PREDICTION OF ENERGY DISSIPATION OVER TRAPEZOIDAL STEPPED SPILLWAY WITH BAFFLES

A

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Submitted by

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CANDIDATE’S DECLARATION

I, Saurabh Pujari, (2K21/HFE/04) student of M.TECH (Hydraulics and Water Resources Engineering), hereby declare that the project dissertation titled as **“Prediction of Energy Dissipation over Trapezoidal Stepped Spillway with Baffles”** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled as **“Prediction of Energy Dissipation over Trapezoidal Stepped Spillway with Baffles”** which is submitted by **Saurabh Pujari**, **2K21/HFE/04** Student of **M.TECH (Hydraulics and Water Resources Engineering)**, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

The stepped spillway of a dam holds significant importance in the field of river engineering and can be utilized in diverse applications. Conducting research on flood control is imperative to examine the mechanism by which energy dissipation occurs across stepped spillways. Numerous research endeavours have been conducted in the past to investigate rectangular stepped spillways without baffles, employing diverse research methodologies. The present research was carried out on a tilting flume in order to compute the energy loss through the trapezoidal stepped spillway at various channel slopes for different baffle arrangements. Additionally, it demonstrates the application of a machine learning method, specifically Support Vector Machine (SVM), for predicting the energy dissipation in terms of nondimensional parameters. The models were constructed using laboratory datasets of an exceptionally high quality, which were gathered from both recent and earlier experiments. The experimental findings suggest that the energy dissipation rises with an increase in the number of baffles from zero to five, and is comparatively greater in channels with zero degree slope as opposed to those with one degree slope. The research has determined that the trapezoidal stepped spillway experiences a twenty percent increase in energy dissipation compared to the rectangular stepped spillway. The statistical indices developed during the experimental research are utilized to validate the suggested models and assess their efficiency and usefulness. The proposed models appear to be influenced by a diverse range of factors, including but not limited to the dimensions of the spillway in terms of width and height, the positioning of the baffle, the upstream and downstream heads, the slope of the channel, the inclination of steps, and the Froude number. A nonlinear relationship has been identified between the aforementioned factors. The results demonstrate that the SVM model proposed, which employs a quadratic kernel function, yields the most accurate predictions for energy dissipation across a trapezoidal stepped spillway. This is evidenced by its superior R^2 value and lower RMSE, MSE, and MAE values. The observed phenomenon of overtraining is not exhibited by it. The present research validates the application of machine learning methodologies in this field, and it is noteworthy for its ability to predict energy dissipation across trapezoidal stepped spillways, incorporating diverse baffle designs and configurations.

Keywords: Trapezoidal stepped spillway, Baffle arrangements, Channel slope, Statistical analysis, Support Vector Machine (SVM).

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NOMENCLATURE

E_u = Energy at upstream

E_d = Energy at downstream

E_L = Energy loss

E_T = Total energy

y_1 = upstream head

y_2 = downstream head

V_1 = Upstream velocity

V_2 = Downstream velocity

H = height of spillway

y_c = critical depth of flow

a = distance of baffle from the toe of spillway

h_b = height of baffle

w_b = width of baffle

W = width of spillway

V = velocity of flow

g = acceleration due to gravity

H_u = hydraulic depth
H/y_c = relative spillway height

a/y_2 = relative baffle distance

h_b/y_1 = relative baffle height

w_b/W = relative baffle width

F_1 = Froude number at upstream

$(E_T-E_L)/E_u$ = relative energy loss

a = actual values

p = predicted values

$\bar{a}$ = mean of actual values

$\bar{p}$ = mean of predicted values

CHAPTER 1

INTRODUCTION

1.1 General

Flooding is the natural catastrophe that occurs the most often throughout the globe, and its prevalence has been growing over the last two decades. This is because of the extremes, unpredictability, and uncertainty of the hydrological system. It is anticipated that the frequency of very severe floods would rise as a result of climate change. As a result of population increase, the development of catchment areas, and climate change, intense rainfall events will result in significant flooding. This will result in catastrophic breakdowns of essential infrastructure, which will inevitably lead to losses of life as well as expenses connected with damage. This presents an ever-greater risk to the welfare of society. Dams have to be constructed in such a manner as to avoid these losses, and in the case of a significant flood, the dam ought to be outfitted with a spillway system that allows for the outflow of surplus flood water. The usage of a structure known as a spillway allows for the managed discharge of flows from a dam into an area farther downstream. This is achieved by directing the flow of water. A spillway with a capacity that is far higher than what is necessary, on the other hand, would not be an economically viable design. In addition to having sufficient capacity for discharge, the spillway has to be safe from both a hydrodynamic and structural point of view. Because of the tremendous velocities that are created as water falls from the top of the reservoir to the tail water below, the surface of the spillway should be resistant to erosion. This will allow it to withstand the force of the falling water. In order to assist in the dissipation of any excess energy, baffles or buckets, which are often designed to disperse energy, are typically installed at the base of the control structure. This is done in order to ensure that the control structure is able to fulfil its function in the most efficient manner possible.

1.2 Types of spillways

The following different types of spillways are employed for operating dams:

Ogee Spillway: An ogee spillway is a type of hydraulic structure commonly used in dams and reservoirs to release excess water and prevent damage to the dam. It is a curved spillway designed to smoothly transition the water from the dam to the downstream environment, dissipate the energy of the flowing water, and prevent erosion downstream. The ogee spillway gets its name from the shape of the curve, which resembles an "S" or "C" shape. The spillway is usually constructed with concrete or steel and may be lined with abrasion-resistant materials to withstand the erosive effects of high-velocity water. When water flows over an ogee spillway, it enters the curved section and begins to accelerate due to gravity. As the water flows down the curved surface, it begins to create a hydraulic jump, which is a turbulent zone of water that helps to dissipate the kinetic energy of the flowing water. The energy dissipation and turbulence created by the hydraulic jump prevent damage to the downstream environment and help to prevent erosion. The design of an ogee spillway can vary depending on the specific requirements of the dam or reservoir, the expected flow rates, and the characteristics of the downstream environment. Factors such as the height and length of the spillway, the curvature of the curve, and the presence of other structures, such as stilling basins, can all affect the design of an ogee spillway. Proper maintenance and monitoring of ogee spillways are also critical to ensure their safe and efficient operation. Regular inspections and repairs can help to identify any potential issues before they become a problem and ensure that the spillway is functioning properly.

Chute Spillway: A chute spillway is a type of hydraulic structure used to safely release water from a dam or reservoir. It is typically a steep channel or chute that is designed to dissipate the kinetic energy of flowing water, reduce the velocity of the water, and prevent damage to the downstream environment. Chute spillways are usually constructed with concrete or steel and are often lined with abrasion-resistant materials to withstand the erosive effects of high-velocity water. The design of a chute spillway can vary depending on the specific requirements of the dam or reservoir and the expected flow rates. When water flows over a chute spillway, it enters the steep channel and accelerates due to gravity. The steep slope of the chute helps to dissipate the kinetic energy of the water, and the turbulence created by the flowing water further reduces its velocity. The water then flows out of the end of the chute and into a stilling basin, where any remaining kinetic energy is dissipated and the water is allowed to flow out into the downstream environment at a safe velocity. Chute spillways are often used in conjunction with other types of spillways, such as overflow spillways or gated spillways, to provide multiple means of releasing water from a dam or reservoir. The design of a chute spillway must take into account the expected flow rates, the downstream environment, and the potential for erosion or other types of damage. Proper maintenance and monitoring of chute spillways are also critical to ensure their safe and efficient operation.

Side Channel Spillway: A form of hydraulic construction known as a side channel spillway is used to release water from a dam or reservoir in a controlled and safe manner. This is accomplished by redirecting some of the flow of water to a secondary channel that goes around the main structure of the dam. It is also known as an auxiliary spillway or emergency spillway and is designed to handle excess water in case the primary spillway becomes overwhelmed. A side channel spillway typically consists of a channel or chute that is constructed adjacent to the main dam structure. When water levels in the reservoir rise above a certain level, the excess water is diverted into the side channel, where it is allowed to flow downstream at a controlled rate. The side channel may also contain structures such as gates or weirs to help regulate the flow of water. The design of a side channel spillway must take into account the expected flow rates, the downstream environment, and the potential for erosion or other types of damage. Proper maintenance and monitoring of side channel spillways are also critical to ensure their safe and efficient operation. Side channel spillways are often used in conjunction with other types of spillways, such as overflow spillways or gated spillways, to provide multiple means of releasing water from a dam or reservoir. The use of a side channel spillway can help to prevent overtopping of the main dam structure, which can lead to catastrophic failure and loss of life downstream.

Stepped Spillway: The safe discharge of surplus water from a dam or reservoir is accomplished with the help of a form of hydraulic construction known as a stepped spillway. Before the water reaches the environment farther downstream, it passes through a series of steps that are intended to slow it down, so reducing the amount of kinetic energy that it carries with it. The stepped spillway consists of a series of steps, or pools, that gradually decrease in elevation. The pools are usually constructed with concrete and may be lined with abrasion-resistant materials to withstand the erosive effects of high-velocity water. The design of a stepped spillway can vary depending on the specific requirements of the dam or reservoir, the expected flow rates, and the characteristics of the downstream environment. When water flows over a stepped spillway, it enters the first pool and begins to accelerate due to gravity. As the water flows over the step, it creates a hydraulic jump, which is a turbulent zone of water that helps to dissipate the kinetic energy of the flowing water. The energy dissipation and turbulence created by the hydraulic jump prevent damage to the downstream environment and help to prevent erosion. The water then flows into the next pool and continues the process until it reaches the end of the spillway. The gradual decrease in elevation and the presence of the hydraulic jumps help to reduce the velocity of the water and prevent damage to the downstream environment. Stepped spillways are often used in conjunction with other types of spillways, such as ogee spillways or gated spillways, to provide multiple means of releasing water from a dam or reservoir. The design of a stepped spillway must take into account the expected flow rates, the downstream environment, and the potential for erosion or other types of damage. Proper maintenance and monitoring of stepped spillways are also critical to ensure their safe and efficient operation.

1.3 Energy dissipation

In hydraulics, energy dissipation refers to the process of reducing the kinetic energy of flowing water by converting it into another form of energy, such as heat, sound, or potential energy. This is important because high-velocity water can cause significant damage to hydraulic structures and the environment downstream. When water flows through a hydraulic structure, such as a spillway or weir, it possesses kinetic energy due to its velocity. If the water is not slowed down before it reaches the downstream area, it can cause erosion, cavitation, or other types of damage to the hydraulic structure or the environment. Energy dissipation is used to reduce the velocity of water, typically through the use of various hydraulic structures or devices, such as hydraulic jumps, stilling basins, or deflectors. The goal of energy dissipation is to safely and efficiently reduce the velocity of water so that it can be safely discharged into the downstream environment without causing damage. This is achieved by converting the kinetic energy of the water into other forms of energy, such as turbulence or potential energy. Proper design and implementation of energy dissipation techniques are critical for the safe and effective operation of hydraulic structures. Energy dissipation is a crucial aspect in the design and operation of hydraulic structures, such as dams, spillways, weirs, and channels. When water flows through these structures, it possesses kinetic energy due to its velocity. If this kinetic energy is not dissipated, it can cause significant damage to the hydraulic structure and the environment downstream. Energy dissipation is important in hydraulic structures for the following reasons:

- Protecting the structure: As water flows through a hydraulic structure, its velocity decreases due to the presence of obstacles such as gates, weirs, or other control structures. If the water is not sufficiently slowed down, it can cause erosion or cavitation, which can lead to damage to the structure. Energy dissipation helps to reduce the water velocity and minimize the impact of the water on the structure.
- Protecting the environment: The high-velocity water leaving a hydraulic structure can cause significant erosion downstream and damage the environment. Energy dissipation reduces the water velocity and helps to mitigate these impacts, protecting the ecosystem downstream.
- Reducing noise: High-velocity water can create a significant amount of noise, which can be a nuisance to nearby residents. Energy dissipation can help to reduce the water velocity and the associated noise.

There are various techniques for energy dissipation, such as hydraulic jump, stilling basins, and deflectors, which are designed to dissipate the kinetic energy of water and protect the hydraulic structure and the environment downstream. Proper design and implementation of these techniques are critical for the safe and efficient operation of hydraulic structures. The primary effects of energy dissipation are:

- Velocity reduction: Energy dissipation is used to reduce the velocity of flowing water, which helps to protect hydraulic structures from damage due to high-velocity impacts. This also reduces the potential for erosion and other environmental impacts downstream.
- Turbulence: Energy dissipation often results in the formation of turbulent flow patterns, which help to further dissipate the kinetic energy of water. Turbulence also helps to mix water with air, which can increase the oxygen levels in the water and improve the health of aquatic ecosystems.
- Heat generation: When water flows through hydraulic structures, some of the kinetic energy is converted into heat energy due to friction and turbulence. Energy dissipation devices such as hydraulic jumps and stilling basins can generate significant amounts of heat, which can be a concern in certain situations, such as when the water is used for cooling purposes.

- Noise reduction: High-velocity water can be very noisy, and energy dissipation techniques can help to reduce the amount of noise generated by flowing water.
- Sedimentation: Energy dissipation can also lead to the settling of sediment in the water, which can be beneficial in certain situations. For example, sedimentation can help to reduce erosion downstream of hydraulic structures and create new habitats for aquatic organisms.

