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Reduction of Scour Depth Downstream of Pipe Outlet Stilling Basin Using End Sill

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Abstract

This paper presents an experimental study about scour pattern downstream of stilling basin for non circular pipe outlet using end sill of different geometry. The study was conducted by designing new stilling basin models in a rectangular shaped pipe outlet of size 10.8cm x 6.3 cm with three inflow Froude numbers namely, Fr = 1.85, 2.85 and 3.85. To study the scour pattern downstream of stilling basin, total 33 test runs were conducted using same test run time and sand bed material. The scour pattern (depth and location) after the end sill were measured for each test run. The study indicates that there is a significant effect of the shape of the end sill geometry on the reduction of scour depth downstream of end sill for the pipe outlet stilling basin.

Keywords: Froude number, Scour depth, Stilling-basin. Pipe.

Introduction

To prevent the scouring of the riverbed and failure of the structure, stilling basins are commonly used for the purpose of dissipating the excessive kinetic energy of flowing water downstream of the hydraulic structures.[1]

Appurtenances play an important role in the reduction of scour depth downstream of the stilling basin. 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. The 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. Several shapes of the end sill have been used by many investigators such as vertical, stepped, sloped or dentated / solid wall, etc[2]. In the USBR stilling basin type VI model, a sloping end sill is used as proposed by Bradely and Peterka[3] while Garde et al.[4], Verma and Goel[5] have recommended a semi circular shaped end sill as well. Tiwari[6] also worked for the design of stilling basin model using sloping end sill.

The present research paper investigates the effect geometry of the end sill on scour pattern downstream of stilling basin for rectangular pipe outlet in comparison to USBR impact type VI stilling basin model keeping same length of basin. Different types of end sill used are shown in figure 1.

Materials and Methods

Flume and Stilling Basin: To attain the purpose of this study, experimental investigations were carried out in a recirculating flume of dimensions 0.95 meter wide, 1 meter deep and 25 meter long in the hydraulics laboratory of Civil Engineering Department of MANIT Bhopal. The width of flume was reduced to 58.8 cm. by constructing a brick wall along the length for suiting the requirement of width of flume according to the stilling basin design considerations as suggested by Bradely and Peterka[3]. A rectangular pipe of 10.8 cm x 6.3 cm was used to represent the outlet pipe. This pipe was connected with feeding pipe of diameter of 10.26 cm connected with centrifugal pump. The exit of outlet pipe was kept above stilling basin by one equivalent diameter (d = 9.3 cm). A wooden floor of size 58.8cm wide and 78.6 cm long was provided, downstream of the exit of the pipe outlet for fixing the appurtenances inside the basin. Three inflow Froude numbers namely Fr = 1.85, 2.85 and 3.85 were used as per discharge consideration in the flume. A manual tail gate was used at the end of the flume to control the tail water depth in the flume for experimentation.

Bed Materials: To observe the scour, after the end sill of stilling basin, an erodible bed, consisting of coarse sand of specific gravity as 2.76, and passing through IS sieve opening size 2.36 mm. and retained on IS sieve opening size 1.18mm was used. For all testing same bed material was used to compare the basin performance. The characteristics of bed materials are summarized in table-1.

End Sills: During the experimentation to study the scour pattern for a stilling basin models, rectangular, square, and triangular of varying slope from 1V:0.5H to 1V:2H and trapezoidal end sills were used as shown in figure -1. Impact wall of dimension 1d x 2.2d was employed to facilitate the dissipation of energy in the basin.

Table-1
Characteristics of sand bed materials

Specific gravity (S)	Density ρ_s (kg/m^3)	Uniformity coefficient c_u	Coefficient of curvature c_c	d_{60} (mm)	d_{50}(mm)	d_{30}(mm)	d_{10}(mm)
2.76	1648	1.57	0.93	2.2	1.9	1.7	1.4

