ANALYSIS OF FLOW OVER A STEPPED SPILLWAY USING ANSYS FLUENT

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

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HYDRAULICS AND WATER RESOURCES ENGINEERING

Submitted by

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CANDIDATE DECLERATION

I, Ankit Kumar, Roll No. 2K18/HFE/003 student of M.Tech (Hydraulics and Water Resources Engineering), hereby declare that the project Dissertation titled “Analysis of Energy Dissipation of flow over a Stepped Spillway using Ansys Fluent” which is submitted by me to the Department of Civil Engineering, DELHI TECHNOLOGICAL UNIVERSITY, Delhi in partial fulfillment of the requirement 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 "Analysis of Energy Dissipation of flow over a Stepped Spillway using Ansys Fluent" which is submitted Ankit Kumar, Roll No. 2K18/HFE/003 (Civil Engineering), DELHI TECHNOLOGICAL UNIVERSITY, Delhi in partial fulfillment 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 of full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

In this Dissertation, the flow over a stepped spillway will be analyzed. The CFD analysis will focus on the energy dissipation which is caused by stepped spillway and transition of flow from nappe regime to skimming regime with the change in step size(height and length) for a constant slope and discharge and variation of discharge with constant step size and slope. As the regime condition are changed, there will be the change in the efficiency of energy dissipation by the stepped spillway. After studying the different flow regimes for different step sizes, I will compare the variation of energy dissipation with manual calculations of energy dissipation on stepped spillway.

The project is divided into 3 segments:

1. For a constant discharge per unit width and a constant slope, variation of the number of steps i.e. changing the height and length of steps by varying the no. of steps keeping the total height of spillway being same is analyzed.
2. For fixed step size and constant slope, variation of flow profile by varying discharge per unit width is studied.
3. Comparison of above stepped spillway results with the manual approach is done.

This work is very important related to the stability of downstream bed channel. The aim of project is to reduce the total energy of water flowing over a spillway to a considerable extent so that scouring will be minimized due to the energy of flowing water on the downstream side of river bed.

ACKNOWLEDGEMENT

I take this opportunity to express my sincere regards and deep gratitude to **Dr. RAKESH KUMAR** (Professor, Civil Engineering Department, DTU) for his consistent guidance, monitoring and constant encouragement throughout the course of this project work. Also, I express my gratitude to **Department of Civil Engineering, DTU** for giving me such an opportunity to commence this project in the first instance.

Professor and faculties of Civil Engineering Department, DTU have always been very supportive and cooperative. They have been always present for their kind opinions and suggestions regarding this project work and therefore I am deeply Obliged to them.

Last but not the least, I would like to thank my family and colleagues from the department who encouraged me to bring this work to a successful completion.

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CHAPTER 1

INTRODUCTION

1.1 SPILLWAY AND ITS REQUIREMENTS

Spillway is a structure, constructed on the downstream side of a dam so that it can discharge the excess flood to the tail race level of the channel. Generally, water is stored on the upstream side of the dam which is diverted for beneficial use for example generation of hydropower. But from practical and economic point of view, it is necessary to pass the excess water safely on the downstream side of dam without overtopping or damaging the dam. This can be done with the help of spillways. When water is discharges from the spillway it flows from a high elevation level (where it has considerably large amount of energy) to tail race level. As water impinges on the river bed, due to sufficient kinetic energy it will cause scouring of the river bed.

1.1.1 **Problem associated with scouring**

Scouring is a phenomenon where erosion takes place in the river bed channel and its equilibrium is disturbed which causes the instability in the side slope and bed slope of the channel. This will lead to degradation in the river channel. This is undesirable because it changes the flowing condition of river, alignment of river and amount of silt which is carried by the river channel. Degradation on the downstream side will lead to aggradations at other points of river channel where the excess of silt will get deposited. This will eventually lead to meandering condition in the river channel and ultimately

the design purposes of other hydraulic structures will be different. This is why scouring need to be minimized in the river channel.
Energy dissipating devices are used to minimize scouring at the toe of the spillway.

1.2 TYPES OF SPILLWAY:

1.2.1 Free over fall Spillway

In this type of spillway water drops freely down the crest for instance like an arch dam. In this case of freely falling, water is sufficiently aerated or ventilated and avoids pulsating, jerky or varied jet of flow. There is a possibility of scouring a hole on the downstream of unprotected beds. We can correlate volume and depth with the variation of discharge, drop height and depth of tail water.

1.2.2 Overflow Spillways

In this type, spillway has a shaped crest. At low discharges, the profile of water is like a shape of lower nappe of a freely flowing weir transmitting the discharge but if discharges are high, there is a possibility where water profile get detached from the surface and negative pressure may built up which will disturb its efficiency.

1.2.3 Chute Spillway

This is an open channel type spillway, where the discharge is conveyed from the ponding structure to the downstream level of river. They are generally used for embankment dam, for instance Tehri dam. The advantage of these types of spillways is that their design is very simple and they can be constructed on a number of foundation materials i.e., from clay to rocks.

1.2.4 Side Channel Spillway

In this type of spillway, the side channel can divert discharge into a closed conduit which may run under pressure, or into a chute channel (spillway) or into an open channel. The side channel spillway is expensive and also it is not hydraulically efficient but it is advantageous where it is required to limit the afflux with the help of a long overflow crest. It is also desirable in the locations where the abutments are steeper.

1.2.5 Shaft Spillway

In this spillway, water enters through a horizontal lip, then falls through a vertical or inclined shaft and after that it flows to downstream channel of river with the help of a tunnel or conduit. These types of spillways required piers or guide vanes to minimize the effect of vortex in the reservoir. These types are required in cases where there are narrow gorges and steep rise abutments.

1.2.6 Tunnel Spillway

In this type of spillway, a closed passage transmits the flood water around a dam with the help of the neighbouring hill sides. They are generally suitable in the cases where the valleys having large width because in these cases, the application of these types of spillways would enable it to be constructed below the dam in a close proximity to the stream bed.