1.4 Objectives of the study

The objectives of the present study, which focuses on prediction of energy dissipation over a trapezoidal stepped spillway with baffles, are the following:

- To determine the energy dissipation over trapezoidal stepped spillway with different baffle arrangements and channel slopes.
- To compare the energy dissipation over trapezoidal to rectangular stepped spillway.
- To predict the energy dissipation over stepped spillway using support vector machines.

1.5 Organization of the thesis

The project work is organized in five different chapters whose content are summarized below:

Chapter 1 is an introductory chapter which describes the motivation behind the work, objectives and scope of the project.

Chapter 2 is and introducing the existing literature for the energy dissipation over the spillways.

Chapter 3 deals with the methodology used in the study.

Chapter 4 deals with the results and discussions of the study.

Chapter 5 is concluding chapter in which conclusions are discussed.

1.6 Scope of the work

The current study may either be used as a foundation for a new study or as a supporting document for more research aimed at identifying the many factors. It is possible to get started on the following research so that they may give a broad range of applicability in the area of energy dissipation across the spillways.

- The study can be done using different shapes of baffles to determine the effect on energy dissipation.
- Effect of shape of steps of spillways can be studied to quantify the effect of energy dissipation over different types of spillways.
- Future research may focus on the impact of spillway dimensions on energy dissipation over stepped spillways.

CHAPTER 2

REVIEW OF LITERATURE

2.1 General

Energy dissipation through spillways is an important aspect of dam design and operation, as it is necessary to ensure that the water flowing out of the dam does not cause erosion or other damage downstream. A review of the literature reveals that there are several approaches to designing spillways that minimize energy dissipation and mitigate the associated risks. Hydraulic jumps occur when the water flowing out of the spillway hits a pool of water below, causing a sudden increase in depth and a decrease in velocity. This sudden change in flow conditions causes turbulence and energy dissipation, which can help to reduce the erosive potential of the water. Stilling basins are large pools of water that are designed to slow down the velocity of the water flowing out of the spillway, allowing it to dissipate energy gradually. Stilling basins can be designed using various configurations, such as stepped, sloping, or flat-bottomed, to optimize energy dissipation and minimize erosion. There are other approaches to energy dissipation, such as the use of vortex dissipators, impact blocks, and baffle blocks. Vortex dissipators work by creating a vortex in the water flow, which causes turbulence and energy dissipation. Impact blocks and baffle blocks work by disrupting the flow of water and creating turbulence, which also leads to energy dissipation. There are numerous approaches to designing spillways that minimize energy dissipation and mitigate the associated risks. Each approach has its advantages and disadvantages, and the choice of approach will depend on a range of factors, such as the type of dam, the expected flow rates, and the available budget. Therefore, careful consideration must be given to the design of spillways to ensure that they provide adequate energy dissipation and minimize the potential for damage downstream.

2.2 Literature review

Peyras et al. (1992) shows one-fifth-scale model testing of high standard prototypes with established quantified energy-dissipation requirements and efficient stilling-basin design guidelines, saving 10–30% on basin length in comparison to existing approaches. These experiments were conducted on high-quality prototypes. In addition to this, an examination and description of the many forms of flow that may occur over a stepped face are provided. These include skimming flow, isolated nappe flow, and partial nappe flow. If the placement of the gabions is done in strict accordance with the code of practice, stepped gabion spillways are able to sustain flows of up to 3 cumec without suffering significant damage from a purely technical standpoint.

Chanson (1993) conducts a comprehensive analysis of contemporary advancements in the design of stepped spillways. Additionally, he deliberates on the implications of air entrainment and introduces novel computation techniques that incorporate the impact of flow aeration on flow attributes and energy dissipation rates. The implementation of the aforementioned measures results in a noteworthy augmentation of the energy dissipation rate transpiring on the spillway facade, while concurrently diminishing the dimensions of the downstream energy dissipation reservoir that is necessary. The utilization of stepped spillways in conjunction with roller compacted concrete and gabion construction methodologies yields a cost-effective solution for the construction of spillways.

Chanson (1996) conducted a study on stepped channels, wherein two distinct flow regimes were observed. The first regime was characterized by nappe flow, which occurred under conditions of low discharges and flat slopes. The second regime, on the other hand, was characterized by skimming flow, which occurred under conditions of larger flow rates. The present study introduces a straightforward analytical approach for forecasting the initiation of skimming flow. The methodology is founded on the alteration of momentum orientation during the collision of the jet with the subsequent step in the flow. The initiation of skimming flow can be characterized by the primary variables of the initial Froude number and the angle of the jet. The extrapolation of the findings permits the anticipation of the initiation of skimming flow, and consequently, the potential for jet deflection at the foremost upstream stage.

Chatila and Jurdi (2004) pertain to an experimental inquiry on the hydraulic characteristics of stepped spillways with ogee-profile. The research aims to assess the feasibility of these spillways as a substitute for smooth-back spillways and to evaluate their effectiveness in mitigating the downstream energy and length of the hydraulic jump. A single, continuous model was utilized as a reference point to evaluate and contrast against stepped models that were constructed by combining crests and bottoms of varying step heights. The experimental results indicate noteworthy decreases in both terminal velocities and total energies. The tested stepped spillway profiles demonstrated high efficacy in terms of energy dissipation for flows at or below the design head. The stepped spillway configuration experienced a decrease in effectiveness for flows exceeding the design head, with negligible impact observed for heads surpassing one and a half times the design head. The study determined that the predominant factor in the dissipation of flow kinetic energy and consequent reduction in the length of the downstream hydraulic jump is the quantity of steps taken.

Boes and Hager (2005) utilized fiber-optical instrumentation to examine a large model flume in their experimental investigation. Their findings suggest that the initiation of skimming flow is dependent on critical depth, chute angle, and step height. The formula for determining the required length of a spillway to achieve uniform flow is dependent on both the critical depth and the angle of the chute. Stepped spillways exhibit a considerably greater flow resistance in comparison to smooth chutes, primarily due to the presence of macro roughness caused by the steps. The friction factor pertaining to uniform aerated flow exhibits an approximate magnitude of 0.1 in relation to typical slopes of gravity dams and embankment dams. Conversely, the impact of relative roughness is relatively negligible.

Tabbara and colleagues (2005) conducted numerical simulations to investigate the water flow characteristics over stepped spillways featuring diverse step configurations. The ADINA software's finite element computational fluid dynamics module was utilized to forecast the primary attributes of the fluid flow. The tasks encompassed the computation of the water surface, the analysis of skimming flow over corner vortices, and the quantification of energy dissipation. The k-epsilon flow model was employed due to the turbulent nature of the flow in question. A biphasic solution methodology was implemented to enhance the overall computational efficacy of the simulation. During the initial phase, a basic and rational water surface comprising of three linear segments was employed as an initial approximation and was regarded as an immovable barrier. During the second phase, the initial conditions obtained from the first phase were utilized, and the water surface was regarded as a free surface that underwent evolution until it achieved a stable state configuration. The water surface profile predicted for all cases examined exhibited a high degree of concurrence with the experimentally measured water surface profile along the entire length of the spillway. The anticipated dissipation of energy was found to be similar to the values obtained through experimentation.

Qian et al. (2009) utilized a mixture multiphase flow model to conduct a numerical simulation of water flow over a stepped spillway. Various turbulence models are selected to encompass the governing equations. The present study examines various turbulence models, including the realizable k-ε model, SST k-ω model, v2 -f model, and LES model. The present study conducts a comparative analysis between the computational outcomes of four turbulence models and experimental data in terms of mean velocity, spanwise vorticity, and the growth of the turbulent boundary layer thickness in the streamwise direction. The comparative analysis reveals that the k-ε model with the incorporation of the rotation tensor, known as the realizable k-ε model, exhibits commendable efficacy in simulating flows that entail rotation, boundary layer, and recirculation. The k-ε model that is realizable has been found to be the most effective in the simulation of flow over stepped spillways.

Shahheydari et al. (2015) involved an examination of the flow over a stepped spillway through the utilization of Flow3D software as an analytical flow field. The turbulence model employed in this study was the RNG k-ε model, while the free surface flow profiles were determined using the Volume of Fluid (VOF) model. In the initial phase, the model underwent validation through dependable empirical evidence. Subsequently, in an effort to examine the diverse characteristics of the skimming flow regime, a total of 112 numerical spillway models were developed. Of these models, 96 were designed as stepped spillway models while the remaining 16 models were constructed as smooth spillway models, specifically utilizing the WES profile. The findings suggest an inverse correlation between the discharge coefficient rate and energy dissipation rate. It was observed that an increase in relative discharges resulted in a decrease in energy dissipation rate and an increase in discharge coefficient rate.

Schleiss and Chanson (2015) conducted experiments on three gabion stepped weirs, both with and without capping, in addition to a flat impervious stepped configuration. Systematic air-water flow measurements were conducted in detail for a variety of discharges for each configuration. The empirical findings have brought to the fore the phenomenon of seepage flow across the gabion structures and the interplay between seepage and overflow. The analysis of air-water flow characteristics revealed that the gabion stepped weir exhibited lower numerical values for air concentration, bubble count rate, and specific interface data in comparison to the impervious stepped chute. However, higher velocities were observed at the downstream section of the gabion stepped chute. The rate of re-oxygenation was determined by integrating the mass transfer equation, taking into account measurements of the air-water interfacial area and velocity. The gabion stepped weir exhibited inferior aeration capabilities compared to the flat impervious stepped chute, albeit solely for the minimum discharge. The flow properties of the two configurations that implemented step capping were found to be similar to those observed in the impervious stepped configuration.

Tabari and Tavakoli (2016) aimed to examine the impact of various parameters, including the number of steps (N_s), step height (h), step length (L), and discharge in width unit (q), on energy dissipation in a simple stepped spillway. The researchers utilized the Flow-3D model to investigate the correlation between energy dissipation and flow critical depth in the stepped spillway. The extant equations were solved using the finite volume method, and the K-ε model was utilized to examine flow turbulence. The findings indicate that an increase in flow discharge is associated with a decrease in energy dissipation. Similarly, a decrease in energy dissipation is observed with an increase in the number of steps and a decrease in their height.

Reddy and colleagues (2017) investigated the characteristics of unsteady magnetohydrodynamic natural convection, heat transfer, and electrically conductive non-Newtonian Casson fluid on an oscillating vertical porous plate, while taking into account the effects of viscous dissipation. The present study utilizes a computational Finite Element Method (FEM) that is highly efficient in solving non-dimensional partial differential equations governing the boundary layer phenomena. The equations pertain to the distribution of velocity and temperature, and incorporate the effects of emerging dimensionless parameters. Furthermore, the coefficients for local skin-friction and local Nusselt number are acquired and scrutinized via graphical and tabular representations. The findings indicate that an increase in the Eckert number results in a corresponding increase in both velocity and temperature distribution, while simultaneously causing a decrease in the coefficients of local Skin-friction and Nusselt number. An escalation in the Casson parameter results in a reduction of the velocity distribution and the local skin-friction coefficient. The current findings were juxtaposed with previously documented investigations on the analytical solutions of fluid flow problems involving both Newtonian and non-Newtonian fluids. The present findings exhibit a high degree of concurrence with previously established outcomes.

Mero and Mitchell (2017) executed a sequence of trials within a controlled laboratory environment utilizing a stepped spillway model featuring a moderate slope. The study examined flow patterns by utilizing various step configurations, such as uniform horizontal steps with a 5 cm height, as well as inclined and horizontally curved steps with and without reflector blocks. A comparative analysis was conducted to evaluate the energy losses incurred over a horizontal stepped spillway. The study involved a comparison of the obtained results with those of previous studies of a similar nature, as well as with the outcomes of the new step configurations. The findings indicate a high level of concurrence with prior research regarding the horizontal steps. Moreover, the energy dissipation of the inclined and horizontal curved steps was approximately twice that of the horizontal steps. The findings underscore the significance of incorporating diverse step configurations in the design of spillways in situations where flow rates are uncertain and dissipation of energy is a crucial factor.

Aminpour and Farhoudi (2017) reports findings from 67 experiments conducted on stepped spillways at two distinct scales. The purpose of the experiments was to investigate the phenomenon of local scour that occurs downstream of the structure. The experimental design encompassed a diverse set of geometrical parameters, flow dynamics, and sediment attributes. The experiments were conducted for a duration ranging from 6 to 24 hours, resulting in over 80000 data points for analytical purposes. The outcomes were utilized to formulate regression equations that establish the likeness between the scour hole profile and its geometric properties. It was noted that achieving an equilibrium state would necessitate a prolonged period of observation. However, semi-equilibrium conditions will be attained after a period of approximately 24 hours. It was observed that the depth of the scour hole near the channel walls was greater compared to that of the centerline. It was ultimately determined that the utilization of a stepped spillway induces energy dissipation ranging from 42.06% to 74.82%, thereby leading to the formation of a scour hole with a lesser depth in comparison to that of ogee spillways.

