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## **HYDRODYNAMIC MODELING OF FLOW OVER DIFFERENT TYPE OF STEPPED SPILLWAY**

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### **ABSTRACT**

The potential energy over the spillway has high discharge. This potential energy converts itself into kinetic energy when it starts flowing over the spillway, and fail downstream of the dam. Therefore it is very much essential to dissipate the kinetic energy to minimize the damage. In recent time lot of works are being done to improve the energy dissipation over the conventional type of spillways. In this research, investigate energy dissipation stepped spillways of different step shapes were considered. Physical wooden models were fabricated in the Bharati Vidyapeeth University, college of engineering. Three different shapes of the steps were reproduces such as; i) a step with 4 cm raise, 4 cm tread and 30 cm wide, ii) a step with 4 cm raise, 5 cm tread and 30 cm wide (adverse slope) and iii) a step with 4 cm raise, 5 cm tread and 30 cm wide (end sill) Experiments have been carried out for different conditions such as horizontal steps, end sill steps with thickness of 1 cm and steps with bottom adverse slope of 1:4. Overall, 180 experiments were done, the hydraulic parameters of flow over the model were measured and the energy dissipation of flow were calculated. From the results, it is clear that, energy loss is more in adverse slope and end sill experiments as compared to the horizontal step spillway, which is in conjunction with the general understanding.

**Keywords:** *Energy Dissipation, Stepped Spillway, End Sill Steps, Inclined Steps, Flow Regime*

### **INTRODUCTION**

Stepped spillways have been used for more than 3,000 years (Chanson, 1995, 1997). The development of new construction materials such as roller compacted concrete and strengthened gabion has created a renewed interest in stepped chutes. The steps increase the rate of energy dissipation and reduce the size of required downstream energy dissipation basin. Various investigator are trying to explore and obtain the best possible design/arrangement of steps to increase more and more energy dissipation and hence, reduction in basin. Even in spillways, the momentum approach has been found to agree well with the experimental data. Based on the experimental observations Essery and Horner (1971) and Sorensen (1985) classified the flow over stepped spillway into; Nappe flow regime or jet flow regime for lower discharges, Skimming flow regime for higher discharges and Transition flow for medium discharges.

A stepped spillway is an energy dissipater having profile made up of steps. It dissipates much more energy than other types of spillways, when water is flowing over the spillway profile. The stepped spillways are structurally stable, resistant to water loads and significantly increase the rate of energy dissipation on the spillway face thus eliminating or greatly reducing the need for a large energy dissipation basin at the spillway toe.

Two types of flow regime may occur above a stepped spillway: nappe flow and skimming flow. Peyras *et al.*, (1991, 1992) indicated two types of nappe flow: 1. Nappe flow with fully developed hydraulic jump for low discharge and small flow depth and 2. Nappe flow with partially developed hydraulic jump. The flow from each step hits the step below as a falling jet, with the energy dissipation occurring by jet breakup in air, by jet mixing on the step and by the formation of a fully developed or partial hydraulic jump on the step.

In the skimming flow regime, the water flows down the stepped is same as a coherent stream and skimming flow over the steps and cushioned by the recirculation fluid trapped between them. The flow is smooth along the upstream steps, and in this case air entrainment is not occurs. The flow is characterized

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by a large amount of flow aeration in downstream and a strong vortex at the step toes is occurs there. Most of the energy is dissipated by momentum transfer between the main stream and the recalcitrating fluid.

For small dams and weirs Ellis (1989) and Peyras *et al.*, (1991, 1992) suggested that nappe flow regime occurs when higher energy dissipation and then in the skimming flow regime. However nappe flow situations require relatively large steps. Such geometry is not often practical but may apply to flat spillways, streams and stepped channels.

**Crest Design and Deflecting Jet Flow**

The shape of the crest profile is important to achieve a proper flow behavior on the upstream steps. Model and prototype observations should be the possibility of the jet deflection at the first step (Chanson, 1997), if the upstream steps are too high. An analytical condition for jet deflection is –

$$\frac{dc}{h} < \frac{Fr^{1/\tau} \times \sqrt{1 + \frac{1}{Fr^{\tau}}}}{\sqrt{1 + \tau \times Fr^{\tau} \times (1 + \frac{1}{Fr^{\tau}})^{\tau/\tau} \times (1 - \frac{\cos \alpha b}{\sqrt{1 + \frac{1}{Fr^{\tau}}}})}} \quad \text{--- (3.1)}$$

Where,

- db = Flow and depth at brink
- αb = Angle between invert and horizontal.