1.2.7 Stepped Spillway

These types of spillways are consisting of a series of steps which starts at the crest of spillway (Upstream) and propagates towards downstream. The stepped spillways are commonly used since ancient times due to considerable loss of energy on steps as in form of energy dissipation which is caused by different steps on these spillways. But in the recent years, new technologies are developed like new concrete manufacturing techniques and compact roller concrete, innovations in the use of different admixtures, the stepped spillways are more in use.

The only limitation of these stepped spillway is that due to very high discharges, there is a possibility that water jet will not be aerated for some distance on the downstream portion of spillway and low pressure may build up which may lead to the cavitation damage.

1.3 FLOW CLASSIFICATION OVER A STEPPED SPILLWAY

The idea of stepped spillway was came in 1892-1906 in new croton dam. For the very first time, stepped spillway is used in intermediate erodible river reaches which was done by Lombardi and Marquenent. Slope of these reaches were sufficient to cause hydraulic jump at base of each fall.

Basically, there are three types of flow over a stepped spillway which are as follows:

- **Nappe flow**
- **Skimming flow**
- **Partial nappe flow (Also called Transition flow)**

For low discharges the flow is occurs to be nappe flow, for intermediate discharges flow is occurs to be partial nappe flow and for high discharges the flow is occurs to be skimming flow.

1.3.1 Nappe Flow

In Nappe Flow water flow over the steps in form of series of jumps which falls from one step to another step in form of a very thin layer which is attached to the visible side of each step. In this type of flow, there may be different modes of energy dissipation. For occurrence of nappe flow, step height should be large enough.

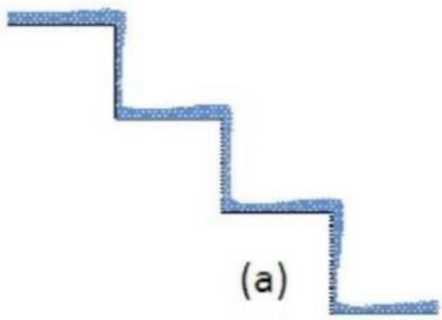


Figure 1.3.1 (Nappe Flow)

1.3.2 Partial Nappe Flow

In this type of flow, the nappe does not completely depend on the step surface and it will dissipate an appreciable amount of turbulence. Flow is supercritical in this type of spillway. For a given geometrical model, if we increase the discharge, there will be an intermediate change of flow profile from nappe and skimming flows. Properties of flow in on each step which varies in longitudinal direction can be excluded with the help of intermediate flow patterns. It does not represent the coherent emergence of skimming flows.

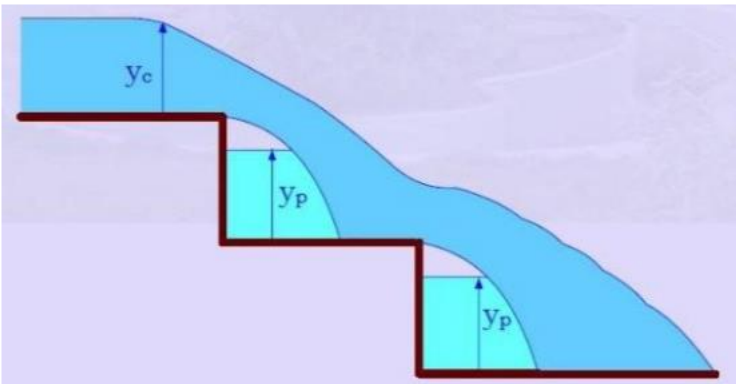


Figure 1.3.2 (Partial Nappe Flow)

1.3.3 Skimming Flow

Here, the discharge flows over the steps as a consistent course skimming over the steps and these are padded by recirculating flow which is entrapped between them. Skimming flow occurs over outer sides of steps which behaves like pseudo. The flow is lucid and clear which has a shiny appearance at upstream end and there is no air entrainment. Below the few steps, the flow is allotted by entrainment of air such as a self-aerated flow through an inverted spillway.

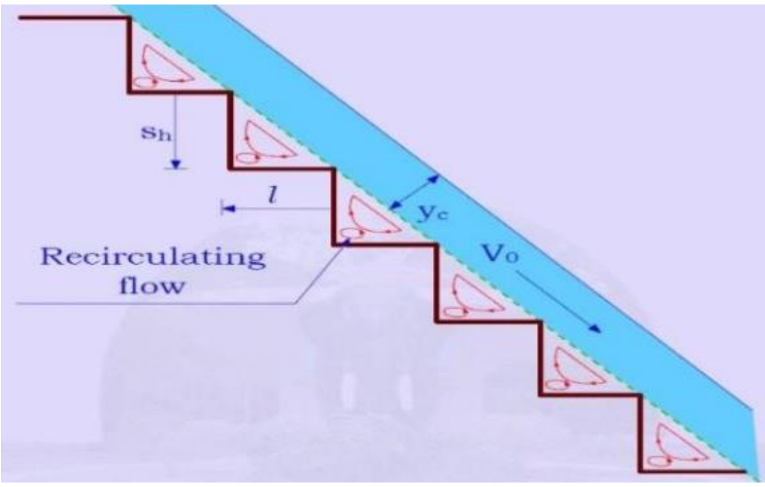


Figure 1.3.3 (Skimming Flow)

1.4 ANSYS FLUENT

ANSYS is an advanced software which can solve all the problems of the engineering related simulations which are related to fluid dynamics, hydrodynamics, chemical engineering, metaphysics. environmental engineering, structural mechanics, electromagnetics, and so on. In this project fluent is going to be used because all the project is related to the system of fluid dynamics. The Company (Ansys Fluent) is founded by Mr. John A. Swanson. In Computational fluid dynamics (CFD), a mathematical tool is used which is based on computer programming. There is growing interest in the field of CFD which is based on simulations. Experimental and numerical analysis consume lot of time so CFD has been widely used by engineers to save time where experimental or numerical analysis becomes difficult. Movement of fluid is determined in detail by solving a system set of nonlinear governing equations before that, the use of specified boundary conditions over the ambit of interest is the basic principle which is going to be used in the analysis of CFD problems. The simulations which are based on CFD are occurring depend upon combined numerical accuracy, cost of computations and precision of modelling.