Mansoori et al. (2017) pertained to the dissipation of energy in a particular category of stepped spillways. The objective was to attain optimal energy dissipation downstream of the spillway. The procedure entailed utilizing a particular form of geometry for the step, which resulted in a significant increase in surface roughness. Steps were identified as a significant impediment to the smooth flow of fluid. The shape and quantity of the aforementioned objects were intentionally configured to minimize the amount of flow energy in this particular phase, specifically prior to reaching the downstream area. Thus, it can be asserted that the structure located downstream will exhibit the greatest energy dissipation rate. Furthermore, the implementation of a stilling basin in a project can lead to a reduction in the associated expenses related to its design and construction. The present investigation utilized FLOW-3D software to analyze and acquire data on energy dissipation rate. To clarify, it was observed that the optimal state was achieved through implementation of a Λ-shaped step at an angle of 25 degrees in relation to the energy dissipation rate, as opposed to a smooth step.

Li et al. (2018) examined eight distinct configurations of stepped spillways featuring slopes of 45° by the numerical investigation. The configurations characterized by rounded and sharp shapes demonstrated the highest and second highest concentrations of air, respectively. The configuration characterized by baffled shifting and rounding exhibited the least air concentration, but the highest rates of turbulent dissipation and water head dissipation. The configuration with a rounded shape exhibited the highest interfacial velocities and the lowest frictional drag. The rounded configuration exhibited a higher turbulent dissipation rate compared to the sharped configuration. The configuration with a shifted and sharpened sill exhibited the least turbulent dissipation rate. The mixing layer and interfacial region exhibited high levels of turbulent dissipation rates, accompanied by air concentrations of 90%. The baffled-shifted rounded configuration exhibited residual energy levels that were approximately 8% and 13% lower than those observed for the rounded and sharped configurations, respectively. The baffled-shifted sharped configuration exhibited a positive correlation with the residual energy, whereby the highest residual energy was observed in conjunction with the lowest turbulent dissipation rate.

Hekmatzadeh et al. (2018) aims to assess various Reynolds-averaged Navier-Stokes (RANS) turbulence models in simulating hydraulic flow on diverse designs of low gradient stepped spillways, which include non-uniform stepped spillway, pooled stepped spillway, and alternate flat and pooled stepped spillway. The present study conducted a simulation of flow over a stepped spillway featuring a novel combination of flat and pooled steps, representing a first-time endeavor in this particular context. The study revealed that among all geometries, the alternate flat and pooled stepped slipway exhibited the highest energy dissipation rate, indicating its potential as an exceptional dissipater. There was a common assumption that a stepped spillway with pooled steps dissipated a greater amount of energy compared to a flat stepped spillway, due to the presence of the pooled steps. The findings of the study suggest that in cases where the spillway slope exceeds 14 degrees, the flat stepped spillway exhibits superior effectiveness in terms of energy dissipation as compared to the pooled stepped spillway.

Reeve et al. (2019) employed a computational model to examine the flow characteristics of gabion stepped spillways. The validation of the model was initially conducted by comparing it against experimental findings that have been previously published. Subsequently, gabion stepped spillways featuring four distinct step geometries were subjected to identical testing conditions to enable cross-comparisons and determine the optimal choice with regards to energy dissipation. The findings indicate that conventional gabion steps exhibit a higher capacity for energy dissipation in comparison to overlap, inclined, and pooled steps. A comprehensive battery of tests was conducted, encompassing a range of slope gradients, stone dimensions, and levels of porosity. The present study has developed two novel empirical equations through the application of regression analysis, aimed at enhancing the performance of gabion stepped spillways.

Ashoor and Riazi (2019) conducted a numerical investigation on non-uniform stepped spillways with the objective of achieving maximum energy dissipation. In order to achieve this objective, a series of experiments were conducted in InterFOAM, wherein four distinct categories of non-uniform step lengths, namely convex, concave, random, and semi-uniform configurations, were examined within the skimming flow range. The findings of the study demonstrate that in semi-uniform stepped spillways, a vortex interference region arises within the two adjacent cavities of the entire stepped chute when the ratio between the lengths of the successive steps is 1:3. This leads to a notable increase in energy dissipation, up to 20%.

Li et al. (2020) investigated the hydraulic properties through the implementation of numerical simulations. The two-phase Mixture Model is employed in conjunction with the realizable k-ε turbulence model. The findings suggest that spillways with rounded steps exhibit greater air concentrations compared to those with trapezoidal steps. However, the aeration performance with cavity blockages does not appear to be influenced by the roughness density and cavity shape. The trapezoidal steps layout exhibits a greater characteristic air water velocity in comparison to the rounded steps layout. Nevertheless, it is noteworthy that both layouts lack sensitivity to the density of roughness. The velocity outcomes for the cases of trapezoidal cavity and rounded cavity exhibit a near lack of dependence on the roughness density. The velocity in all cases, except for those involving trapezoidal steps, exhibits a positive correlation with an increase in roughness density. Furthermore, the correlation between energy loss and roughness density as well as step edge/cavity shape remains unclear.

Eghlidi et al. (2020) investigated the impact of the slope of the stilling basin on bed scouring downstream of the Javeh dam. A series of experiments were conducted at the hydraulic structure's laboratory of the University of Kerman, involving six distinct discharges and five varying stilling basin slopes. The findings indicate that at a stilling basin slope of 0.02, there was a 47% increase in the average of maximum relative scour depth, while at −0.02, there was a 52.2% decrease. Furthermore, it was observed that the maximum scour depth distance from the stilling basin was positively correlated with an increase in the slope of the stilling basin, while a decrease in the slope of the stilling basin resulted in a decrease in the maximum scour depth distance.

Arjenaki and Sanayei (2020) conducted a study on the impact of utilizing five distinct staircases with novel and varied geometries, in contrast to prior research, with regards to the dissipation of energy. The simulation was executed utilizing the Flow 3D software and the RNG turbulence model. The calibration process utilized two turbulence models, namely the RNG and k-ε models. The RNG model was found to yield superior outcomes compared to the k-ε model. The simulation outcomes were juxtaposed with the empirical model outcomes, revealing RMSE error indices of 0.035, 0.014, 0.021, 0.032, and 0.031 for type A-E spillways, respectively. Subsequent to this stage, in order to enhance the experimental model, obstructions were installed on the type D spillway, which was deemed the most effective experimental model for the dissipation of energy. The numerical simulation outcomes indicate that the inclusion of said barriers results in a 15% increase in energy dissipation.

Ghaderi et al. (2020) introduced a spillway design featuring Trapezoidal Labyrinth Shaped steps (TLS) and conducted a numerical investigation thereof. The findings indicate that the spillway's efficacy improves with an increase in the magnification ratio. The study indicates that TLS stepped spillways exhibit superior performance in terms of energy dissipation for magnification ratios of 1.25, 1.45, 1.65, and 1.85, as compared to conventional stepped spillways. The improvement in energy dissipation is observed to be 5.6%, 8.5%, 12.6%, and 17%, respectively. The TLS stepped spillway exhibits a reduced residual head and an increased friction factor. The friction factor exhibits variability ranging from 0.79 to 1.33 across diverse magnification ratios, whereas the corresponding value for the flat stepped spillway is approximately 0.66.

Ikinciogullari (2021) utilized numerical methods to investigate the energy dissipation capabilities of trapezoidal stepped spillways. The Flow3D software was employed for this purpose. This study employed four distinct models and three distinct discharges for the purpose of achieving its objectives. Based on the findings, it can be concluded that the trapezoidal stepped spillway exhibits greater efficacy, by up to 30%, in terms of energy dissipation when compared to conventional stepped spillways. The energy dissipation rate of the trapezoidal stepped spillway was found to be significantly impacted by the depth of the trapezoidal step and the length of the bottom base of the trapezoid.

Ghaderi et al. (2021) utilized numerical simulations to investigate the impact of geometric attributes of pooled steps on energy dissipation efficacy, flow pattern characteristics, velocity rates, and pressure distributions across a spillway. The evaluation of the inception point of air entrainment was also conducted, which is a crucial design parameter for spillways. Various step configurations were considered to achieve this objective, such as flat, pooled, and notch-pooled designs. The computational methodology was initially verified using empirical data from prior research and subsequently employed to evaluate the hydraulic performance resulting from diverse geometrical arrangements. Among the various configurations, the flat step configuration exhibited superior performance in terms of energy dissipation. The implementation of the notched pooled step configuration resulted in a 5.8% enhancement in the efficiency performance of the pooled structure. The flat stepped spillway exhibited lower interfacial velocities in comparison to the pooled structure.

Nasralla (2021) conducted study by utilized an experimental approach to examine the stepped spillway. The spillway consisted of four steps, each with a height of 32 cm and a width of 54 cm. Additionally, the width of the wing wall was contracted by 0.2 from the width of the flume. A total of eighteen experimental runs were conducted to investigate the impact of varying positions, heights, and widths of the baffle on the energy dissipation efficiency of the contraction stepped spillway. The findings of the study revealed that the optimal location of baffles was at 1.4, with a relative height of 0.95 and relative widths of 0.68. This was in contrast to the scenarios of a contraction stepped spillway that lacked baffles. The findings indicate that the baffles installed on the stilling basin located downstream of the stepped spillway lead to an augmentation in the dissipation of energy.

Salmasi and Abraham (2022) examined a series of nine physical models of stepped spillways, featuring slopes of 15, 25, and 45 degrees, and a range of step quantities from 5 to 50. The spillway crests are designed with Ogee profiles that conform to standard specifications. A uniform slope is maintained from the crest to the spillway toe. The study revealed that the Froude number and q2 /(gHdam3) are the two primary dimensionless parameters that significantly impact energy dissipation. The rate of energy dissipation is minimally affected by the slope of the spillway and the number of steps present. In the case of a uniform discharge over a stepped spillway, it has been observed that augmenting the spillway slope and the number of steps results in a higher degree of energy dissipation.

Ikinciogullari (2023) constructed the Circular Stepped Spillway (CSS), subjected to numerical investigation. A comparative analysis has been conducted to evaluate the energy dissipation rate between the CSS and the flat stepped spillway, utilizing three distinct models and discharges. Based on the results of the simulation, it can be inferred that the performance of the CSS improves with decreasing step radius. The CSS models featuring step depths of 0.50, 1.50, and 2.50 cm have demonstrated a respective increase in energy dissipation of 21.4%, 38%, and 50.7% in comparison to the flat stepped spillway.

CHAPTER 3

METHODOLOGY

3.1 Experimental setup

The experiments were carried out at the Hydraulics laboratory of Delhi Technological University. The tests were performed in a rectangular tilting flume of 8 m long, 0.30 m wide and 0.40 m deep which has a facility to make it horizontal and sloping as well (shown in figure 3.1). The flume consists of an inlet section, an outlet section, a collecting tank at downstream end which is used to measure the discharge. Figure 3.2 depicts the model of rectangular stepped spillway with three and five baffle arrangements prepared using acrylic sheet having a of width of 0.30 m, a height of 0.20 m and a base length of 0.40 m. Total four steps were designed with a step height of 0.05 m, the step length is 0.10 m and rectangular shaped baffles of length 0.10 m, and height of 0.05 m were arranged in different manner. Figure 3.3 and 3.4 represents the geometric dimensions and different arrangements of baffles in trapezoidal stepped spillway. At first, the experiment was conducted for no baffle condition. Thereafter the experiment was conducted for the first arrangement of three baffles, in which two baffles were placed at a distance of 0.10 m from the toe of the spillway and a distance of 0.10 m was maintained between the first two baffles and the third baffle was placed between the first two baffle at a distance of 0.20 m from the toe of the spillway. After that the experiment was conducted for the third arrangement of baffle which consists of five baffle, two more baffle were introduced at a distance 0.30 m from the toe of the spillway and a distance of 0.10 m was maintained between them. Similarly, the same procedure has been adopted for the analysis of trapezoidal stepped spillway having dimensions as 0.20 m height, 0.30 m width, 4 number of steps and these steps are inclined at an angle of 45°. The baffles used in the experiment were of rectangular shaped which had a height of 0.05 m and length of 0.10 m. The experiments were conducted for five different discharges 2 l/s, 4 l/s, 6 l/s, 8 l/s and 10 l/s. For the purpose of determining the head values both upstream and downstream of the spillway model, a point gauge with a precision of 0.1 mm was used. In order to determine the average velocities of the upstream and downstream portions, respectively, a pitot static tube was used in conjunction with a digital manometer.

