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EXPERIMENTAL STUDY OF EFFECT OF SHAPE AND SIZE OF END SILL ON HYDRAULIC ENERGY DISSIPATION BEHAVIOR IN INCLINED SPILLWAY

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ABSTRACT
Changes in land use due to urbanization, intensive agricultural activities, poor or inappropriate supporting management practices and monoculture productions lead to accelerated soil erosion which proves to be a detrimental process both on-site and off-site. Soil erosion not only depletes soil depth, but also reduces the capacity of soil to hold water due to sealing, and affects adversely the available plant nutrients in the soil. This reduces soil productivity and causes long term reduction in crop yields, as the necessary plant nutrients are washed away. It has been estimated that due to erosion problems crop, production is becoming uneconomical on about 20 million hectares of land annually. This raises concern about the ability of land to feed the ever-increasing population. Moreover, water erosion also creates offsite environmental problems, such as water pollution, siltation of reservoirs and degradation of coastal ecosystems. It was observed that in case of triangular shaped end sill, the minimum hydraulic jump efficiency occurred in seven combinations of end sill height and discharge out of total 12 combinations tried and the minimum height of jump. Similarly, semi-circular, rectangular and diagonal vertical downstream shaped end sill provided maximum hydraulic jump efficiency in 4 cases out of 12 combinations tried for each while each of them provided minimum hydraulic jump efficiency only in one case. The diagonal vertical upstream shaped end sill provided minimum hydraulic jump efficiency and maximum hydraulic jump efficiency in only one case each. It was also found that the triangular shaped end sill resulted in minimum height of jump, in general, for different combinations of height and discharge. On the basis of above was therefore concluded that the triangular shaped end sill in general, provided the minimum hydraulic jump efficiency and the least height of jump for various combinations of end sill height and discharge and thus can be designated as the best performing end sill.

KEY WORD: hydraulic jump efficiency, end sill, height of jump.

INTRODUCTION

Stilling basins are normally used in reducing the excess energy downstream of hydraulic structure like over flow spillway, sluices, pipe outlets, *etc*. A stilling basin for a pipe outlet consists of appurtenances like splitter block, impact wall, intermediate sill and an end sill *etc*. The vertical end sill is a terminal element in the stilling basin, which has a great contribution in reduction of energy of flowing sheet of water and assists in to improve the flow pattern downstream of the channel thereby helps in reducing the length of stilling basin also. End sills are vertical, stepped, sloped or dentate/solid wall placed at the downstream end of the stilling basin. Its main function is to reduce the length of the hydraulic jump and to control scour in large basins that are designed to reduce high incoming velocities. The end sill is usually dentate to perform an additional function of diffusing the residual portion of the high velocity jet that may reach the end of the SAF Stilling basin. The end sill also helps in deflecting the bottom currents upward and away from the stream bed. In addition, a ground roller is created under the deflected stream, which brings bed material from downstream and deposits it at the end of the stilling basin. The effect of end sill on the flow and scour characteristics depends upon the configuration of the end sill, the end sill geometry and the flow regime. The end sill height, configuration and position have great impact on the formation and control of hydraulic jump and ultimately leading to the dissipation of energy of flowing water and also to optimize the hydraulic jump length. The several studies The step geometry of stepped spillway can be horizontal, inclined (upward or down ward) and pooled step. For a given chute geometry, the flow pattern may be either nappe flow at low flow rates, transition flow for intermediate discharges or skimming flow at larger flow rates (Chanson, 2001). Various types of recommended stilling basin designs for pipe outlets recommended (Fiala and Albertson, 1961; Keim, 1962; Goel and Verma, 2000; 2001; Achour and Dehabeche, 2003; Goel and Verma, 2003; Goel, 2008; Abbaspour *et al*., 2009; Ali and Mohamed, 2010; Alikhani *et al.,* 2010; Kumar *et al.,* 2010 and Mubeen, 2014). In all above mentioned studies, end sills used are either sloping Peterka (1957), or semicircular, Goel and Verma (2000). Tiwari (2013) inspected the energy dissipation by varying the gap of baffle wall in the stilling basin to protect the downstream structures from immense scouring. Experiments have been carried out for Froude number 3.85, 2.85, 1.85 with keeping the baffle wall at same location. Experiments resulted with much effect on the performance of the stilling basin by changing the gap underneath the wall from the basin floor due to change in floor pattern. During the study it was found that the flow condition as well as the scouring pattern in downstream of the stilling basin affected by the gap of impact wall in the basin. The present work deals with a study on hydraulic jump in stilling basin with different shapes such as, rectangular, triangular, semicircular, diagonal vertical upstream and diagonal vertical downstream of different sizes and to observe flow parameters and compare their efficacy in reducing the out flow velocity and hydraulic energy dissipation with the objective To observe hydraulic energy dissipation behavior in a SAF stilling basin for a particular shape of end sill of selected heights with varying discharge.