Using ANSYS CFD, with the help of computer analysis, the system of fluid flow can be simulated. First of all, analysis is started with creating a mathematical model of physics whose problem is associated. The CFD method of solving generally used 3 approaches:

- Finite element method
- Finite difference method
- Finite volume method

In ANSYS fluent for the analysis of flow over stepped spillway finite volume method is going to be used.

1.4.1 Advantages of CFD

1. Real time simulation conditions can be achieved which are difficult to maintain in the experimental analysis.
2. The simulation cost is minimized and optimized.
3. High speed performance.
4. Margin of error is negligible if done carefully.
5. Multiple changes can be done in geometry until the accurate results are obtained.

1.4.2 Limitations of CFD

1. Physical modelling should be done very accurately because all the analysis and results are completely based on it.
2. The model will give accurate results only if boundary conditions of flow are accurately specified.

1.5OBJECTIVE OF DISSERTATION

The main objective of this study is:

1. To analyse the energy dissipation on the stepped spillway when different parameters such as step height, length and discharge are varied for a constant slope angle.
2. Study of change in energy dissipation as we change in discharge for constant step height, length and constant slope and verify it with the given previous literature work.
3. Study of relationship between the critical depth of flow and associated energy dissipation on downstream side.
4. Compare experimental works of project which is done on the Ansys fluent with the manual approach.

CHAPTER 2

LITERATURE REVIEW

2.1 GEORGE C CHRISTODOULOU (1993)

They conducted the experiment of the energy dissipation of stepped spillway in the laboratory. The flow was considered to be skimming. A moderate number of steps are considered and the ratio of step height to width is kept 0.7. They concluded, the most significant parameters on which the energy dissipation is depend is the ratio of critical depth of flow available over the spillway crest to the height of step (Yc/H) and the other one is number of steps (N). They also concluded that the energy dissipation was more when Yc/H ratio is near to unity and the energy dissipation goes on decreasing with its increasing value. The experiment was conducted at applied hydraulics laboratory situated in the national technical university of Athens. The angle of slope used was 55 degree with respect to horizontal. The spillway was divided into total 15 no of steps in which 7 steps on the curved part and 8 steps are on the straight part. Length of each step was 1.75 cm and height of each step as 2.5cm with l/h ratio as 0.7. Spillway was made of wood material and to avoid warping epoxy coating is done. The model was placed in a laboratory flume which has length of 10m and width 0.5m. The flume has bed slope of is 0.04 and supercritical flow is maintained at the downstream side so that formation of hydraulic jump does not occur.

2.2 M. R. CHAMANI AND N. RAJATRAMAN (1994)

They further extended and carried out the work of Horner and Essery (1969) (experimental work) who had indicated that the dissipation of energy of jet flow regime on a single step is due to mixing of jet with the recirculating back water. And the energy dissipation occurs because of formation of partial hydraulic jump on the deflected jet. They analysed in the experiment, the relative loss of energy on each step. They demonstrated the variation of ΔE/E with Yc. They have taken the ratio of critical depth to step height less than 0.8. They also introduced the concept of a factor (α) which is the cause of relative loss on each step and the value of α is determined using the results of Horner. They finally concluded that α is a dependent on the ratio of Yc/H and H/L where Yc is the critical depth of flow, L is the length of each step and H is the height of step. They also concluded as the ratio of Yc/H exceeds 0.8 then the energy losses becomes insignificant means very less.

2.3 ROBERT M BOES AND WILLI H HAGER (2003)

They conducted the experiment on a big model of flume using fiber optical as instrumentation and indicated that the skimming flow is a function of chute angle, step height and critical depth. Homogeneous mixture depths are used to determine the height of chute sidewalls. Uniform equivalent clear water depths are generally described in form of a roughness Froude number which contains unit discharge, step height and chute angle. The spillway length is required to attain a uniform flow which is expressed as function of critical depth of flow and chute angle. The flow resistance of stepped spillway is considerably larger compared to the smooth chutes because of Marco roughness of steps. The friction factor for uniformly aerated flow is taken as 0.1 for typical gravity dam and embankment dam slopes where the relative roughness effect is very small.

2.4 SAMAN ABBASI AND AMIR KAMANBEDAST (2012)

Their aim of experiment was to investigate the effect of changes in dimension and hydraulics (flow condition) of stepped spillway in order to study energy dissipation. The software which is used in experiment was CFX. They found out the comparison of their work with the work of rajatram and salmasi and finally, found out the percentage error in the results. They also found out the effect of variation of number of steps, step height and discharge on the energy dissipation.

2.5 HAMID REZA VOSOUGHIFAR AND AZAM DOLATSHAH (2013)

Their study was concerned with the development of computational dynamics of fluid code which is known as V flow with the help of MATLAB for a 2-dimensional modelling of unsteady flow over a stepped spillway. V Flow can be analysed with GAMBIT software and modelling for that can be done for varying spillway geometries using linear mesh elements. For solving the governing equations, the volume of fluid method was used. Moreover, flow over the spillway was considered to be laminar. For the purpose of discretization, power law scheme, the implicit time approximation, gauss siedel method and simple algorithm were used. For the purpose of validation, the simulation of the experimental model using both v flow and the fluent software was done. Results of both obtained and they were in good agreement with each other.

2.6 MOUSSA RASSAEI AND SEGHEH RAHBAR (2014)

They experiment on the stepped spillway to maximize the energy dissipation. For their method of study, they used computer software. ANSYS fluent software is used in their study. For the analysis purpose, the regular mesh was used. The finite volume method is used in order to solve the governing Navier stokes equation and k-€ turbulence model was used in order to access the turbulence effect.

To validated the results, they compared their results with the work which done by the other researchers who did same experiments and validated their results. Their results were better than most of the other researchers because of turbulence model is incorporated in the latest version of ANSYS fluent.