Figure 3.1. Rectangular tilting flume

(a) (b)

Figure 3.2. Rectangular stepped spillway with (a) three baffle arrangement (b) five baffle arrangement

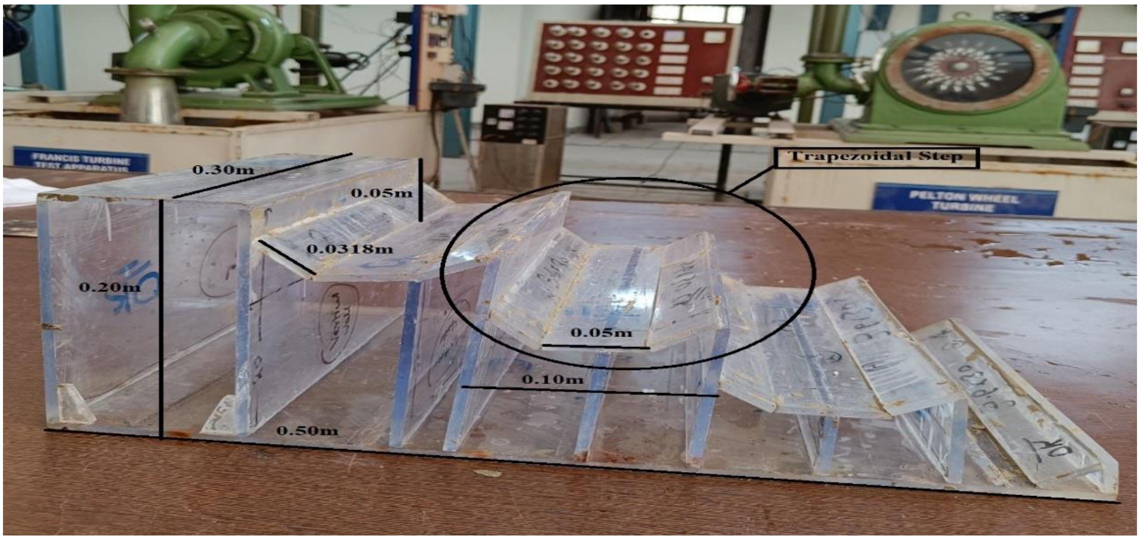


Figure 3.3. Dimensions of trapezoidal stepped spillway

Figure 3.4. Arrangements of baffles in trapezoidal stepped spillway

3.2 Computation of energy dissipation

Nasralla (2021) proposed an empirical equation (3.1) using multivariate regression analysis to predict the relative energy over rectangular stepped spillway in terms of nondimensional parameters like spillway relative height, relative baffle location, relative baffle height, relative baffle width and Froude number. The energy dissipation over rectangular stepped spillway is calculated using the equations 3.2 to 3.4.

$$\frac{E_T-E_L}{E_u} = -0.099 + 0.085F_1 - 0.022\left(\frac{a}{y_2}\right) + 0.047\left(\frac{h_b}{y_1}\right) - 0.051\left(\frac{w_b}{W}\right) \qquad (3.1)$$

$$E_u = y_1 + \frac{V_1^2}{2g} \tag{3.2}$$

$$E_d = y_2 + \frac{V_2^2}{2g} \tag{3.3}$$

$$E_L = E_u - E_d \tag{3.4}$$

The numerous factors have an effect on the energy dissipation that occurs via the stepped spillways, and the functional connection that exists between these parameters may be described as follows:

$$\frac{E_T - E_L}{E_u} = f(H, y_c, a, y_2, h_b, y_1, w_b, W, V, g, H_u, \theta) \tag{3.5}$$

After dimensional analysis, the necessary dimensionless equation may be expressed as follows:

$$\frac{E_T - E_L}{E_u} = f\left(\frac{H}{y_c}, \frac{a}{y_2}, \frac{h_b}{y_1}, \frac{w_b}{W}, F_1, \theta\right) \tag{3.6}$$

3.3 Support vector machine model

Support vector regression (SVR) is a widely used machine learning algorithm for regression analysis. It is based on the same principles as support vector machines (SVMs) for classification but is used for predicting a continuous output variable based on input variables. The key idea behind SVR is to find a function that maps input variables to output variables with minimum error while satisfying a specified margin. This is achieved by transforming the input variables into a higher dimensional space using a kernel function and then finding the regression line that maximizes the margin while keeping the error within a specified tolerance level (Drucker et al., 1997). One of the main advantages of SVR is its ability to handle non-linear relationships between input and output variables. This is achieved by using kernel functions such as polynomial, radial basis function (RBF), and sigmoid functions, which allow for more complex relationships to be captured (Smola and Schölkopf, 2004). SVR has been successfully applied in various fields, such as finance (Sharma et al., 2012), transportation (Yeh et al., 2010), and medical imaging (Borges et al., 2016). However, it is important to carefully select and tune the kernel function and other parameters for optimal performance. The simple approach to converting a linear classifier into a non-linear classifier is to apply a non-linear function that transforms the input space x to a feature space F. An alternative method is to utilize a non-linear function for the mapping. In space F, the discriminating function is:

$$f(x) = w^T \varphi(x) + b \tag{3.7}$$

In the subspace, the statistical method, which is indicated by the algebraic expression f (x, w), can be expressed in the following way:

$$w = \sum_{i=1}^{n} \alpha_i x_i \tag{3.8}$$

$$f(x, w) = \sum_{j=1}^{n} \alpha_i x_i \varphi_i(x) + b \tag{3.9}$$

$$f(x) = \sum_{i=1}^{n} \alpha_i x_i^T x + b \tag{3.10}$$

In the feature space, F, this expression takes the form:

$$f(x) = \sum_{i=1}^{n} \alpha_i \varphi(x_i)^T \varphi(x) + b \qquad 0 \leq \alpha_i \leq C \tag{3.11}$$

$$k(x, x') = \varphi(x)^T \varphi(x') \tag{3.12}$$

$$f(x) = \sum_{i=1}^{n} \alpha_i k(x, x_i) + b \tag{3.13}$$

On the other hand, there are a variety of additional useful kernel functions that may be implemented in a variety of contexts.

Linear kernel: $k(x_i, x_j) = x_i^T x_j$

Polynomial kernel: $k(x_i, x_j) = (\gamma x_i^T x_j + r)^d,\ \gamma > 0$

RBF kernel: $k(x_i, x_j) = exp(-\gamma \|x_i - x_j\|)^2,\ \gamma > 0$

Sigmoid kernel: $k(x_i, x_j) = tanh(\gamma x_i^T x_j + r),\ \gamma > 0$

Where C, γ, r, and d are parameters used in the SVM model. The performance of the SVM model is dependent on the quality of the settings chosen for these parameters, as well as the kernel parameters. The values chosen for C, γ, and r control the complexity of the regression model, and their selection further complicates the problem of determining optimal parameters. Kernel functions are employed to decrease the input space's dimensionality and enable classification. The SVM model is refined through exposure to data sets, similar to other neural network models. To determine the energy dissipation over trapezoidal stepped spillway, high quality experimental data set of present study and Nasralla (2021) dataset were used. Before constructing the SVM model, the data is separated into training and test sets in 70:30 in MATLAB R (2019). Table 3.1 represents the different models created for energy dissipation using different kernel functions and kernel scale keeping the same relationship and percentage of training and testing datasets.

Table 3.1. Different models developed using support vector regression

Model	**Preset**	**Kernel function**	**Kernel scale**	**Prediction speed (obs/sec)**	**Training time (sec)**
M1	Linear SVM	Linear	Automatic	680	18.49
M2	Quadratic SVM	Quadratic	Automatic	790	17.05
M3	Cubic SVM	Cubic	Automatic	630	20.91
M4	Fine Gaussian SVM	Gaussian	0.61	750	15.80
M5	Medium Gaussian SVM	Gaussian	2.4	740	19.42

3.4 Statistical measures

For further testing of the accuracy of the developed models by GEP approach, various types of error analysis, such as the coefficient of determination (R^2), mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE), are analyzed using the following equations (Kaushik and Kumar 2022).

$$R^2 = \frac{\sum_{i=1}^{N}(a_i-\bar{a})^2\ (p_i-\bar{p})^2}{\sum_{i=1}^{N}(a_i-\bar{a})^2\ \sum_{i=1}^{N}(p_i-\bar{p})^2} \tag{3.14}$$

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}|p_i - a_i| \tag{3.15}$$

$$\text{MAPE}(\%) = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|p_i-a_i|}{a_i} \times 100\right) \tag{3.16}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(p_i - a_i)^2} \tag{3.17}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Energy dissipation over trapezoidal steeped spillway

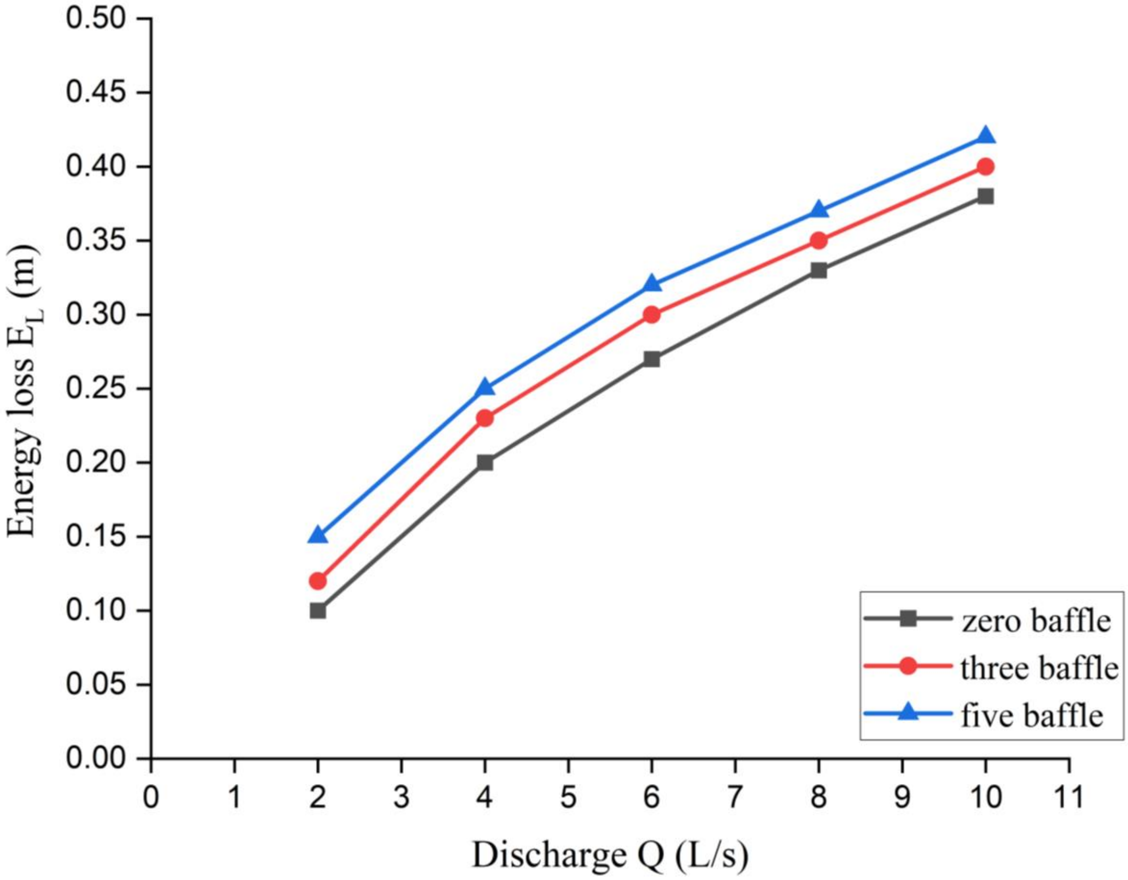


Figure 4.1. Variation of energy loss with discharge for zero degree channel slope

Figure 4.1 represents the variation of energy loss with the flow rate at zero degree channel slope for different baffle arrangements. The energy loss increases as the discharge increases for different baffle locations. At zero degree channel slope, energy loss increases from 5 to 50% as baffle increases from zero to five.

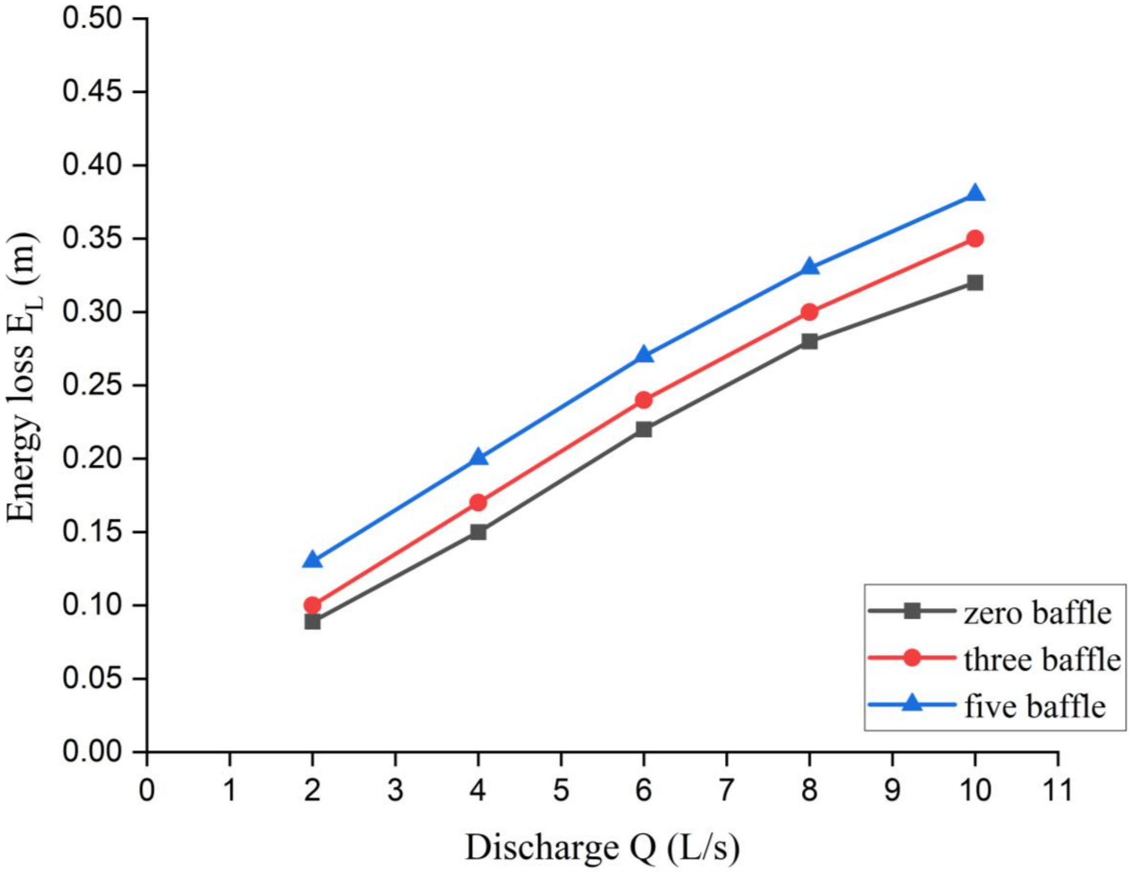


Figure 4.2. Variation of energy loss with discharge for one degree channel slope

Figure 4.2 depicts the fluctuation of energy loss with flow rate at one degree channel slope for various baffle configurations. For varied baffle placements, the energy loss increases as the discharge increases. Energy loss increases from 7 to 46% at zero degree channel slope as baffle increases from zero to five. The largest energy loss was recorded for zero degree channel slope because flow accelerates due to the change in velocity downstream, resulting in a drop in energy loss at one degree channel slope.

