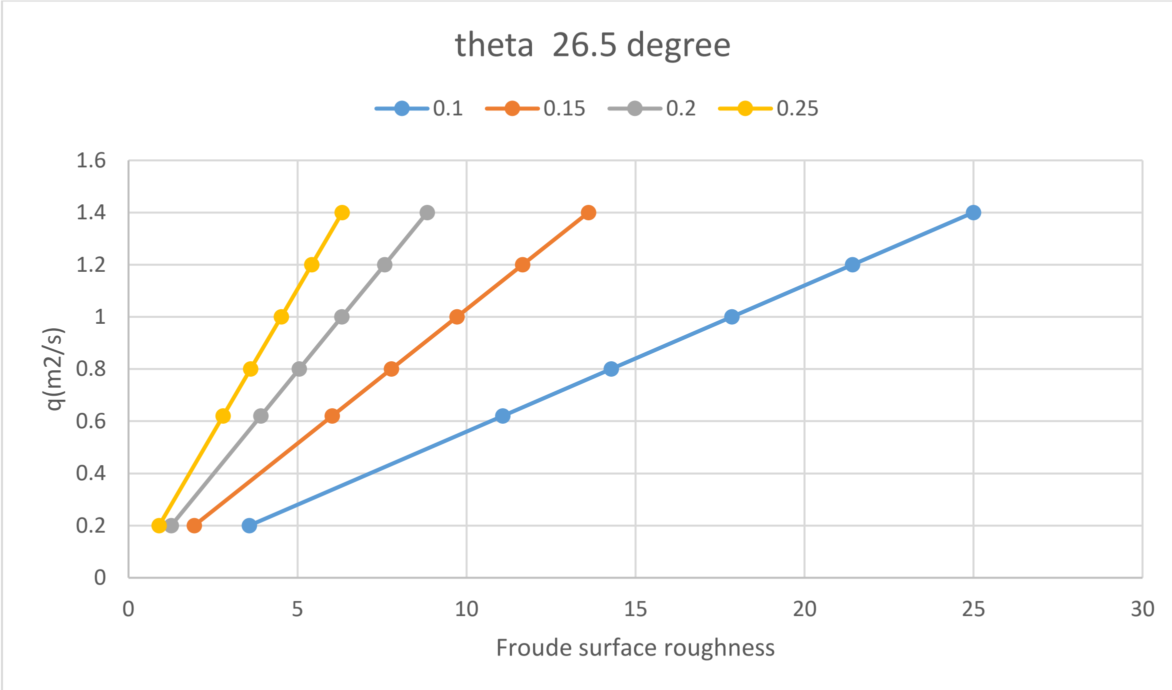


Figure 8: the relationship between Froude surface roughness and discharge with slope 26.5^o

The variation of the Froude surface roughness by taking in consideration the discharge at various step heights is displayed in Figure 7 and 8. The direction of the figure displays that it is at the highest step, the Froude surface roughness is the minimum below all circumstances of various discharges. Under the same discharge, the Froude surface. Simulated water behavior for various stepped spillway models with different slopes ranging from steep to steep slopes. The scraping flow system can be generated by increasing the flow rate of a stepped spillway. The stepped spillway's scrape flow system is dependent on the discharge as well as the height and length of the steps. The discharge value must be greater than the crucial value for all discharges to pick the scrape flow system. Li rises with critical depth in all regression channels of stepped spillways as critical depth rises. The product of the critical depth of the step height and the relative depth of flow is the relative depth of flow. The relative flow depth indicates that when the minimum channel slope values increase, the relative flow depth increases, as does the length of the unventilated flow area.

SLOP EFFECT ON INSPECTION POINT

Stepped spillways acts a significant part throughout the construction of spillway. The stepped spillway Slope is a significant consideration for detecting the beginning point position and unventilated flow region length. In this case, the starting point position determines its location upwards as the downstream slope rises, the value of the unventilated flow area decreases while the downstream slope is increased for all drains. Figures 9 to 10 demonstrate water volume fraction profiles for different states.