MATERIALS & METHODS

Description of Materials Used

An inclined spillway

To conduct experimentation, an inclined spillway with SAF stilling basin was used. An inclined spillway is a structure in which all or a part of the energy is dissipated. An inclined spillway, designed for a total drop of 63 cm and for design discharges of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec installed in the Department of Soil and Water Conservation Engineering laboratory was used for this study. A line diagram of the inclined spillway along with SAF stilling basin is shown in Fig 1. The spillway has a rectangular inlet section of 10cm x 12.5cm x 22cm size, a 190 cm long steep sloping channel section and a 132 cm long outlet section in the form of a SAF stilling basin. It is fabricated by using an approximately 3 mm thick metallic sheet.

End Sill

End sill may be described as a vertical, stepped, sloped or dentate/solid wall at the downstream end of the stilling basin. End sill plays an important role in the design of a stilling basin for reducing the length and also helps in improving the flow pattern at downstream of the channel. The effect of end sill on the flow and or scour characteristics depends on the configuration of the end sill, the end sill geometry and the flow regime. The end sill height, configuration and position have a great impact on the formation and control of hydraulic jump and ultimately leading to the dissipation of energy of flowing water, and also to optimize the hydraulic jump length.

METHODOLOGY

Fabrication of end sills of different shapes and heights

The end sill is usually dentate to perform an additional function of diffusing the residual portion of the high velocity jet that may reach the end of the SAF Stilling basin. The end sill height, configuration and position have great impact on the formation and control of hydraulic jump and ultimately leading to the dissipation of energy of flowing water and also to optimize the hydraulic jump length. In the present study, end sills with following shapes were used. (1)Rectangular end sill (RES), (2)Triangular end sill (TES), (3)Semicircular end sill (SCES), (4)Diagonal vertical upstream end sill (DVUES) and (5)Diagonal vertical downstream end sill (DVDES)The end sills of the above shapes were fabricated with heights of 3 cm, 4 cm and 5 cm with a base width of 4.0 cm and 10 cm length.

Fixing different shape and size of end sill

The different shapes and sizes of end sills were fixed one by one with the SAF stilling basin. At first the rectangular shape of end sill at selected heights of 3 cm, 4 cm and 5cm were fixed with the help of m-seal in the SAF stilling basin for selected discharges of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively, and observations were recorded for the flow depth at inlet and outlet sections. Then the triangular shaped end sill for the selected heights was fixed with the help of m-seal in the SAF stilling basin. Similar procedure was adopted to fix remaining shapes (semi-circular, diagonal vertical upstream, diagonal vertical downstream) end sills. In fact, to test 15 different end sills for their energy dissipation performance, 15 models of inclined spillway were required.

(a) Recording of hydraulic jump parameters

When hydraulic jump formation got stabilized in the stilling basin for particular set of conditions, observations were recorded. The flow depths at the inlet and outlet were observed to obtain the hydraulic jump parameters, such as flow energy at inlet, flow energy at outlet, total energy loss, hydraulic jump efficiency, and relative loss of energy and height of jump. The procedure was repeated every time for different conditions of end sill shape, size and discharge.

(b) Determination of hydraulic energy dissipation

The difference in the total flow energy at the inlet (E_i) of the test structure and at the outlet (E_0) of the test structure gives the total amount of energy dissipated (ΔE) between the two section. The total energy of flow comprises of the sum of position head, pressure head and velocity head at a point can be shown as below.