CHAPTER 3

MAKING MODEL

3.1 GEOMETRY SET UP

The geometry for the stepped spillway is going to create in the design modular of ANSYS workbench. In this thesis, a total of 8 models has been created in which there are 3 variants of discharge and 5 variants of step size. The creation of geometry in design modular of ANSYS is a very cautious and difficult task because the overlapping of any two nodes should be done carefully otherwise creates an error. A small gap left between any two nodes can disable the geometry to be generated. The dimensioning of the model is as per the given model requirements which are given below. Slope of steps is taken as 30 degree. While creating the geometry, inlets of water and air both the fluids have been specified properly. This is necessary because in open channel flows, without defining the interface between the two different fluids computations cannot be carried out.

3.2 MESHING

Meshing of the structure means discretization or fragmentation of the whole fluid domain so that analysis can be done block by block of the flow in the domain region. Analysis will not consider the whole domain but, analysis will proceed from one cell to another cell. Meshing is required so that solver will be able to solve for numerous equations because the complex geometrical model is now divided into a finite number of standard shapes.

3.3 FLUENT SET UP

After meshing step done, for a particular model, first and foremost step is to defining of gravity in negative direction which is in y direction. The flow over the spillway includes movement in the both X and Y directions. The governing equations for computing the results in Ansys are Reynolds averaged Navier stoke equation which accounts for the conservation of mass and conservation of momentum principle. Volume of fluid model is generally used for defining of intermixing of 2 different fluids and k € model has been used for accessing the effect of turbulence.

3.4 MATERIALS

Define 2 materials of fluid: water and air

3.5 BOUNDARY CONDITION

3.5.1 Inlet

The inlet condition was further divided into two – air inlet and water inlet. First of all, we assign air as inlet fluid for whole domain. Then with the help of the technique of patching, the fraction of air for the region is given zero up to a height of water over the crest of the spillway.

This will automatically fill that portion of the geometry with the water creating the 2-phase inlet. Pressure inlet is applied as inlet for air. The inlet for the water is mass flow rate which is discharge taken in experiment.

3.5.2 Symmetric boundary conditions

If there is no flow across the boundary, in this case velocities normal to the boundary will be assigned to be zero. However, the scalar flux from the boundary is zero. The cases where symmetric boundary conditions are going to be used, the values of ascribes immediate to the domain of the solution are taken as the values at the nearest node within the domain.

3.5.3 Wall boundary conditions

No slip boundary condition will be assigned as wall boundary condition. This boundary condition is the most common condition which is used in the confined fluid flow problems. This is the most appropriate and important condition for the flow velocity components at the wall.

Out of both components of velocity, the normal velocity component can be initialized with zero velocity and tangential velocity component is initialized with the velocity of the wall i.e. velocity of wall.

3.5.4 Outlet

At the downstream end of the spillway (At outlet), the pressure boundary condition will be assigned.

3.6 SOLUTION

The next step of process is to initialize the solution. The no. of iterations is to be done and the solution is computed until it is converged. It is necessary for a solution to get to be converged. After the analysis, under CFX-POST which is embedded in ANSYS workbench can be used to view the results. Upwind scheme is very simple and one of the most stable techniques for discretization characterization by a feature that it is more dissipative in accordance to the flow. It will make the use of the upstream value in the domain region so that it is easy to find out the property on the boundaries of these cells and then makes their use to ascertain the values at the centre of each cell. By this way the chain will propagate from one end of the domain to another end.

CHAPTER 4

NUMERICAL DATA AND RESULTS

4.1 SELECTION OF MODEL

(1) I have selected the model of stepped spillway of height 1m because I have compared my results with George C, M R Chamani, Saman Abbasi. Saman Abbasi had conducted the experiment on Ansys Fluent and his model size of stepped spillway is 1m.

(2) Saman Abbasi conducted the experiment on stepped spillway of slope varying from (30 – 55) degrees. He concluded that max energy dissipation on stepped spillway is when angle of slope is 30 degree. So, slope of model is taken as 30 degree.

(3) Saman Abbasi consider flow over spillway is nappe flow which is super critical condition.

So, discharge and depth of flow are taken such that flow condition will be super critical.

(4) Velocity of flow is taken as 2m/s because the flow surface was considered as rough concrete surface and velocity range for rough concrete is 1.5-2 m/s.

(5) To compare results, experiments are done on Ansys Fluent for variation in different no of steps and different discharges.

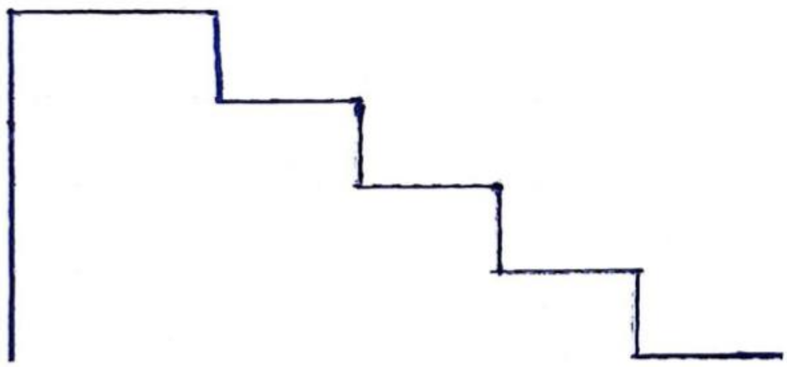
4.2 VARIATION IN NUMBER OF STEPS

4.2.1 Model Specification:

Height of Spillway = 1m
Length of Spillway = 1.725m
Width of Spillway = 0.5m
Angle of Slope = 30 (degree)
No of Steps = 4,6,8,10,12
Velocity of Flow = 2m/s
Depth of flow = 0.05 m
Discharge = 0.1 sqm/s

Critical Depth of Flow = 0.1m
Froude No. = 2.855

4.2.2 MODEL 1



(Figure 4.2.2 Model 1)