**Energy Dissipation**

In skimming flow regime, the water flow exhibits large friction losses over the stepped bottom. Most of the energy is dissipated in maintaining recirculation vortices in the cavities beneath the Pseudo-bottom formed by step edges. If uniform flow conditions are reached before the end of the chute, analytical calculations of the energy dissipation can be developed (Chanson, 1993).

The total head loss along chute ΔH,

ΔH = Hmax – Residual head at the downstream end of channel H1

Hmax = Maximum Head = Hdam + 1.5 dc

For ungated spillway, Hmax = Hdam + H0

H0 = The reservoir free-surface elevation above chute crest.

Hdam = Dam crest head above downstream toe.

Chanson (1994) presented the following expression valid for free flow spillway and nappe flow with fully developed hydraulic jump.

$$\frac{\Delta H}{H_{max.}} = 1 - \left[ \frac{\frac{d^1}{dc} + \frac{1}{\tau} \times \left(\frac{dc}{d^1}\right)^{\tau}}{H_{dam} + H_0} \right] \quad \text{For gated chute --- (3.1)}$$

And

$$\frac{\Delta H}{H_{max.}} = 1 - \left[ \frac{\frac{d^1}{dc} + \frac{1}{\tau} \times \left(\frac{dc}{d^1}\right)^{\tau}}{\frac{\tau}{\tau} + \frac{H_{dam}}{dc}} \right] \quad \text{For ungated chute --- (3.2)}$$

Combining equation 3.1 and 3.2, total energy loss at toe of spillway is given by-

$$\frac{\Delta H}{H_{max.}} = 1 - \left[ \frac{1.0 \times \left(\frac{dc}{h}\right)^{1.75} + \frac{1.75 \times \tau}{\tau} \left(\frac{dc}{h}\right)^{-1.00}}{\frac{\tau}{\tau} + \frac{H_{dam}}{dc}} \right] \quad \text{--- (3.3 a)}$$

The energy dissipation on a stepped spillway is affected by several parameter such as the head of water above spillway crest (H), depth of flow over the step (D), step the model slope (h1), flow mean velocity

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(V), the density of water ( $\rho$ ), general slope of the model ( $\tan\alpha$ ), dynamic viscosity of fluid ( $\mu$ ) and acceleration due to gravity ( $g$ ) or;

$$f(E_f, E_0, E_1, H, D, h_1, V, \tan\alpha, \rho, \mu, g) = 0$$

Which  $E_1$  and  $E_0$  are flow kinetic energy at upstream and downstream of the stepped spillway respectively (Chanson, 2001), and  $E_f$  is the flow energy dissipation ( $E_f = E_1 - E_0$ ). The percentage of dissipated energy using dimensional analysis and experimental data of stepped spillways model was introduced by Barani et al (2005) as;

$$\% \text{ Energy loss (EL)} = 104.3304 (H/h_1) - 0.015 \text{CD}^{0.054}$$

$$\text{CD} = 3.285 \text{Re}^{-0.013} \text{Fr}^{-2.021} (D/h_1)^{0.015} (\tan\alpha)^{0.547}$$

### Experimental

An experimental investigation of the problem has been carried out in the Hydraulics laboratory of Bharati Vidyapeet College of Engineering, Pune. The aim features of the study involved in creating steeped spillway and to study the percentage of energy loss due to flow over the steppe spillway in a rectangular horizontal tilting flume for different flow conditions.

### Physical Model of Stepped Spillway

Three stepped spillway of height 0.34 m having a base width of 0.38 m was fabricated with the wood and covered with a sheet metal as per the desired design. These spillways were fixed with rapid curing adhesive at a distance of 2.0 m from the inlet to have a steady flow passing over the structure. At the test section, it was ensured that there is no leakage either from the bottom of the structure or from the sides. The base length of the spillway as designed for the upstream head 0.3 m so that the structure is able to sustain the water pressure and will be in stable condition.