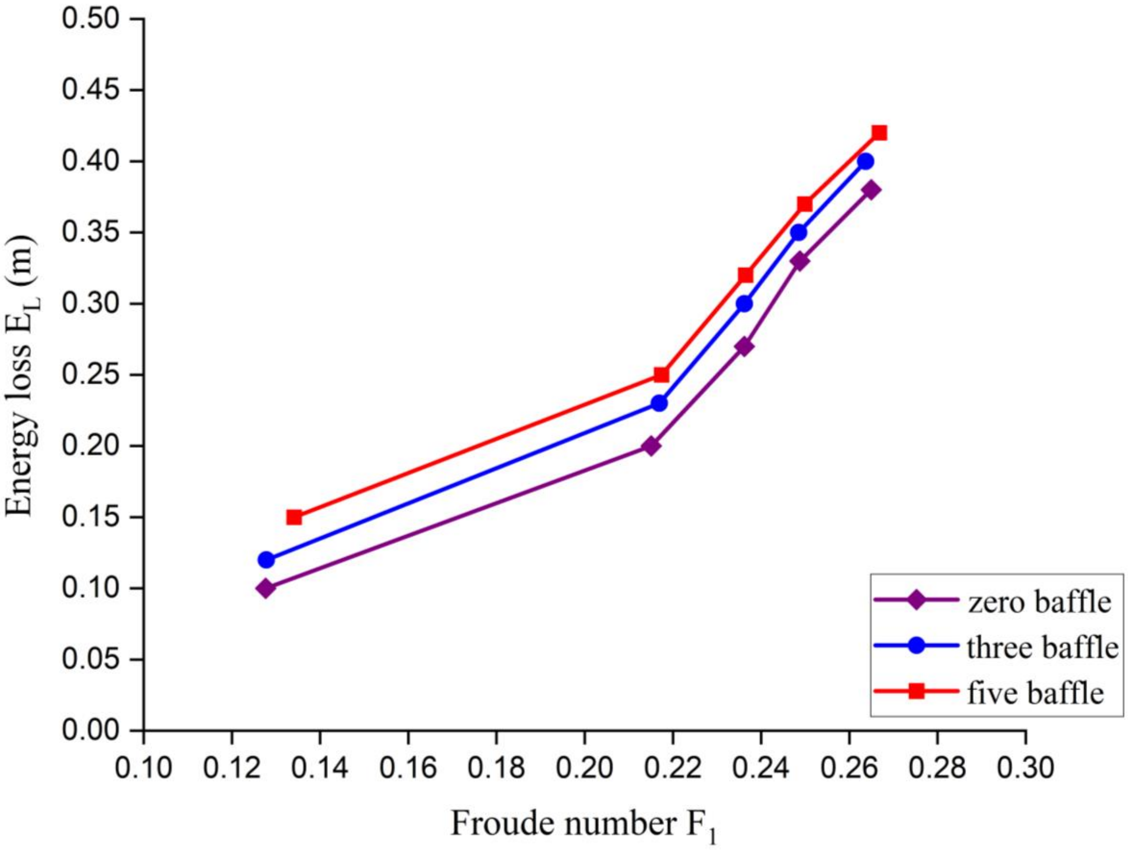


Figure 4.3. Variation of energy loss with Froude number for different baffle locations at zero degree channel slope

Figure 4.3 illustrates how the amount of energy that is lost varies with the Froude number for various baffle configurations when the channel slope is zero degrees. There is a non-linear rise in the amount of energy lost proportional to the Froude number, and it has been determined that the increment is greatest for the five baffles arrangement.

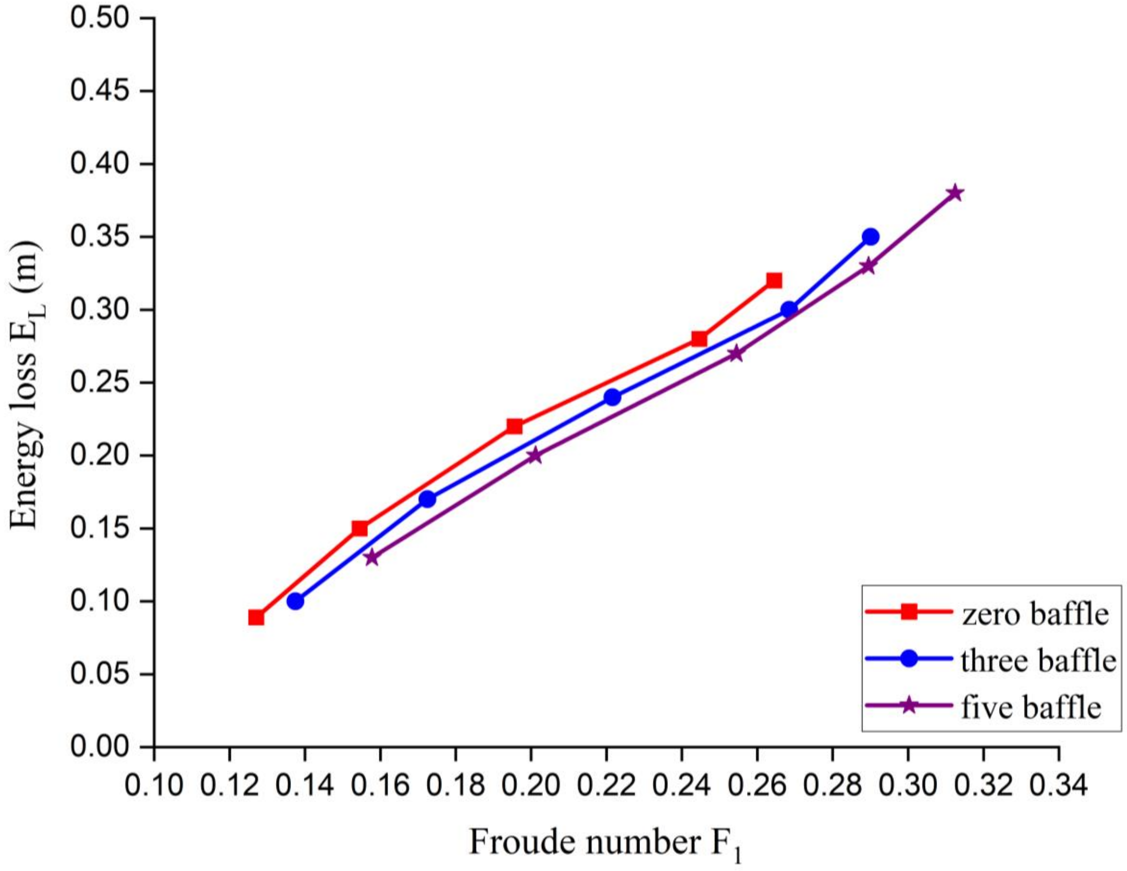


Figure 4.4. Variation of energy loss with Froude number for different baffle locations at one degree channel slope

Figure 4.4 depicts the fluctuation of energy loss with Froude number for various baffle configurations at one degree channel slope. The energy loss increases non-linearly as the Froude number grows, with the increase being greater for the five baffle design. The numbers are near to each other for different baffle arrangements, demonstrating that the increment is minor in comparison to the zero degree channel slope.

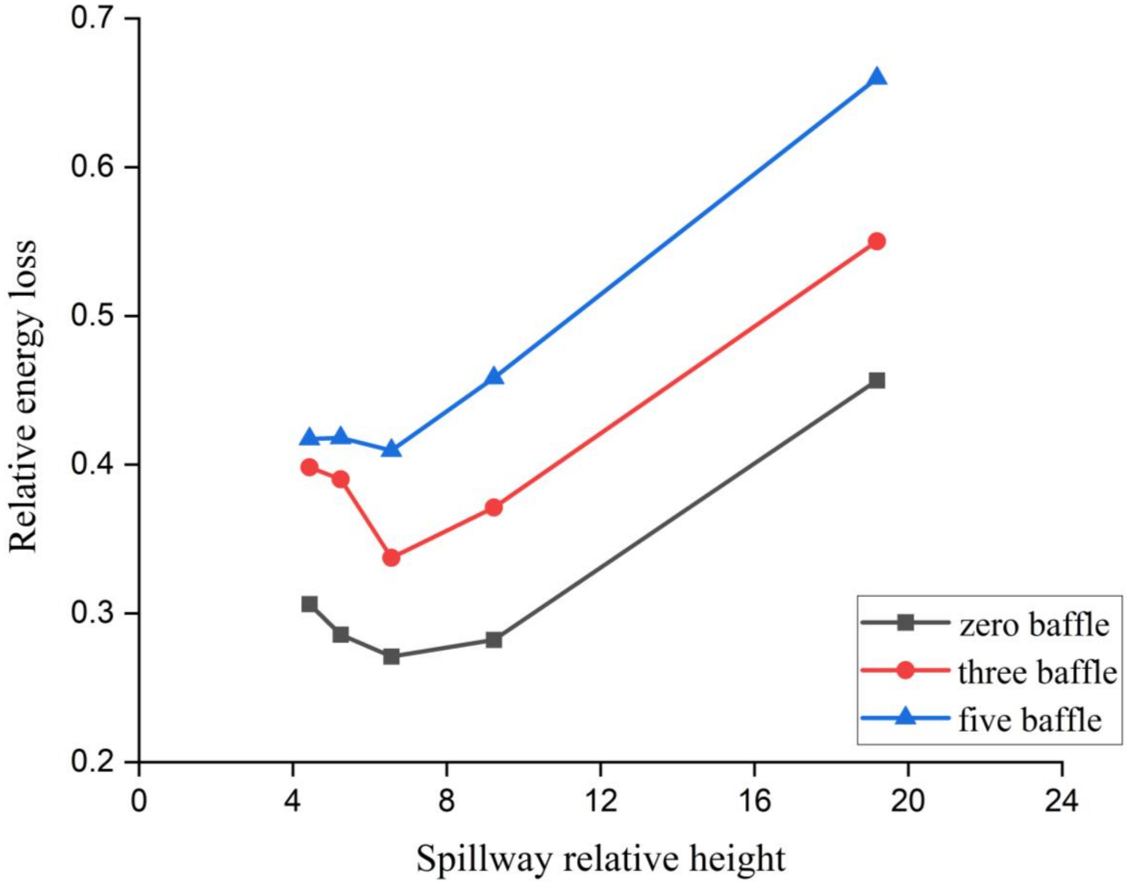


Figure 4.5. Variation of relative energy loss with the spillway relative height for different baffle locations at zero degree channel slope

Figure 4.5 shows the fluctuation in relative energy loss with respect to the relative height of the spillway for a variety of baffle placements at an angle of zero degrees of the channel slope. As the relative height grows, the relative energy loss begins to decrease, eventually reaching a minimum, and then begins to increase. The more baffle arrangements examined, the greater the observed energy loss. The similar pattern of variance may be seen across the various baffle arrangements.