$$\Delta E = E_i - E_0 \quad \ldots\ldots\ldots.. (1)$$

$$E_i = Z_i + d_i + \frac{V_i^2}{2g} \quad \ldots. (2)$$

$$E_0 = Z_0 + d_0 + \frac{V_0^2}{2g} \quad \ldots. (3)$$

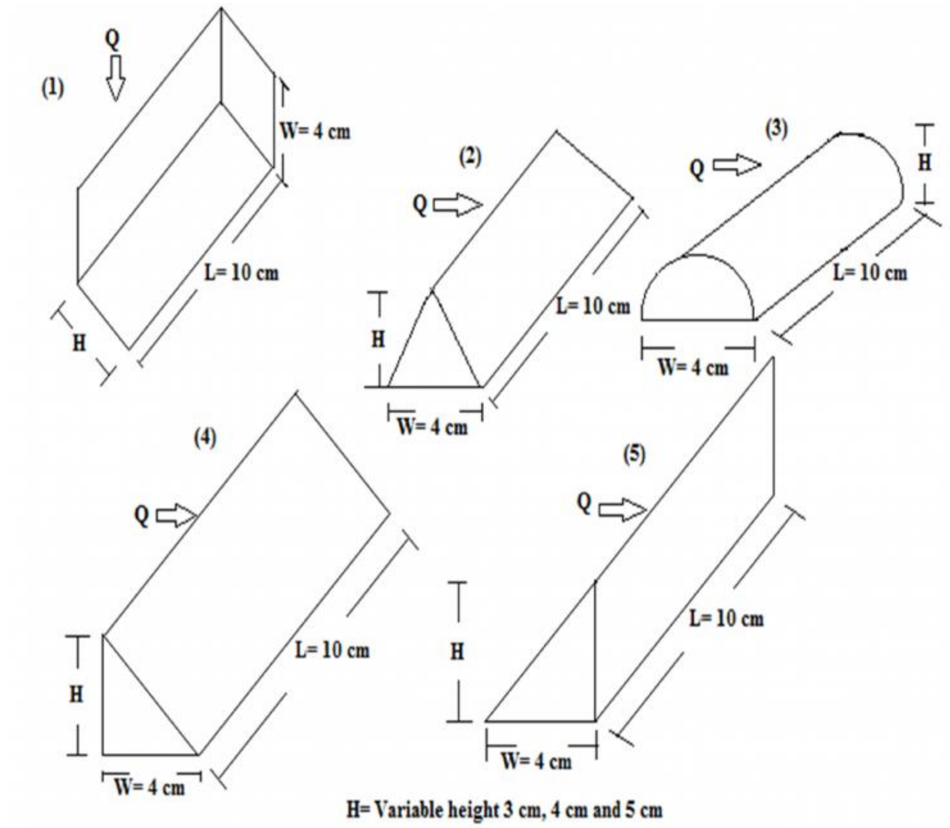
where, (Z) is the position head above a datum, (d) is the depth of flow. (V) is the velocity of flow, (g) is the gravitational acceleration. The suffix (i) and (o) denote inlet and outlet section respectively. The flow velocity before and after jump was determine to the delivery discharge with the cross-sectional area of the channel.

(c) Determination of hydraulic jump efficiency and relative loss

The hydraulic jump efficiency is the ratio of total flow energy at the outlet (E_0) of the test structure and total flow energy at the inlet (E_i) of the test structure. The hydraulic jump efficiency can be calculated by using the formula:

$$\text{JE} = (E_0/E_i) \times 100 \quad \ldots. (5)$$

The value of jump efficiency is the least when for a given amount of inflow energy (E_i), the value of outflow energy (E_o) is minimum. It means, the jump efficiency is minimum when the total amount of energy dissipation is maximum i.e., at the end sill, maximum energy dissipation will be the least efficient in terms of jump efficiency.



1. Rectangular end sill (RES), 2. Triangular end sill (TES)
3. Semi-circular end sill (SCES)
4. Diagonal vertical upstream end sill (DVUES)
5. Diagonal vertical downstream end sill (DVDES)