In the present study different spillways with different stepped arrangements such as;

1. Horizontal steps having raise and tread of the same measurement with very mild slope of channel bed (1:10.000).
2. Horizontal steps having raise and tread of the same measurement with mild slope of channel bed (1:1000).
3. Steps with adverse slope (1V: 4H) with very mild slope of channel bed (1:10.000).
4. Steps with adverse slope (1V: 4H) with mild slope of channel bed (1:1000).
5. Steps with end sill with very mild slope of channel bed (1:10.000).
6. Steps with end sill with mild slope of channel bed (1:1000).

Were studies to know their effect on energy dissipation.

### Measurement of Data

Three trolley wheel assembly and point gauges of 1.0 m length with pinion and rack arrangement were used to measure the water depths.

Out of which one at the static head, second at the crest of the spillway to measure the head over the spillway and the other mounted on a carriage downstream to measure down stream flow depth. The depth of water in the flume was measured to the accuracy of 0.001 cm.



**Figure 1: Energy dissipation on downstream of stepped spillway with horizontal steps**

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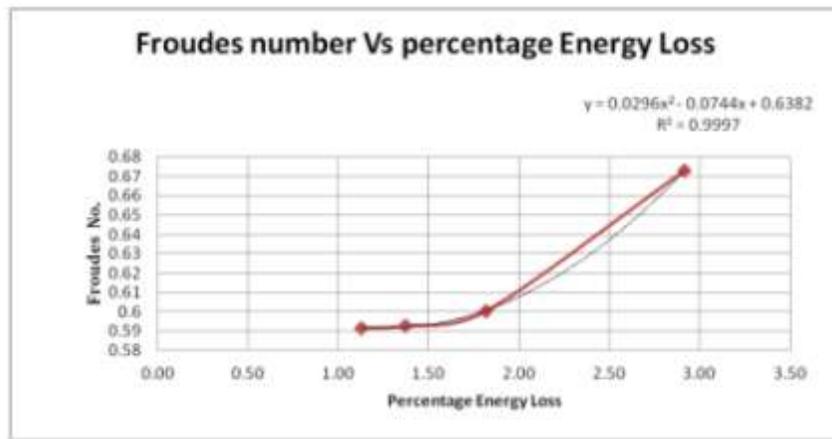
At the downstream end of the flume a rectangular collecting tank is made and excess water is allowed in a rectangular channel having a width of 0.45 m and a depth of 0.75 m which carries the flow to the underground storage tank. A sharp crested rhebock weir is fitted across the channel to measure the flow passing over the spillway. Provision has been made by providing a pointer gauge in a stilling well adjacent to this channel to measure the discharge.

**Experimental Procedure**

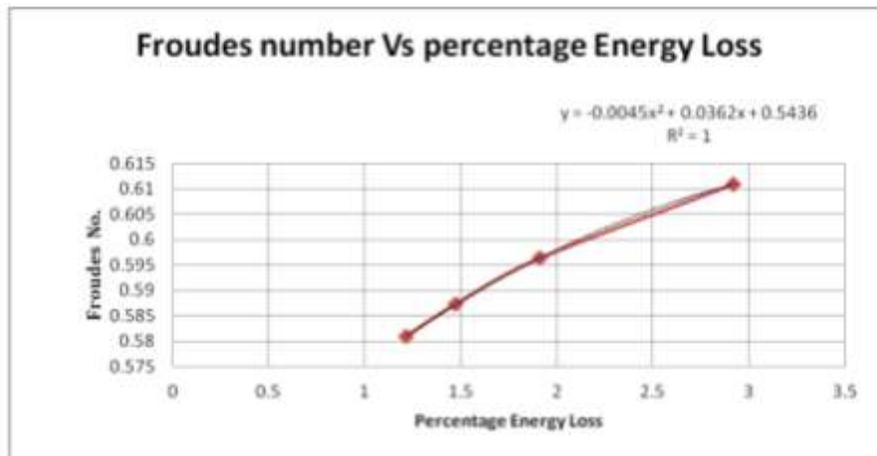
The head causing flow over the spillway was varied from 0.01m to 0.04 m. By controlling the upstream gate the water level was maintained for a particular discharge. With the help of pointer gauge mounted on a carriage on the upstream, downstream and at the crest of the spillway the water depth at these locations were measured. By collecting the head over the Rhebock weir for a particular head upstream of the spillway was measured repeatedly to get the accurate discharge. Similarly the experiments were repeated for different head of flow for different stepped condition. In all the conditions flow on the upstream of the spillway was steady with no turbulence.