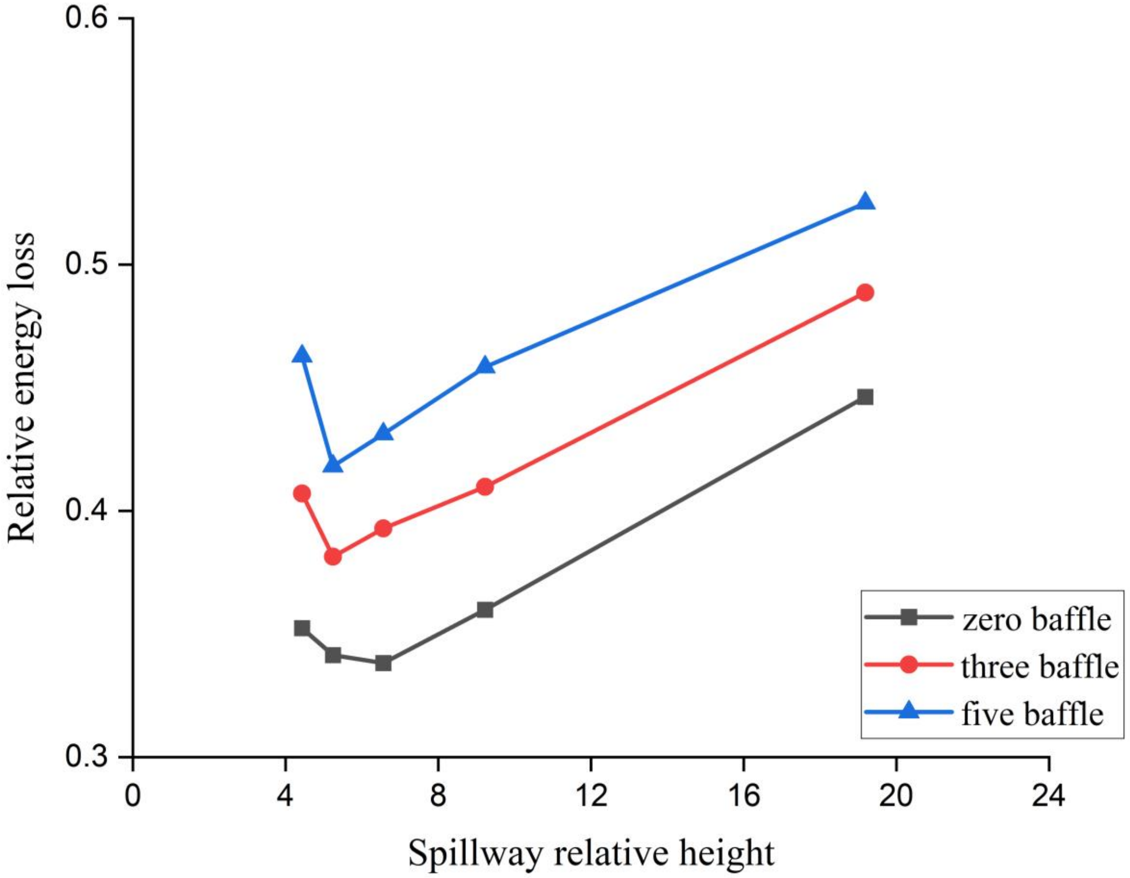
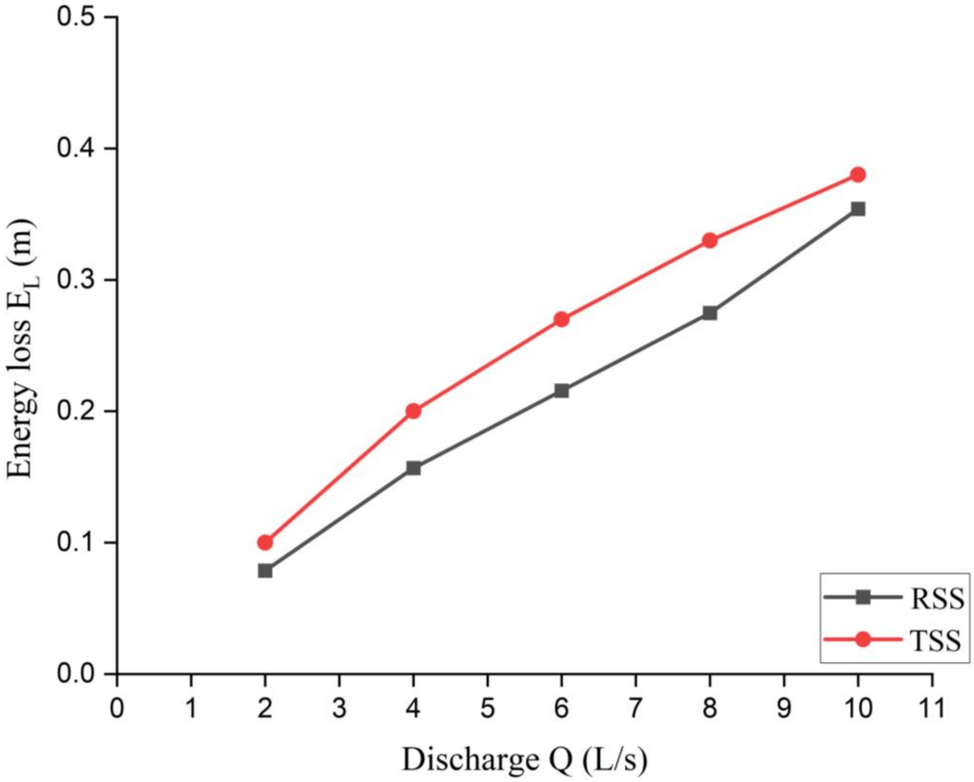


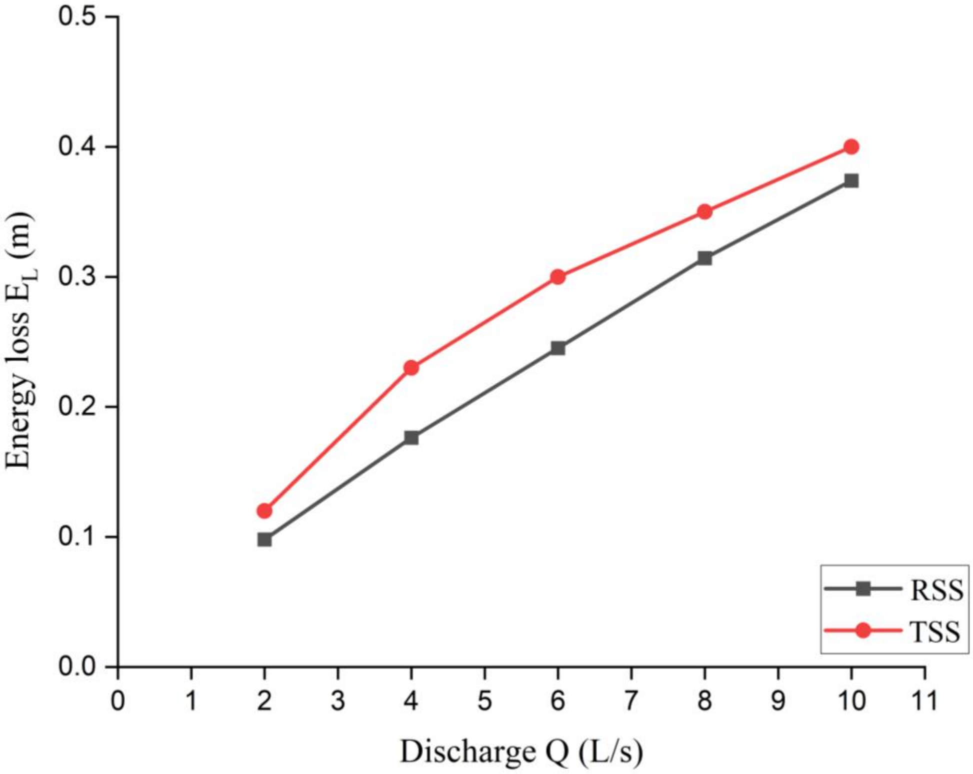
Figure 4.6. Variation of relative energy loss with the spillway relative height for different baffle locations at one degree channel slope

Figure 4.6 shows how the spillway's relative height affects the relative energy loss at various baffle locations with a one-degree channel slope. As the relative height rises, the relative energy loss initially decreases until it reaches a minimum before increasing. Five baffle cases are seen to lose more energy. Different baffle arrangements show the same trend of variation. In comparison to one degree channel slope, energy loss values for trapezoidal stepped spillways are higher at zero degree channel slope.

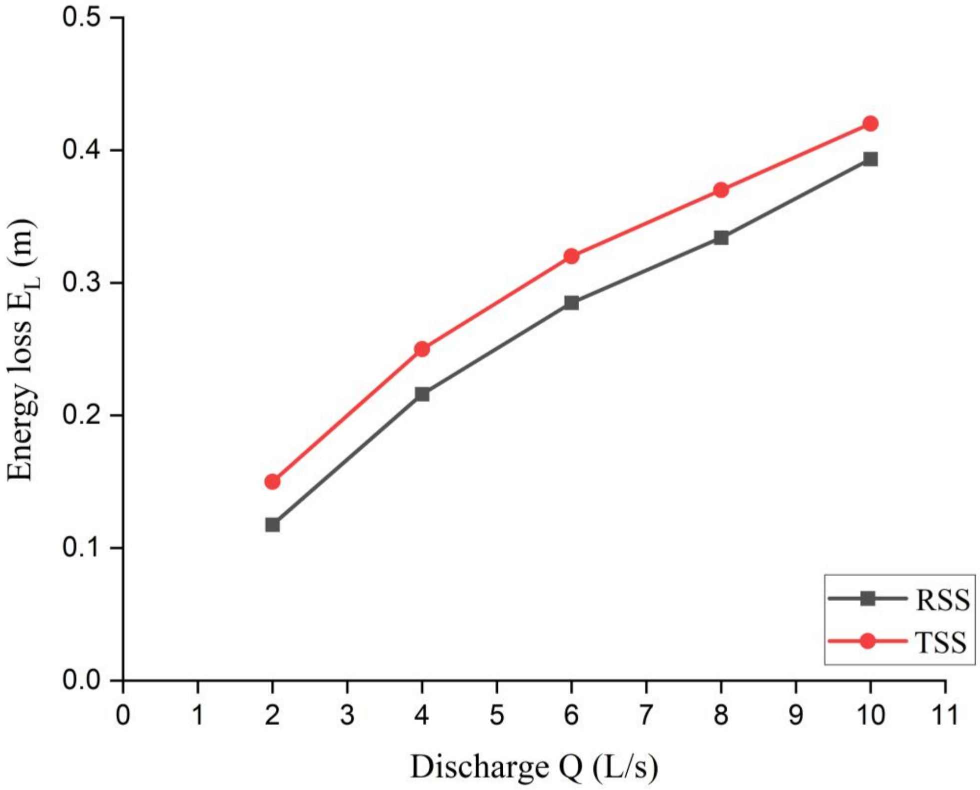
4.2 Comparative study with rectangular stepped spillway



(a)



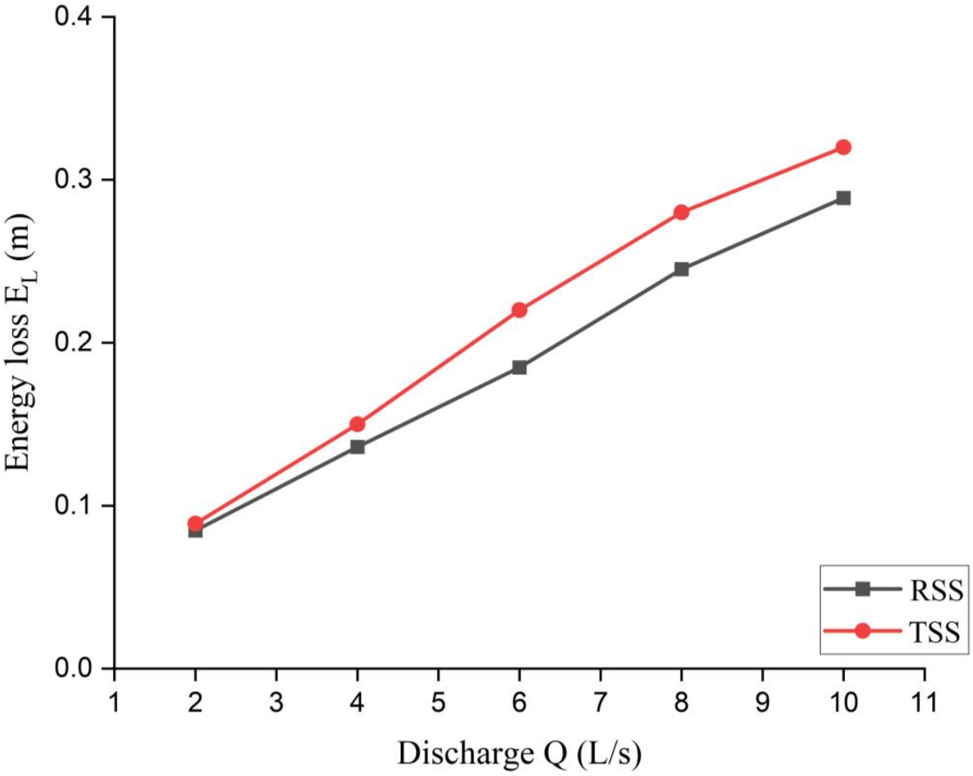
(b)