No of Steps = 4

Step height = 0.25m

Step length = 0.433m

Total height of spillway = 1m

Total length of spillway = 1.725m

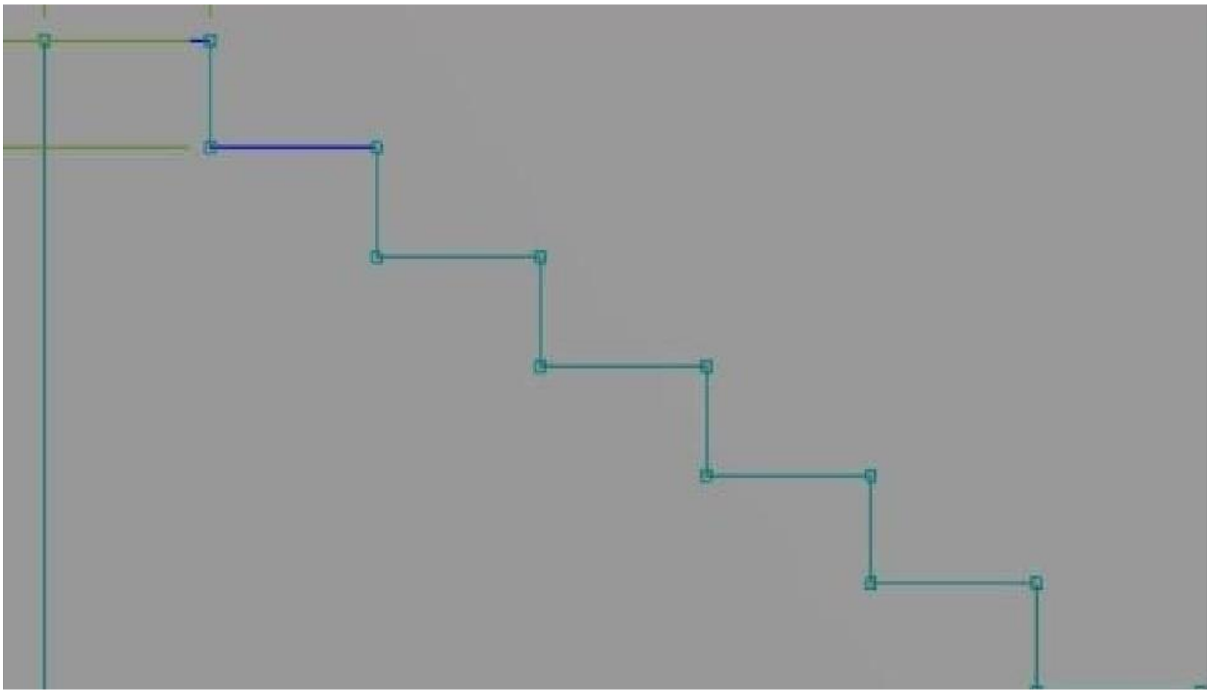
Ratio of critical depth to step height (Yc/H) =0.4

Table 4.2.2 Model 1

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2	0.2	621.10	1	1.263	E_0
1	1.60	0.130	-232.21	0.75	0.856	E_1
2	1.59	0.128	-121.32	0.50	0.615	E_2
3	1.65	0.138	220.61	0.25	0.41	E_3
4	1.53	0.119	578.26	0	0.178	E_4

Energy dissipation = $(E_0 - E_4)/E_0$ = 85.9%

4.2.3 MODEL 2



(Figure 4.2.3 Model 2)

No of Steps = 6

Step height = 0.167m

Step length = 0.288m

Total height of spillway = 1m

Total length of spillway = 1.725m

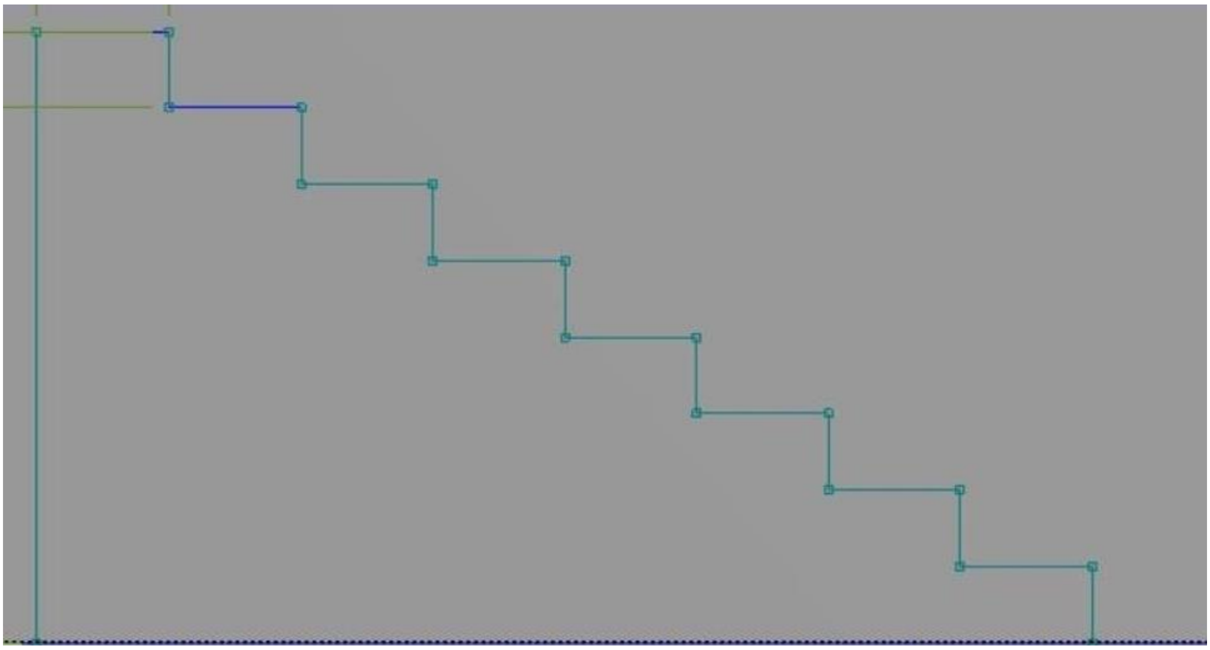
Ratio of critical depth to step height (Yc/H) = 0.6

Table 4.2.3 Model 2

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2	0.2	621.10	1	1.263	**E_0**
1	1.71	0.149	658.21	0.833	1.049	**E_1**
2	1.63	0.135	615.46	0.666	0.863	**E_2**
3	1.56	0.124	599.61	0.5	0.685	**E_3**
4	1.53	0.119	581.26	0.333	0.511	**E_4**
5	1.51	0.116	662.05	0.166	0.35	**E_5**
6	1.50	0.1146	553.21	0	0.171	**E_6**