FIGURE 1: Line diagram showing different shapes of end sill

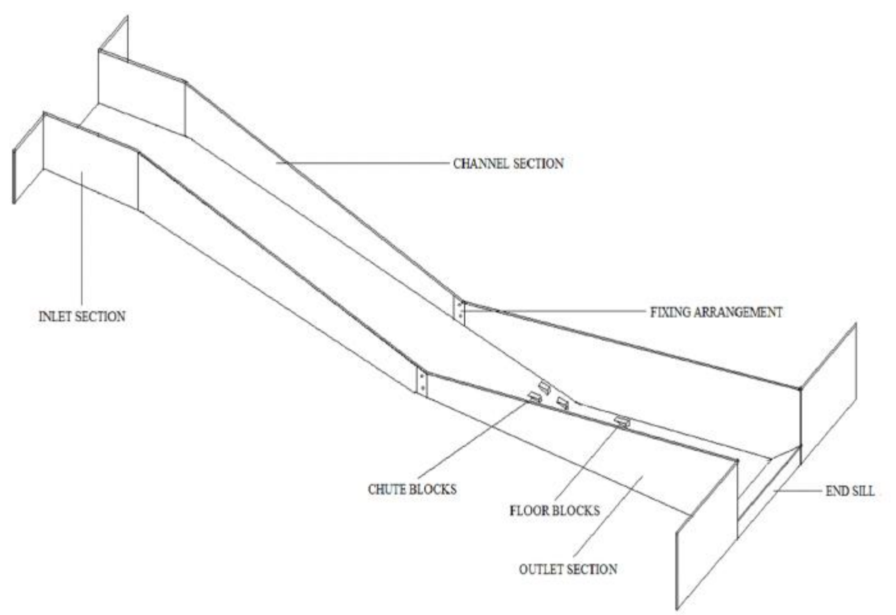


FIGURE 2: Isometric view of inclined spillway with S.A.F. stilling basin

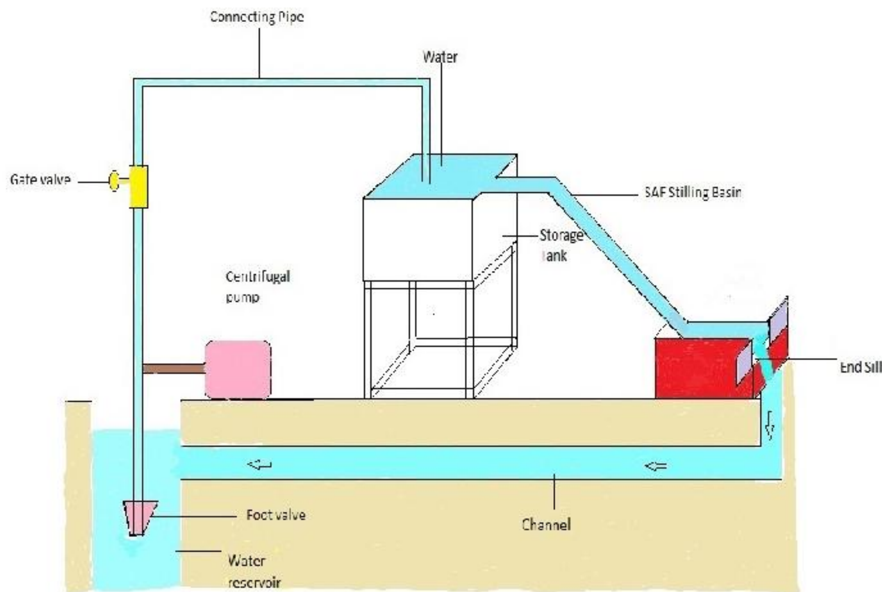


FIGURE 3: Line diagram of experimental set-up

RESULTS & DISCUSSION

Hydraulic energy dissipation behaviors using different heights of end sill for a particular shape at selected discharges

The recorded values of hydraulic jump parameters that for the rectangular end sill (RES) for all different heights of 3 cm, 4 cm and 5 cm in the selected range of discharge, the flow energy dissipated ranged from 41.713 cm to 45.927 cm, the relative loss of energy ranged from 57.917 cm to 62.966 cm while the hydraulic jump efficiency ranged from a minimum 37.033% to a maximum of 42.080%. The flow energy at inlet and outlet was found to be 68.390 cm and 25.327 cm resulting in the total energy dissipation of 43.063 cm at a discharge of 1.65 lit/sec for 3 cm height of end sill. Similarly, the total energy dissipation of 45.927cm, 44.282 cm and 44.032 cm was observed at discharges of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. In case of 4 cm height of end sill the flow energy at inlet and outlet was found to be 68.478 cm and 26.383 cm respectively resulting in the total energy dissipation of 42.195 cm. It was observed that the total energy dissipation of 43.600 cm, 43.336 cm and 43.503 cm occurred at discharges of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. Similarly in case of a 5 cm height of end sill, the total energy dissipation was found to be 41.763 cm, 43.488 cm, 42.507 cm and 42.320 cm at the corresponding discharges of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. It indicated that for all selected heights of end sill the minimum energy dissipation occurs at a discharge of 1.65 lit/sec while there was no definite trend for maximum energy dissipation at these heights of end sill. The graphical representation of hydraulic energy dissipation behavior for all selected heights of rectangular end sill (RES) for all selected discharges. In general it was found that that as the discharge is increasing the amount of energy dissipation has a decreasing trend for all selected end sill heights.