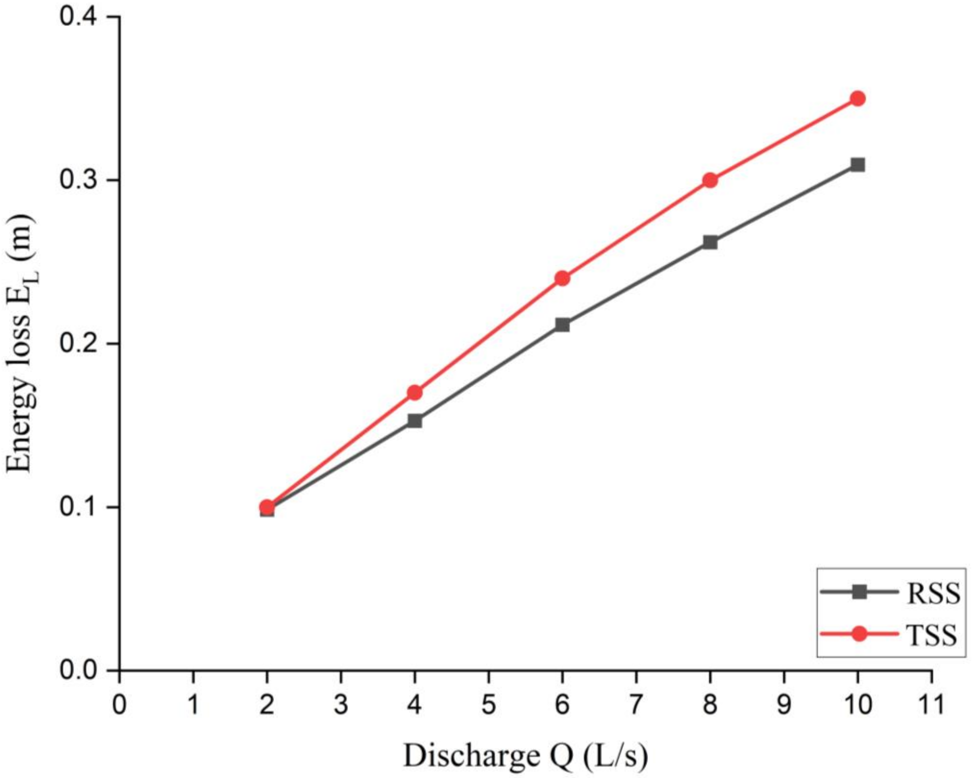
(c)

Figure 4.7. Comparison of energy loss at zero degree channel slope for different arrangement of baffles (a) zero baffle (b) three baffle (c) five baffle

Figure 4.7 illustrates the comparison of the energy loss with discharge for rectangular and trapezoidal stepped spillways at zero degree channel slope for various baffle arrangements. It is discovered that the energy loss grows as the discharge values rise. The energy loss for rectangular stepped spillways at various baffle arrangements has varied according to the same pattern. For zero baffle, three baffle, and five baffle arrangements, the increase in energy loss is 7.37 to 27.55 percent, 6.95 to 30.45 percent, and 6.79 to 27.55 percent, respectively. At zero degree channel slope, the trapezoidal stepped spillway with three baffle arrangement showed the greatest increase in energy loss.


Energy loss E_L (m)
0.0
0.1
0.2
0.3
0.4
Discharge Q (L/s)
1
2
3
4
5
6
7
8
9
10
11
RSS
TSS

(a)


Energy loss E_L (m)
0.0
0.1
0.2
0.3
0.4
Discharge Q (L/s)
0
1
2
3
4
5
6
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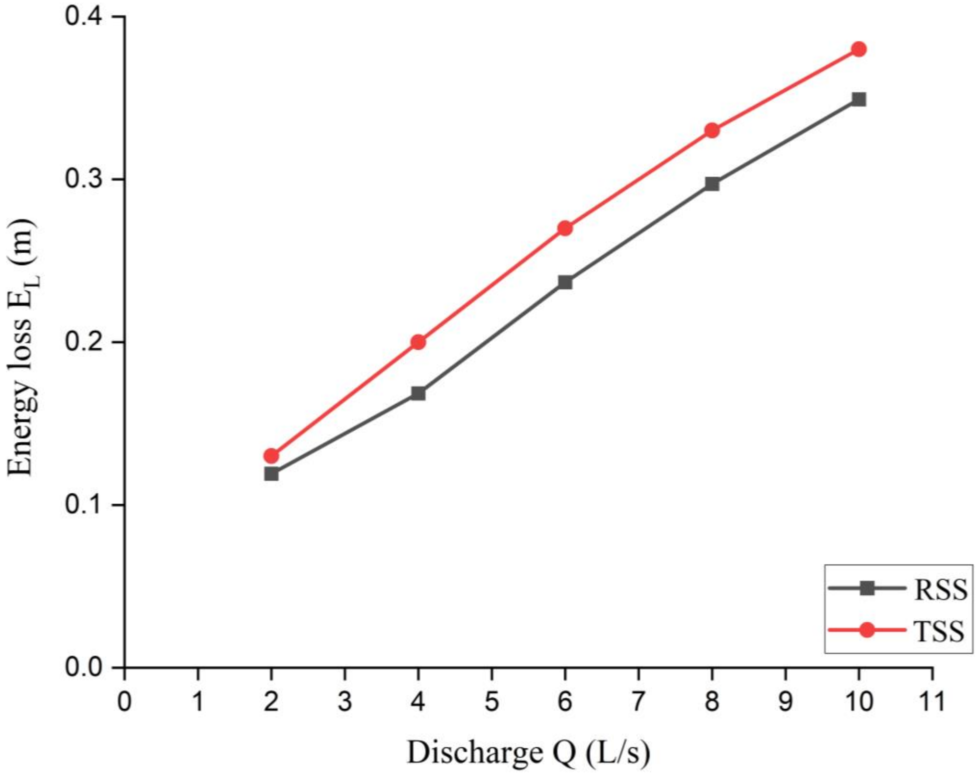
9
10
11
RSS
TSS

(b)



(c)

Figure 4.8. Comparison of energy loss at one degree channel slope for different arrangement of baffles (a) zero baffle (b) three baffle (c) five baffle

Figure 4.8 compares the energy loss with discharge for a rectangular and trapezoidal stepped spillway with a one degree channel slope using various baffle arrangements. It is discovered that the energy loss grows as the discharge values rise. The energy loss for rectangular stepped spillways at various baffle arrangements has varied according to the same pattern. For zero baffle, three baffle, and five baffle arrangements, the increase in energy loss is 5 to 19 percent, 1.5 to 13.5 percent, and 8.8 to 18.7 percent, respectively. With a one degree channel slope, a trapezoidal stepped spillway with five baffles showed the greatest increase in energy loss. It has been found that the energy loss increase for trapezoidal stepped spillways decreases at one degree channel slope compared to zero degree channel slope for rectangular stepped spillways.