Energy Dissipation $(E_0-E_6)/E_0 = 86.53$ %

4.2.4 MODEL 3



(Figure 4.2.4 Model 3)

No of Steps = 8

Step height = 0.125m

Step length = 0.2165m

Total height of spillway = 1m

Total length of spillway = 1.725m

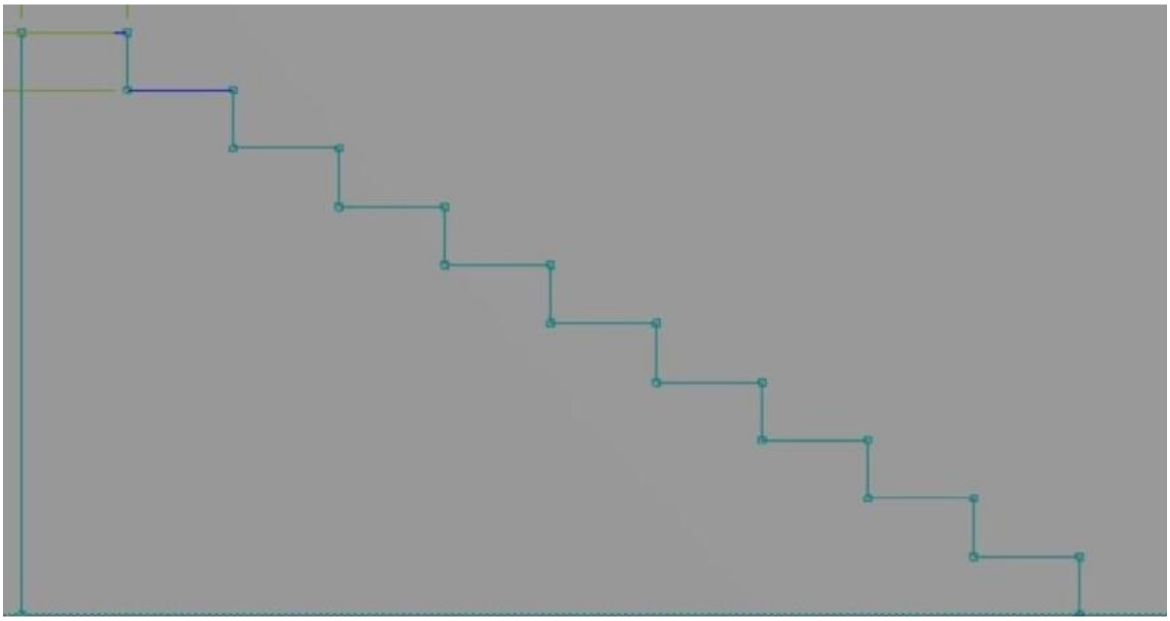
Ratio of critical depth to step height (Yc/H) = 0.8

Table 2.4.4 Model 3

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	623.21	1	1.263	E_0
1	1.74	0.1543	790.17	0.875	1.10	E_1
2	1.68	0.1438	757.46	0.75	0.97	E_2
3	1.63	0.1354	723.54	0.625	0.834	E_3
4	1.55	0.1224	699.65	0.50	0.693	E_4
5	1.49	0.1131	671.43	0.375	0.556	E_5
6	1.41	0.1013	758.81	0.250	0.428	E_6
7	1.37	0.0956	808.65	0.125	0.30	E_7
8	1.35	0.0928	651.20	0	0.159	E_8

Energy Dissipation $(E_0-E_8)/E_0$ = 87.40 %

4.2.5 MODEL 4



(Figure 4.2.5 Model 4)

No of Steps = 10

Step height = 0.1m

Step length = 0.1732m

Total height of spillway = 1m

Total length of spillway = 1.725m

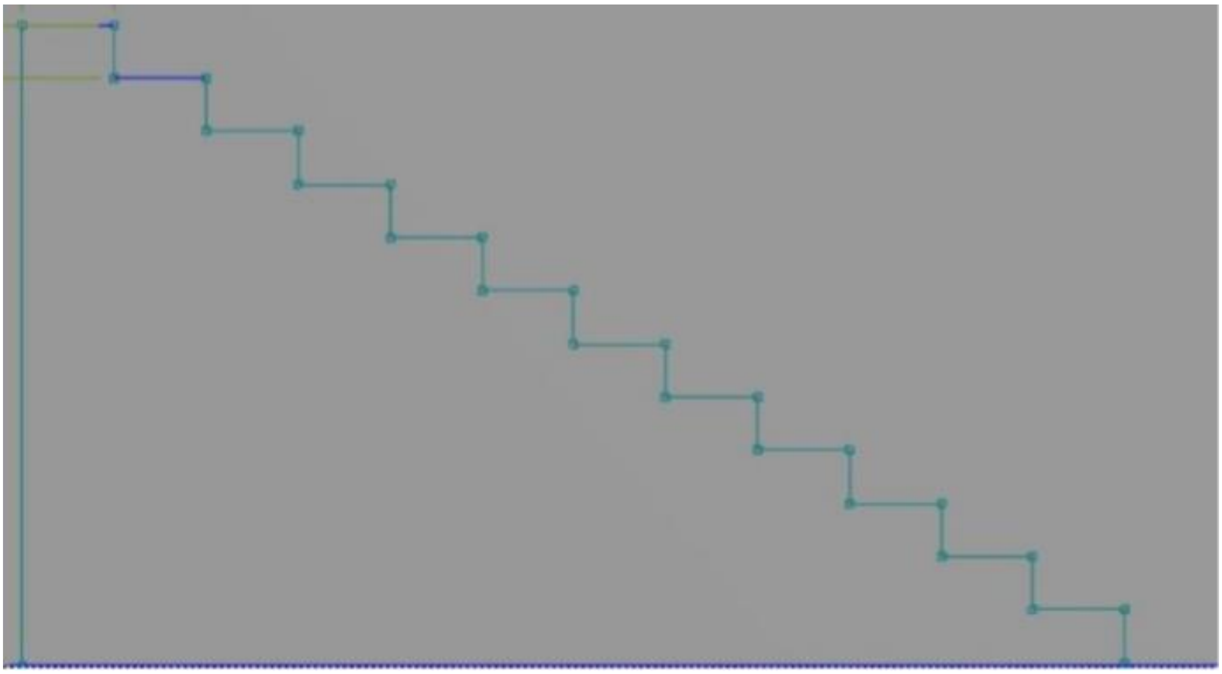
Ratio of critical depth to step height (Yc/H) = 1