Hydraulic energy dissipation behavior using different heights for a triangular shape of end sill at selected discharges

The observed values of hydraulic jump parameter for the triangular shape of end sill (TES) of different heights (3cm, 4cm and 5cm) at all selected discharges of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec. It was found that for a 3cm high end sill, the flow energy at inlet and outlet was 68.390 cm and 25.327 cm resulting in total energy dissipation of 43.063 cm. Similarly the total energy dissipation of 45.927, 45.282 and 44.032 cm observed for the discharges of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec using a height of 3 cm for triangular end sill. In case of 4 cm height of end sill the flow energy at inlet and outlet was found to be 68.478 cm and 26.383 cm at a discharge of 1.65 lit/sec resulting in the total energy dissipation of 42.195 cm. The total energy loss of 43.600 cm, 43.396 cm and 43.502 cm was observed at the discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. In case of 5 cm height of end sill the total energy dissipation was found to be 41.763 cm, 43.488 cm, 42.507 cm and 42.320 cm at a discharge of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively.

The clearly indicate that for all selected heights of triangular end sill the maximum amount of total energy dissipation was found to be 45.282 cm at a discharge of 4.4 lit/sec and end sill height 4 cm for semi-circular. The graphical representation of hydraulic energy dissipation behavior for all selected heights of triangular shape of end sill as for all selected discharge. It was further observed that the trend of energy dissipation with discharge was found on the similar pattern as in case of rectangular end sill.

Hydraulic energy dissipation behavior using different heights for a semi-circular shape of end sill at selected discharges

The observations that for clearly indicate that for all selected heights of end sill, the minimum energy dissipation was found to be 41.427 cm at a discharge of 1.65 lit/sec for 5 cm height of end sill and the maximum amount of energy dissipation was observed to be 43.594 cm at a discharge of 4.90 lit/sec for 4 cm height of end sill. The recorded values of hydraulic jump parameters further indicate that for the semi-circular end sill (SCES) for all different heights of the selected discharge range the flow energy at inlet and outlet was found to be 69.082cm and 25.678 cm resulting in the total energy dissipation of 43.404 cm at a discharge of 1.65 lit/sec for 3 cm height of end sill. While the total energy dissipation of 43.667 cm, 43.547 cm and 43.432 cm was observed at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. In case of 4 cm height of end sill the flow energy at inlet outlet was found to be 68.430 cm and 26.283 cm resulting in the total energy dissipation of 42.147 cm while the total energy dissipation of 43.590 cm, 42.919 cm and 43.056 cm was recorded at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. Similarly, with 5 cm height of end sill the total energy dissipation was found to be 41.427 cm, 43.139 cm, 41.637 cm and 42.367 cm at a discharge of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively.

The observations related to energy dissipation recorded for various combinations of discharge and height of end sill for semicircular shaping end sill were plotted. The graphical representation of hydraulic energy dissipation for semi-circular end sill (SCES) for all selected discharge indicates that similar to earlier cases there was a decreasing trend with the increasing discharge.

Hydraulic energy dissipation behavior using different heights for a diagonal vertical upstream shape of end sill at selected discharges

The hydraulic energy dissipation behavior using different heights for a diagonal vertical upstream shape of end sill at selected discharges was observed by recording hydraulic jump parameters for varying discharge. The observed values of hydraulic jump parameters for this case are recorded, which clearly indicate that for the diagonal vertical downstream end sill (DVUES) of selected heights of 3 cm, 4 cm and 5 cm for discharges of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec were found to be ranging from a maximum of 62.882 cm for 3cm height at 1.65 lit/sec discharge and a minimum of 55.749 cm for 5cm height and 5.50 lit/sec discharge. The flow energy at inlet and outlet was found to be 62.882 cm and 25.370 cm resulting that total energy dissipation of 37.512 cm for 3cm height at 1.65 lit/sec discharges. Similarly, the total energy dissipation of 45.310 cm, 44.166 cm and 43.787 cm was observed at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively for a height of 3 cm diagonal vertical upstream end sill. In case of 4 cm height of end sill the flow energy at inlet and outlet was found to be 68.511 cm and 26.934 cm at a discharge of 1.65 lit/sec resulting in the total energy dissipation of 41.577 cm. The total energy loss of 44.871 cm, 43.248 cm and 42.401 cm was observed at discharge of 4.4 lit/sec., 4.9 lit/sec. and 5.5 lit/sec. In case of 5 cm height of end sill the total energy dissipation was found to be 40.758 cm, 42.883 cm, 41.120 cm and 41.519 cm at a discharge of 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively.