4.3 Computational analysis

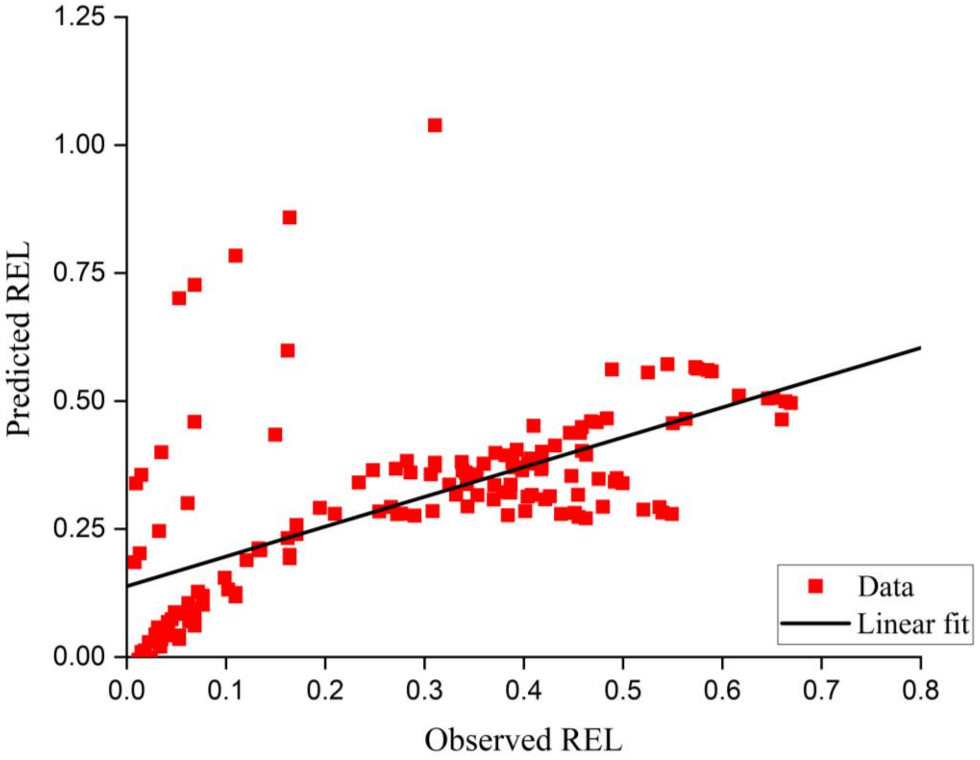


Figure 4.9. Scatter plot for predicted REL using model 1

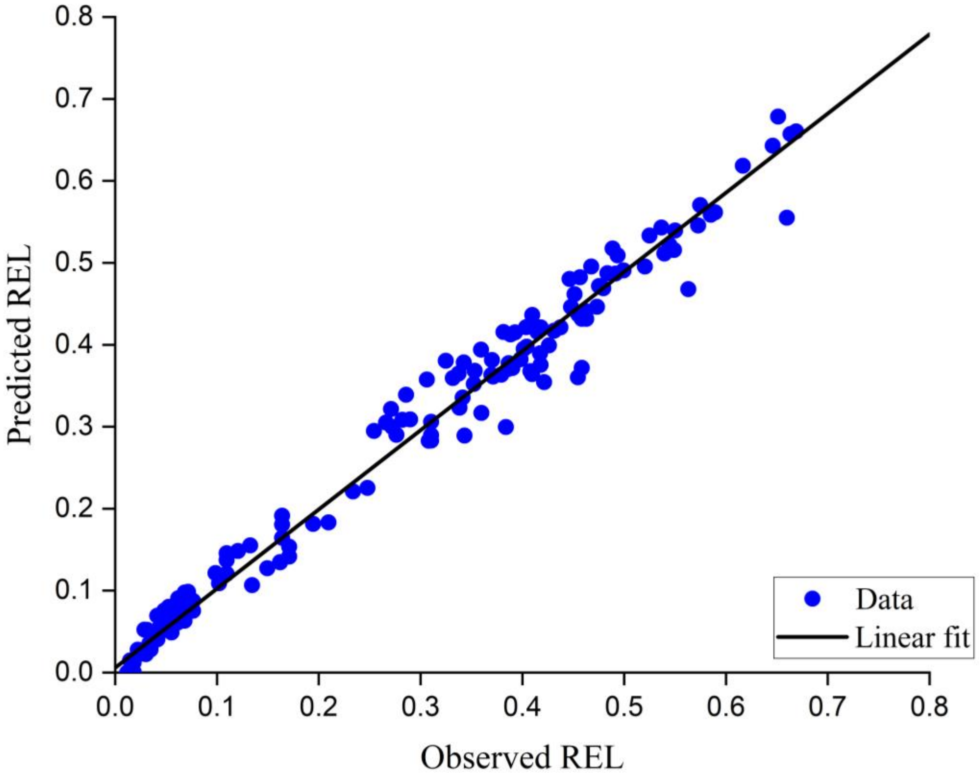


Figure 4.10. Scatter plot for predicted REL using model 2

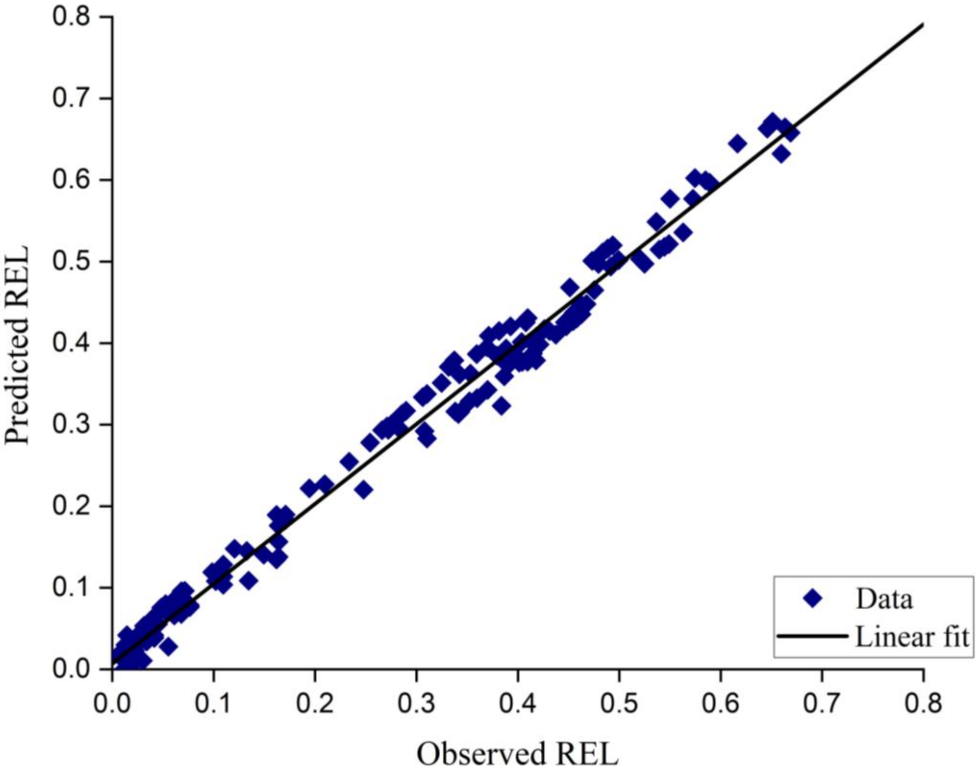


Figure 4.11. Scatter plot for predicted REL using model 3

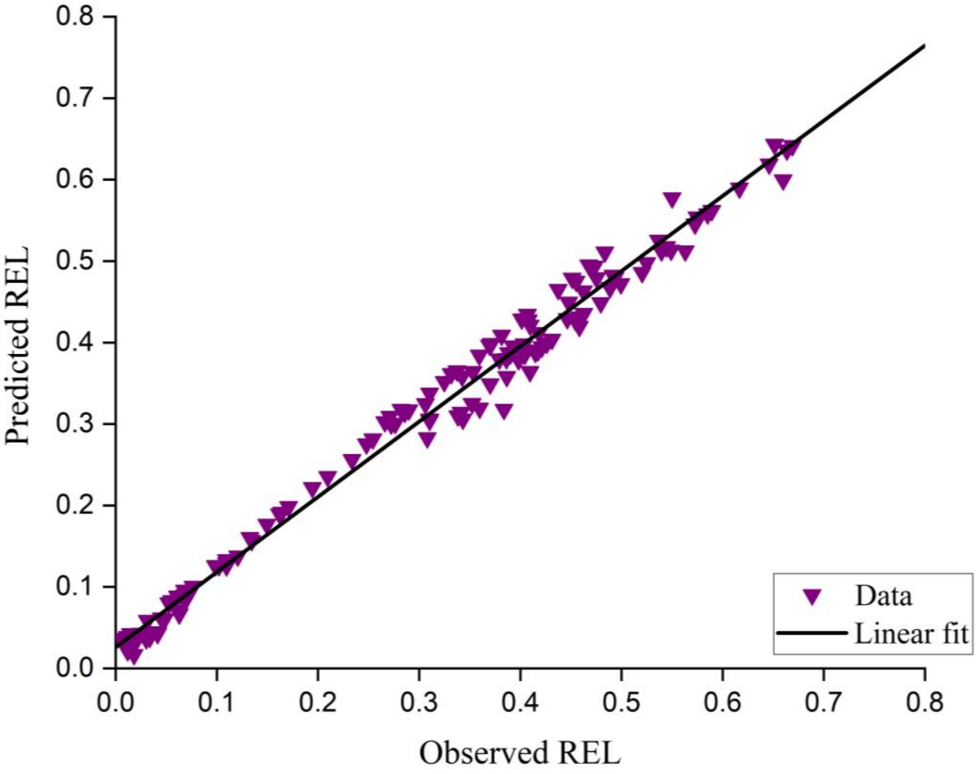


Figure 4.12. Scatter plot for predicted REL using model 4

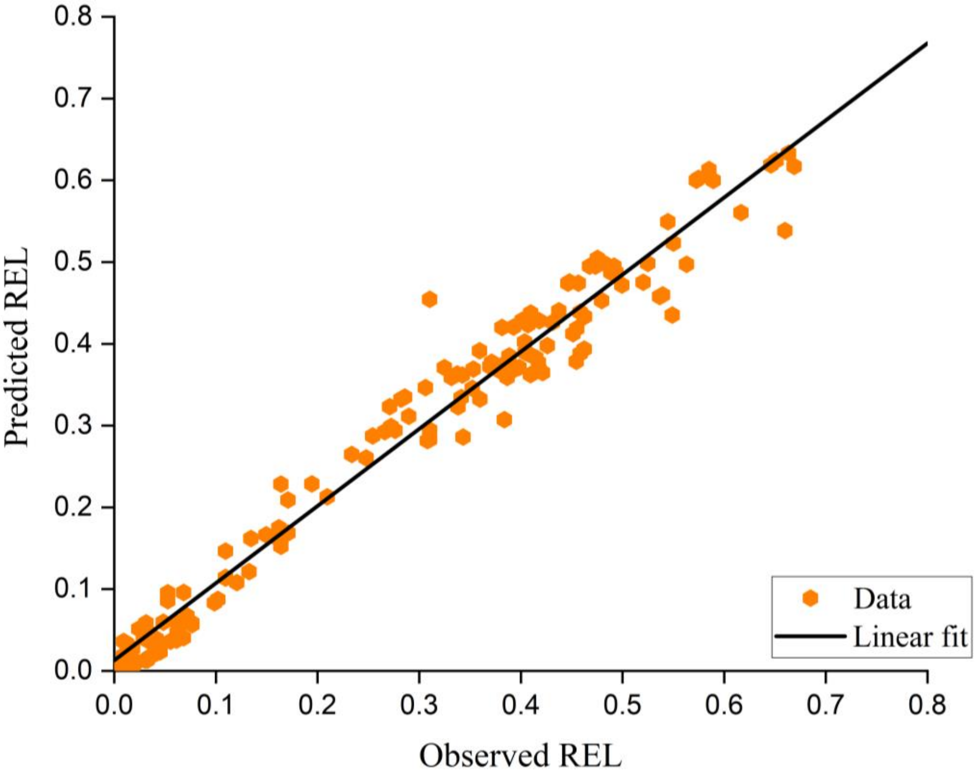


Figure 4.13. Scatter plot for predicted REL using model 5

Figures 4.9 to 4.13 represents the scatter plots which compare the expected and actual values of relative energy loss (REL), show the support vector machine (SVM) approach's capacity to produce precise predictions. A notable sign of the SVM model's potential is the values' proximity to the line designating extraordinary concurrence. High R^2 values are produced by the distributed SVM predicted values over the best-fitting line, which exhibit the maximum degree of agreement with the experimental data. Figure 4.10 shows that, when compared to other developed SVM models, the predicted values of relative energy loss using SVM model two, which was created using a quadratic kernel function and a 70:30 ratio of training and testing data, are found to be closer to the best fitted line.

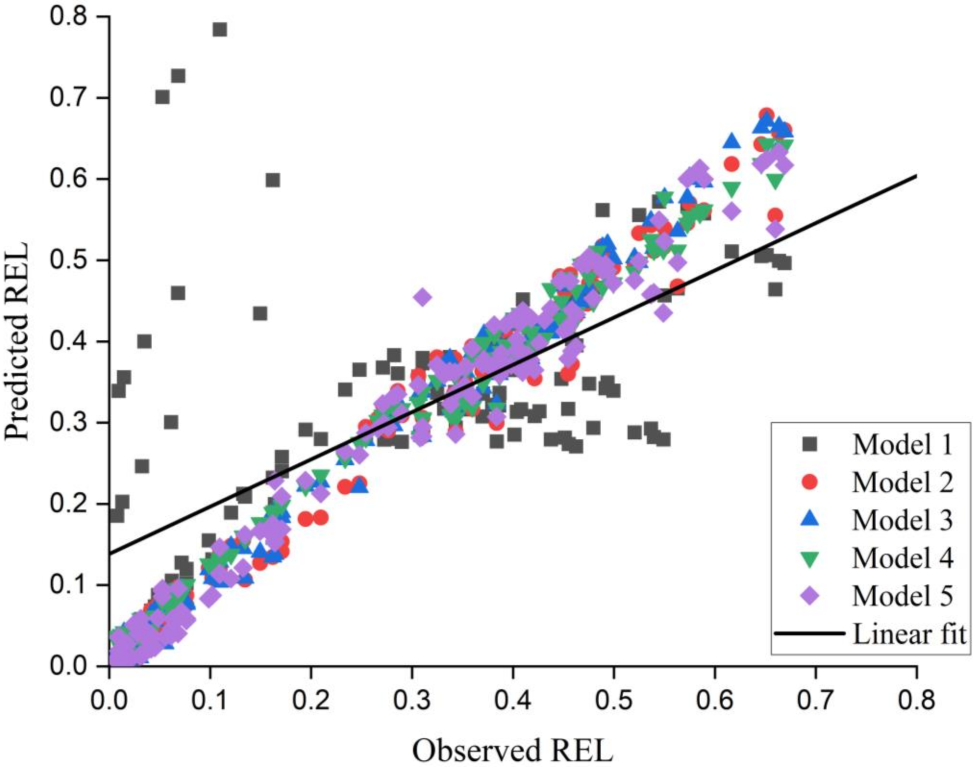


Figure 4.14. Comparison of predicted value of relative energy loss for different models

In figure 4.14, a comparison is made between the various models that have been created to estimate relative energy loss. It has been shown that the developed SVM model two gets fairly close to the line that best matches the data, and it also has a considerable potential for generalization. This was determined by comparing it to other approaches and observing its proximity to the line. They do not exhibit any of the signs or symptoms that are linked to the condition of being overtrained.

Table 4.1. Statistical analysis of predicted REL by various approaches

Statistical parameters	**SVM model 1**	**SVM model 2**	**SVM model 3**	**SVM model 4**	**SVM model 5**	**Nasralla method**
R^2	0.18	0.97	0.96	0.91	0.94	0.84
MSE	0.0313	0.0012	0.0016	0.0034	0.0021	0.0097
RMSE	0.1769	0.0348	0.0395	0.0580	0.0461	0.098
MAE	0.1042	0.0257	0.0295	0.0428	0.0331	0.079

The R^2 value, MSE value, RMSE value, and MAE value are some of the statistical characteristics that were used to evaluate the performance of the proposed models with the previous approach such as Nasralla (2021) method, as shown in Table 4.1. It can be seen from the table that SVM model two with ($R^2 = 0.97$, RMSE = 0.0348 and MAE = 0.0257) gives the best predicting results for the relative energy loss for trapezoidal stepped spillway in comparison to other models of SVM and other previous developed methodologies such as Nasralla (2021) method ($R^2 = 0.84$, RMSE = 0.098 and MAE = 0.079). This is because SVM has a higher correlation and a lower relative standard error. It turns out that the SVM model with the lowest MAE is the best suited technique for predicting energy loss across a trapezoidal stepped spillway.

CHAPTER 5

CONCLUSIONS

The present study employed a tilting flume to determine the energy loss through a trapezoidal stepped spillway at different channel slopes for various baffle arrangements. It also shows the way machine learning techniques, specifically Support Vector Machine, can be applied to predict energy dissipation in terms of nondimensional parameters. The models were created utilizing high-quality laboratory datasets gathered from ongoing and past investigations. The following conclusions and inferences may be drawn from the study's findings:

- For varied baffle placements, the energy loss increases as the discharge increases. The largest energy loss was recorded for zero degree channel slope because flow accelerates due to the change in velocity downstream, resulting in a drop in energy loss at one degree channel slope.
- The quantity of energy loss can be affected by a number of factors, including the flow velocity at different channel slopes and the baffle layout. It was found that the configuration with five baffles resulted in a larger loss of energy when the slope of the channel was zero degree.
- The amount of energy that is lost grows in a manner that is not directly proportional to the Froude number, and it has been discovered that the increment is greater for a five baffles arrangement. When compared to the slope of a channel with zero degrees of inclination, the values that are observed to be near to each other for various baffle arrangements indicate that the increment is minor.
- The comparison research with rectangular stepped spillways reveals that trapezoidal stepped spillways with five baffle arrangements had the greatest increase in energy loss at one degree channel slope. It has been found that the energy loss increase for trapezoidal stepped spillways lowers at one degree channel slope compared to zero degree channel slope for rectangular stepped spillways.
- A wide range of factors, including the size and height of the spillway, the location of the baffle, the heads upstream and downstream, the slope of the channel, the inclination of the steps, and the Froude number, appear to have an impact on the proposed model.
- An examination into the link between the relative energy loss and the nondimensional variables of a trapezoidal stepped spillway was carried out in order to investigate the

nature of this relationship. It has been found that there is a link between all of the components that is not linear in its progression from one to the next.

- When compared to earlier methods, the newly presented models produce improved results for a number of different datasets in terms of R^2, RMSE, MSE, and MAE. These metrics are used to measure the accuracy of the model.
- The findings suggest that SVM models were able to provide an estimation of the amount of energy that was lost across the trapezoidal stepped spillway with a satisfactory level of precision.
- The SVM model two that was constructed using a quadratic kernel function provides the best prediction results for the amount of energy loss through the trapezoidal stepped spillway. This model has the highest R^2 value and the lowest RMSE, MSE, and MAE values. It does not demonstrate any signs of the overtraining phenomenon.

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LIST OF PUBLICATIONS

SCOPUS Indexed

1. Saurabh Pujari, Vijay Kaushik, and S. Anbu Kumar, “Prediction of Energy Dissipation over Stepped Spillway with Baffles Using Machine Learning Techniques,” Civil Engineering and Architecture, vol. 11, no. 5. (Accepted)

2. Saurabh Pujari, Vijay Kaushik, and S. Anbu Kumar, “A Review of Energy Dissipation on Different Types of Spillways,” AIP Conference Proceedings. (Accepted)

Conference Presented

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