Table 4.2.5 Model 4

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	623.21	1	1.263	**E_0**
1	1.77	0.1596	812.43	0.9	1.142	**E_1**
2	1.68	0.1438	789.04	0.8	1.024	**E_2**
3	1.62	0.1337	771.61	0.7	0.912	**E_3**
4	1.55	0.1224	770.05	0.6	0.80	**E_4**
5	1.52	0.1177	753.04	0.5	0.694	**E_5**
6	1.48	0.1116	748.19	0.4	0.587	**E_6**
7	1.41	0.1013	702.21	0.3	0.472	**E_7**
8	1.35	0.0928	770.51	0.2	0.371	**E_8**
9	1.28	0.0835	720.20	0.1	0.256	**E_9**
10	1.26	0.0809	687.60	0	0.151	**E_{10}**

Energy Dissipation $(E_0-E_{10})/E_0 = 88.04$ %

4.2.6 MODEL 5



(Figure 4.2.6 Model 5)

No of Steps = 12

Step height = 0.0833m

Step length = 0.1443m

Total height of spillway = 1m

Total length of spillway = 1.725m

Ratio of critical depth to step height (Yc/H) = 1.2

Table 4.2.6 Model 5

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	622.32	1	1.263	E_0
1	1.79	0.1633	728.32	0.916	1.153	E_1
2	1.61	0.1321	839.32	0.833	1.05	E_2
3	1.55	0.1224	791.71	0.75	0.953	E_3
4	1.51	0.1162	768.30	0.666	0.86	E_4
5	1.48	0.1116	753.04	0.583	0.771	E_5
6	1.46	0.1086	739.90	0.50	0.684	E_6
7	1.45	0.1071	721.21	0.416	0.596	E_7
8	1.41	0.1013	707.40	0.333	0.506	E_8
9	1.34	0.0915	698.20	0.25	0.412	E_9
10	1.23	0.0771	782.80	0.166	0.322	E_{10}
11	1.19	0.0721	876.90	0.083	0.244	E_{11}
12	1.18	0.0709	971.20	0	0.17	E_{12}

Energy Dissipation $(E_0-E_{12})/E_0 = 86.50\ \%$

4.3 VARIATION WITH DISCHARGE

Model No. 3 and 4 gives maximum energy dissipation (Similar values) but model 3 is economically good. So, variation with discharge experiment is done on Model No 3.

4.3.1 Model Specifications:

No of Steps = 8

Step height = 0.125m

Step length = 0.2165m

Total height of spillway = 1m

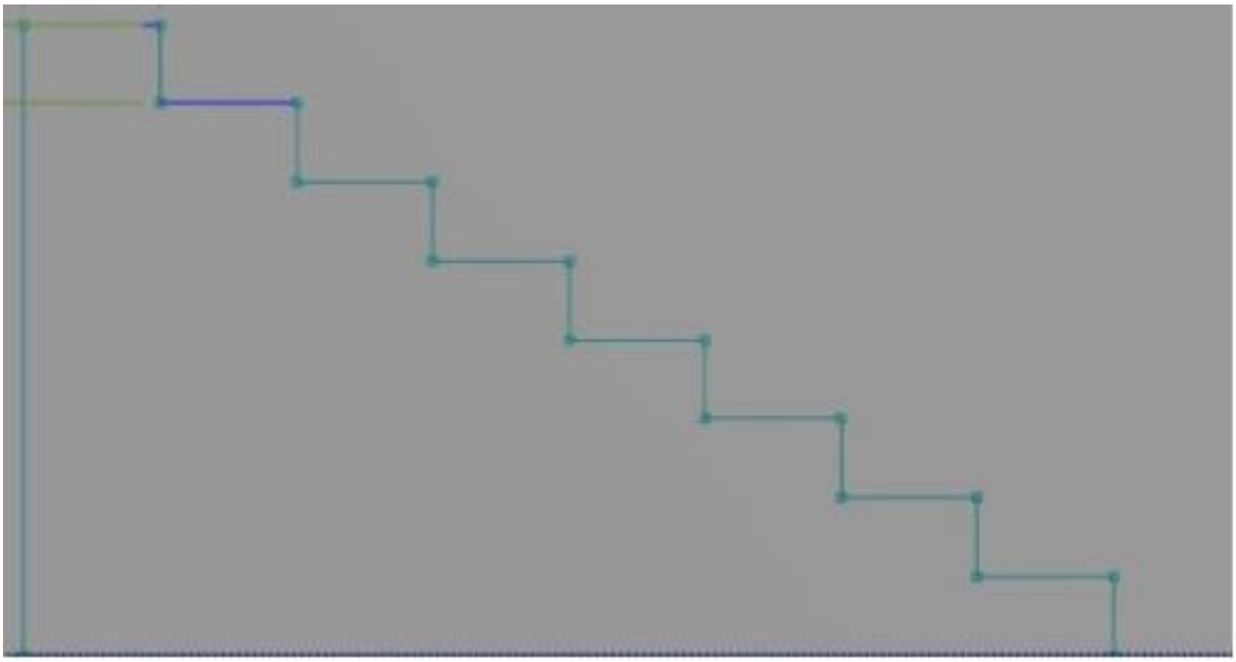
Total length of spillway = 1.725m

Angle of slope = 30(Degrees)

Velocity of flow = 2 m/s

Discharge = 0.1 m^2/s, 0.15 m^2/s, 0.2 m^2/s

Depth of flow = 0.05 m, 0.075 m, 0.1 m



(Figure 4.3.1 Model for Variation of Discharge)