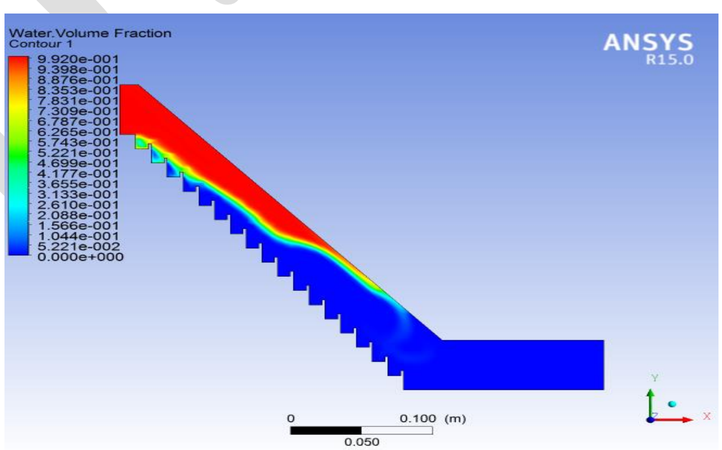


Figure 4.9: volume of fraction for case 1

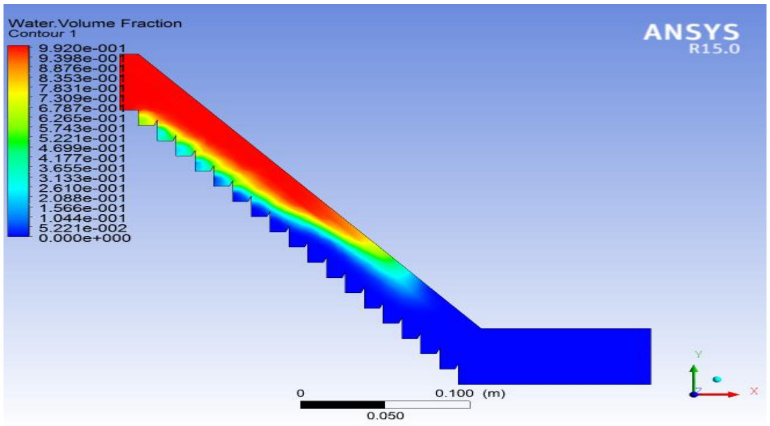


Figure 4.10: volume of fraction for case 1, vel. 2

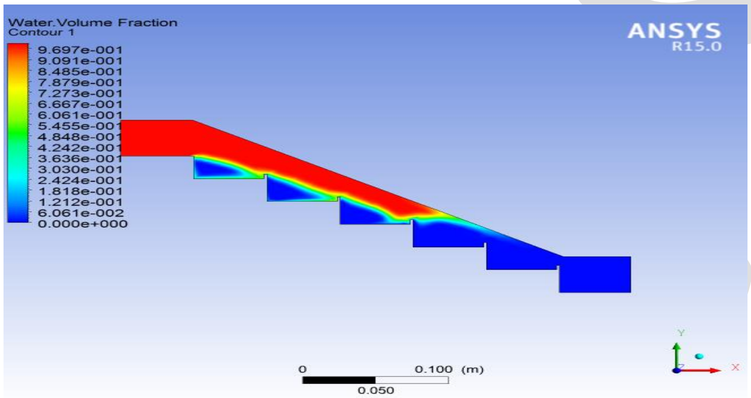


Figure 4.11: volume of fraction for case 2

It is clear from the figure that with the rise of the water flow, the distance of the starting point Li rises, with the difference of the channel slope. On the other hand, Under the same discharge value, Li drops as the pf channel slope increases. This suggests that, based on the constant discharge value, the high channel slope has a smaller non-ventilated flow area.

CONCLUSION AND RECOMMENDATION

In the present research, to explore the flow behavior and investigate the inception point position, four different stepped spillway models with variable slopes and steps are simulated utilizing velocity profile, pressure profile, and VOF using fluent ANSIS models. A skimming flow system is created by increasing the flow rate on a tiered spillway slope. The discharge, step height, and step length all play a role in the stepped spillway's skimming flow mechanism. The study's findings are used to determine the skimming flow system in all discharges; the discharge value must be greater than the critical value. Position of air entrainment (beginning point) travels down when increases the discharge rate. This result observes the importance of the spillway steps shape to generate the pressure force based on height of each step. Also, this work observed that it is feasible to improve the hydraulic behaviors of a pool configurations stepped spillway. the pools in this study present an overcome of the flow stability and energy dissipation issues.

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