**Type of Spillways Selected for the Study**

The height of spillway was kept 60% of the depth of flume so that the head causing flow may be varied between different ranges. In our study we varied head causing flow over the spillway from 3 to 12 % of the height of the spillway, varying the discharge range from 0.0006 to 0.004 cusecs. The range of geometric parameters of the steps is shown in figure 4.3.

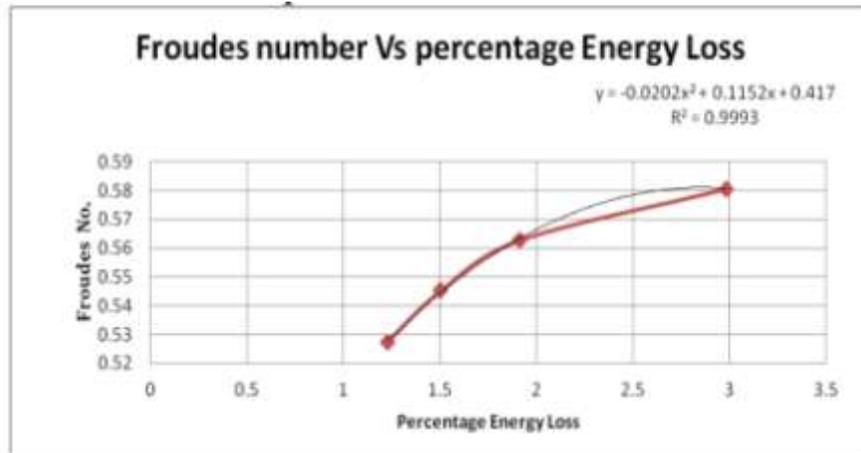


**Figure 2: Relationship between the percentages of energy loss, energy loss and Froude’s number on horizontal steps**

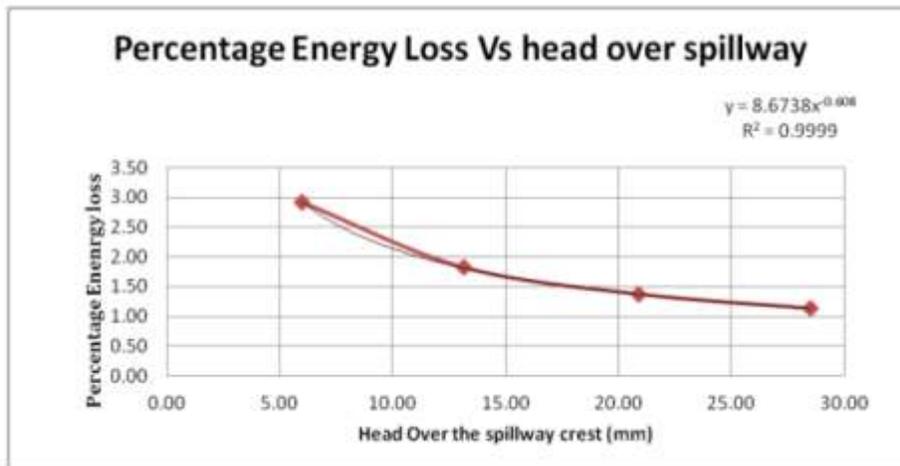


**Figure 3: Relationship between the percentage of and Froude’s number on adverse steps**

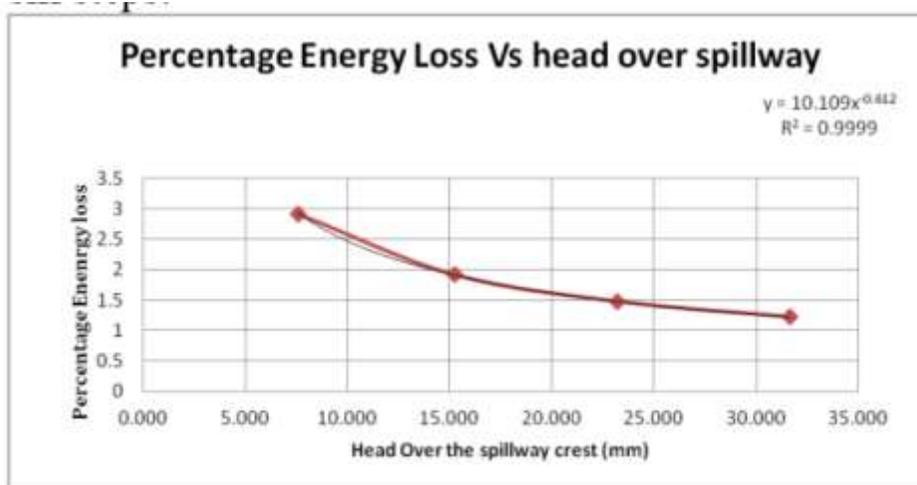
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**Figure 4: Relationship between the percentages of energy loss and Froude’s number on end sill steps**

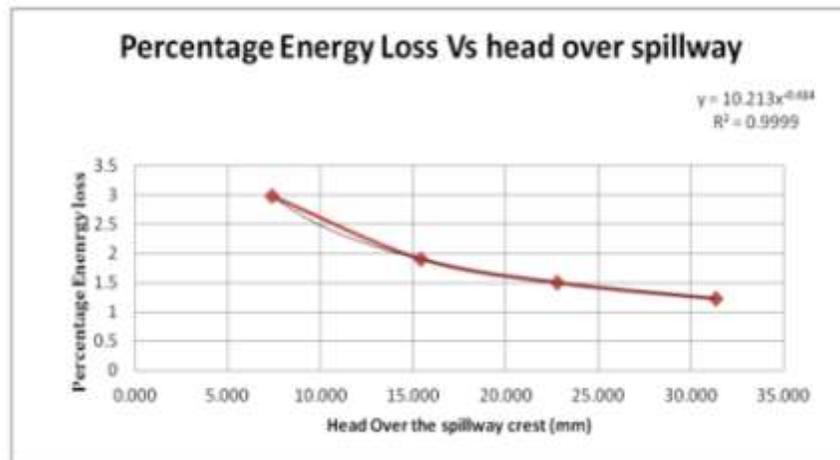


**Figure 5: Relationship between the percentage of energy loss, energy loss and Head over spillway on horizontal steps**



**Figure 6: Relationship between the percentage of and Head over spillway on adverse steps**

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**Figure 7:** Relationship between the percentage of energy loss and Head over spillway on end sill steps

### Analysis of Experimental Results

In the present investigation the following characteristics of the spillway were analyzed; the experiments were conducted for different shapes of steps on the spillway profile expressed as the ratio of raise to tread of the step. The experimental investigations were conducted for three different ratios such as 1:1, 1.25:1 (adverse slope), 1.25:1 (raise in end sill) with very mild slope (1:10.000) and mild slope (1:1000). The experiments were conducted in subcritical range of Froude's number and are varied between 0.5 to 0.7 and the discharge from 0.0006 to 0.004 cusecs. Altogether there were 180 experimental runs.

### CONCLUSION

The results of 180 experiments, which were carried out on the stepped spillway physical model with different step shapes (horizontal, adverse slope and end sill) both with very mild slope (1:10.000) and mild slope (1:1000) lead to the following conclusions;

1. The results of 180 experiments, which were conducted on the stepped spillway model with different stages of physical forms (plain, end sill and adverse) show that the energy dissipation of the flow on the stepped spillway model with adverse and end sill are more than plain form.
2. The energy loss in the flow over a spillway can be reduced by providing steps along the spillway profile.
3. The optimum value of reduction in energy loss was observed at higher Froude's Number around 0.7.
4. The percentage energy loss will be reduced with the increase in the head over the spillway.

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