4.3.2 MODEL 6

Velocity of flow = 2 m/s

Depth of flow = 0.05 m

Discharge = 0.1 m²/s

Critical Depth of Flow = 0.1m

Froude No = 2.855

Table 4.3.2 Model 6

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	623.21	1	1.263	E_0
1	1.74	0.1543	790.17	0.875	1.10	E_1
2	1.68	0.1438	757.46	0.75	0.97	E_2
3	1.63	0.1354	723.54	0.625	0.834	E_3
4	1.55	0.1224	699.65	0.50	0.693	E_4
5	1.49	0.1131	671.43	0.375	0.556	E_5
6	1.41	0.1013	758.81	0.250	0.428	E_6
7	1.37	0.0956	808.65	0.125	0.30	E_7
8	1.35	0.0928	651.20	0	0.159	E_8

Energy Dissipation $(E_0-E_8)/E_0$ = 87.40 %

4.3.3 MODEL 7

Velocity of flow = 2 m/s

Depth of flow = 0.075 m

Discharge = 0.15 m^2/s

Critical Depth of Flow = 0.13m

Froude No = 2.33

Table 4.3.3 Model 7

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	690.21	1	1.27	E_0
1	1.74	0.1543	810.05	0.875	1.11	E_1
2	1.68	0.1438	780.32	0.75	0.973	E_2
3	1.63	0.1354	721.53	0.625	0.829	E_3
4	1.55	0.1224	750.41	0.50	0.698	E_4
5	1.49	0.1131	673.20	0.375	0.558	E_5
6	1.41	0.1013	761.65	0.250	0.435	E_6
7	1.37	0.0956	810.30	0.125	0.315	E_7
8	1.35	0.0928	833.85	0	0.177	E_8

Energy Dissipation $(E_0-E_8)/E_0$ = 86.06 %

4.3.4 MODEL 8

Velocity of flow = 2 m/s

Depth of flow = 0.1 m

Discharge = 0.2 m^2/s

Critical Depth of Flow = 0.159 m

Froude No = 2.01

Table 4.3.4 Model 8

Step No	Velocity (m/s)	Velocity Head (m)	Pressure (Pa)	Elevation head (m)	Total Head (m)	
0	2.0	0.2	881.19	1	1.289	E_0
1	1.74	0.1543	920.23	0.875	1.123	E_1
2	1.68	0.1438	780.46	0.75	0.973	E_2
3	1.63	0.1354	750.54	0.625	0.836	E_3
4	1.55	0.1224	751.65	0.50	0.698	E_4
5	1.49	0.1131	671.43	0.375	0.556	E_5
6	1.41	0.1013	758.81	0.250	0.428	E_6
7	1.37	0.0956	808.65	0.125	0.30	E_7
8	1.35	0.0928	914.29	0	0.186	E_8

Energy Dissipation $(E_0-E_8)/E_0$ = 85.55 %

4.4 RESULTS

1. In Model No 1, energy dissipation is 85.9% but there is development of -ve pressure on step no. 1 and 2 which may lead to cavitation. So, Model 1 is rejected.

2. In Model No 2 energy dissipation increases to 85.53%.

3. In Model No 3 energy dissipation increases to 87.40%.

4. In Model No 4 energy dissipation is 88.04%. Increase in energy dissipation is insignificant from Model 3 to Model.

5. In Model No 5 energy dissipation is 86.50%. So energy dissipation decreases from Model 4 to Model 5.

6. As Discharge increases from Model 6 to Model 8, Energy dissipation decreases considerably.

4.5 COMPARISION OF ANSYS RESULTS WITH MANUAL APPROACH:

Formula for calculation of energy dissipation based on manual approach

$$\frac{\Delta H}{H_{max}} = 1 - \frac{0.54*\left(\frac{d_c}{h}\right)^{0.275} + 1.715*\left(\frac{d_c}{h}\right)^{-0.55}}{\frac{2}{3} + \frac{H_{dam}}{d_c}}$$

Hdam = Height of spillway (m)

Hmax = Total head (m)

dc = critical flow depth

ΔH = Head loss

h = step height

This Formula is given by Hobert Chanson in 1993. It is empirical Formula. This Formula is used my George C and M R Chamani for validation of their results

Table 4.5 Comparison of energy dissipation of manual approach with experimental results:

No. of steps	Energy dissipation from experiments	Energy dissipation from manual approach	% Error
4	85.9	81	5.7
6	86.53	82.27	4.9
8	87.40	83.69	4.2
10	88.04	84.63	3.87
12	86.5	83.79	3.13

CHAPTER 5

CONCLUSION

5.1 From the above computations, we can conclude the following things:

1. As ratio of critical depth (Yc) to step height (H) is less than or equal to **0.4** (Model No 1 Case), there is development of -ve pressure on step 1 and 2 which may lead to cavitation.

2. As ratio of critical depth (Yc) to step height (H) is between **0.4 to 0.8** (Model No 2 to Model No 3), there in increase of energy dissipation on stepped spillway.

3. As ratio of critical depth (Yc) to step height (H) is is between **0.8 to 1** (Model 3 to Model 4), increase in energy dissipation is insignificant which is verified with the results of **M R Chamani Research Paper**.

4. As ratio of critical depth (Yc) to step height (H) increase above **1** (Model 5), Energy dissipation decreases which is verified with the results of **George C Research paper**.

5. As Discharge increases on stepped spillway with constant step size (Model 6 to Model 8), Energy dissipation decreases which is verified with the results of **Saman Abbasi Research paper**.

6. As discharge is high over spillway then high pressure will develop which may cause failure of steps of spillway.

7. Energy dissipation is more if flow over steps of spillway is super critical i.e. depth of flow is less than critical depth of flow.

8. As flow changes from super critical to sub critical flow condition then energy dissipation decreases.

5.2 FUTURE SCOPE OF STUDY

1. Energy dissipation also depends upon the downstream slope which can be further studied.

2. Energy dissipation also depends upon slope at which water enters on steps, this can be studied.

3. This is 2-dimensional model, 3-dimensional model analysis can also be done and results can be compared with 2-dimensional analysis.

4. Energy dissipation is not uniform on each step, so spillway with non-uniform size analysis can be done.

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