The observation recorded and the graphical representation of hydraulic energy dissipation as clearly indicate that for all selected heights of diagonal vertical upstream end sill the maximum amount of total energy dissipation was found to be 45.310 cm with height of end sill 3 cm at a discharge of 4.4 lit/sec. Interestingly, the amount of energy dissipation for different heights of end sill initially increased as the discharge was increased from 1.65 lit/sec to 4.4 lit /sec after that the further increase in discharge resulted in the decrease in amount of energy dissipated.

Hydraulic energy dissipation behavior using different heights for a diagonal vertical downstream shape of end sill at selected discharges

The observation recorded and the graphical representation of hydraulic energy dissipation is clearly indicate that for all selected heights of diagonal vertical upstream end sill the maximum amount of total energy dissipation was found to be 45.431 cm with height of end sill 3 cm at a discharge of 4.4 lit/sec. Similar to earlier case in this case also the amount of energy dissipation for different heights of end sill initially increased as the discharge was increased from 1.65 lit/sec to 4.4 lit /sec after that the further increase in discharge resulted in the decrease in amount of energy dissipated diagonal vertical downstream end sill (DVDES) for all different heights. The flow energy at inlet and outlet was found to be 68.904 cm and 24.986 cm resulting in the total energy dissipation of 43.928 cm at a discharge of 1.65 lit/sec for 3 cm height of end sill. The total amount of energy dissipation of 45.431 cm, 43.546 cm and 43.666 cm was observed at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. In case of 4 cm height of end sill the flow energy at inlet outlet was found to be 68.851 cm and 26.934 cm resulting in the total energy dissipation of 41.917 cm. Similarly, the total energy dissipation of 42.942 cm, 41.058 cm and 41.069 cm was found at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively. The total amount of energy dissipation was found to be 41.482 cm, 42.965 cm, 41.238 cm and 40.515 cm was observed with 5 cm height of end sill at a discharge of 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec respectively.

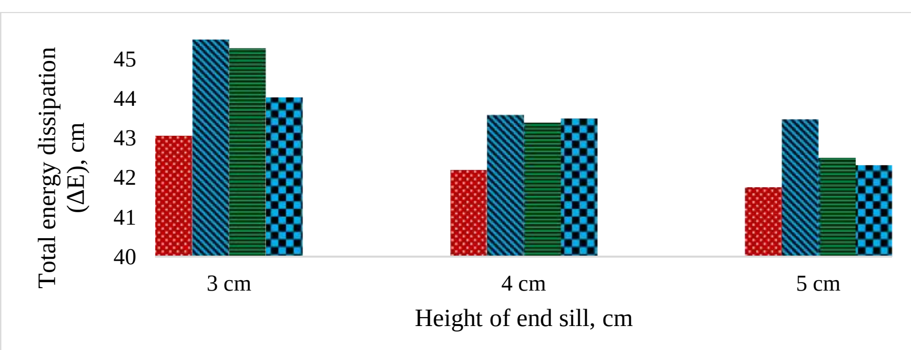


FIGURE 5. Triangular end sill

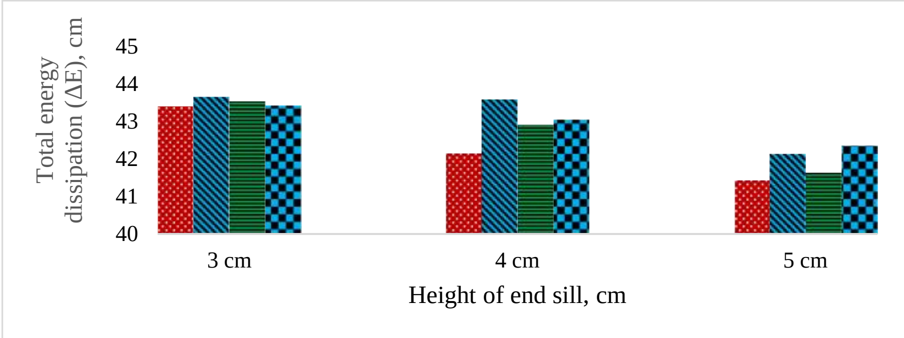


FIGURE 6: Semicircular end sill

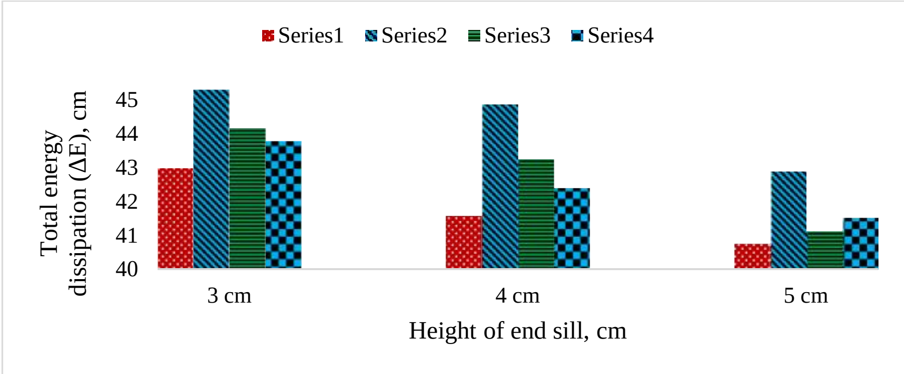


FIGURE 7: Diagonal vertical upstream end sill

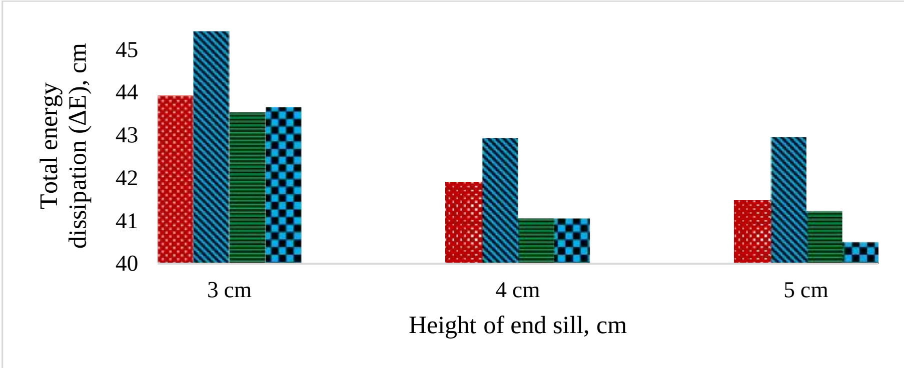


FIGURE 8: Diagonal vertical downstream end sill

SUMMARY AND COCLUSSION

In this study, laboratory experiment was conducted to observe hydraulic energy dissipation behavior through the formation of hydraulic jump in an inclined spillway using SAF stilling basin. The observation were recorded using different shapes of end sill such as rectangular end sill (RES), triangular end sill (TES), semi-circular end sill (SCES), diagonal vertical upstream end sill (DVUES) and diagonal vertical downstream end sill (DVDES). These end sills were used with heights of 3 cm, 4 cm and 5 cm at selected discharge 1.65 lit/sec, 4.4 lit/sec, 4.9 lit/sec and 5.5 lit/sec. The various flow parameters were experimentally observed for 60 different combinations of end sill shape, discharge and height of end sill and compared for assessing their impact on hydraulic jump parameters. Based on the analysis of the observed data in the present study, the following specific conclusions could be drawn. Triangular shaped end sill, it provided the maximum relative loss of energy in 07 combinations of end sill height and discharge out of total 12 combinations tried and in no case it provided the minimum energy loss. (2)Semi-circular, rectangular and diagonal vertical downstream shaped end sill provided minimum energy loss in 4 cases out of 12 combinations tried for each while each of them provided maximum energy loss only in one case. (3)The diagonal vertical upstream shaped end sill provided maximum and minimum relative energy loss in only one case each. (4)The triangular shaped end sill resulted in minimum height of jump, in general, for different combinations of height and discharge. On the basis of above can therefore be concluded that the triangular shaped end sill in general, provided the maximum relative energy loss and the least height of jump for various combinations of end sill height and discharge and thus can be designated as the best performing end sill.

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