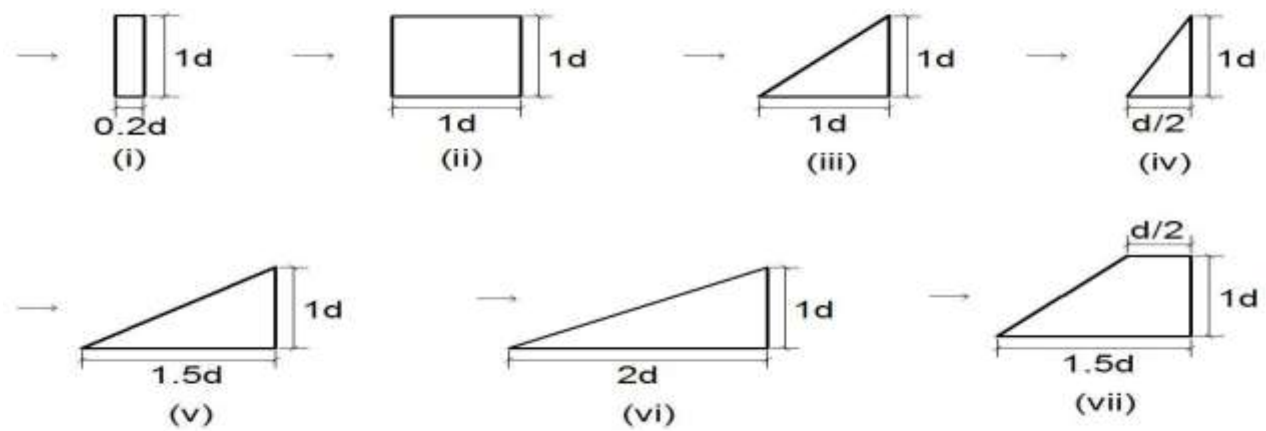


Figure-1
Different shapes of end sills tested

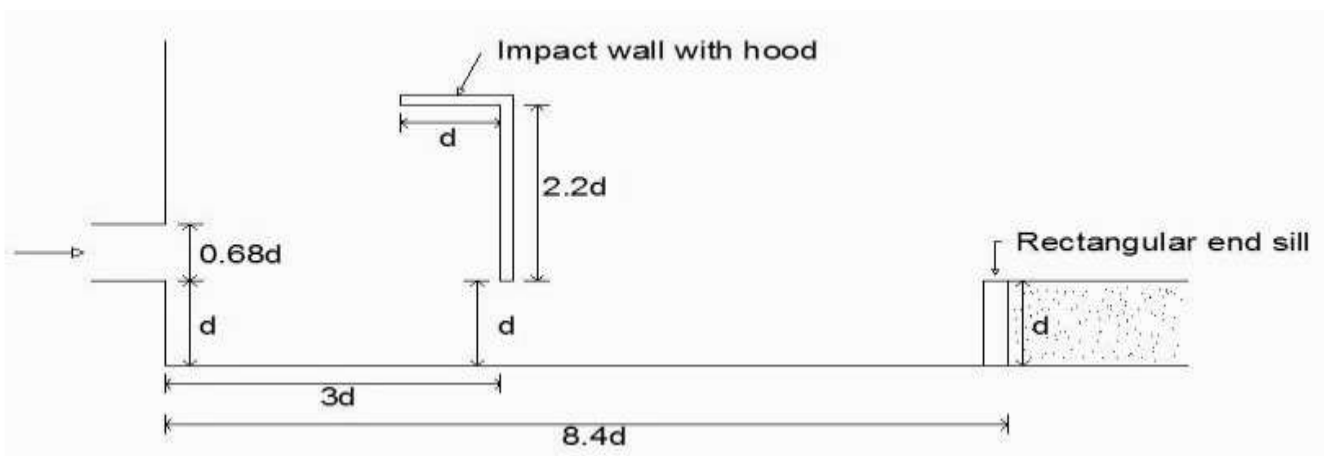


Figure-2
Basin model MSM-4 having rectangular end sill with impact wall

Experimental Procedure: First of all, the bed material was filled up to the height of end sill and gets leveled then normal depth was maintained over the sand bed by allowing the water from the overhead tank inside the flume by operating the tail gate. The flow into the flume was increased gradually so as to achieve required Froude number. The discharge was measured by a calibrated venturimeter installed in the feeding pipe. As soon as the required amount of water flowing from pipe outlet, reached the erodible bed material the movement of bed materials started and the geometry of scour hole started changing with time. After one hour test run, the motor was switched off. The value of maximum depth of scour (d_m) and its location from the end sill (d_s) were noted. All the models were tested for constant run time of one hour and with the same erodible material for all Froude numbers. To start the experimentation, a stilling basin model was designed for the inflow Froude number (Fr = 3.85) and fabricated in the flume as per USBR impact type VI design. It includes an impact wall of size 1d x 2.2d having a bottom gap 1d, located at 3d from the exit of pipe outlet and followed by sloping end sill(slope 1V:1H) of height 1d positioned at 8.4 d where d is the equivalent diameter of the pipe outlet. Later on, in order to study the end sill geometry, new stilling basin models were fabricated by changing shapes and size of end sills (10 Models). During the test runs for all the stilling basin models, the grain size of the material forming the erodible bed and test run time of 1 hour were kept the same for the purpose of comparison. The details of stilling basin models tested in the present work have been mentioned in table-2.

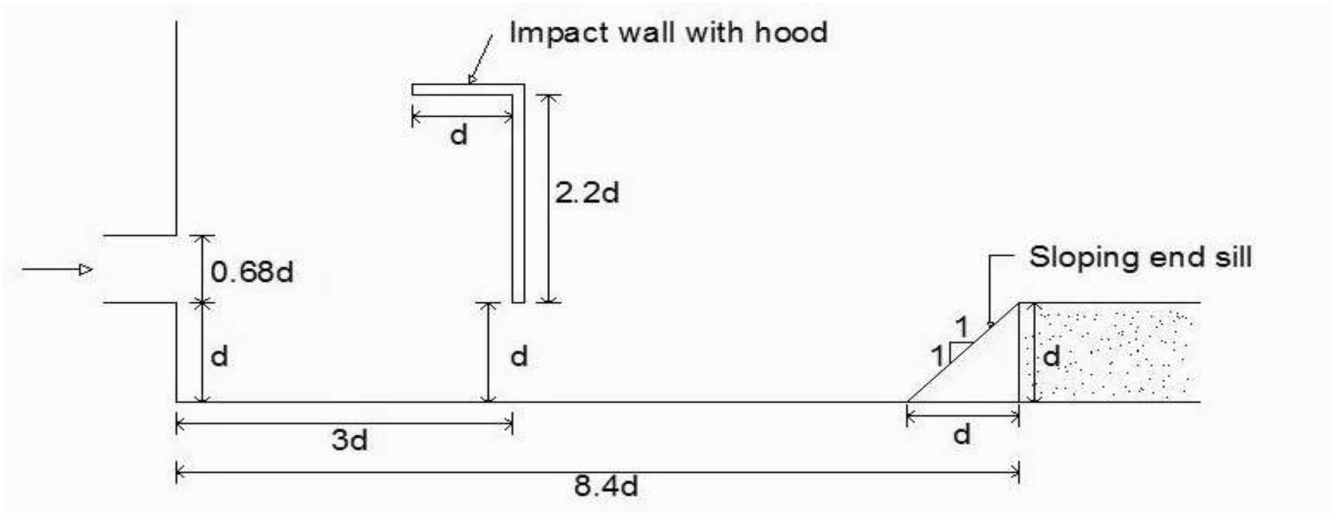
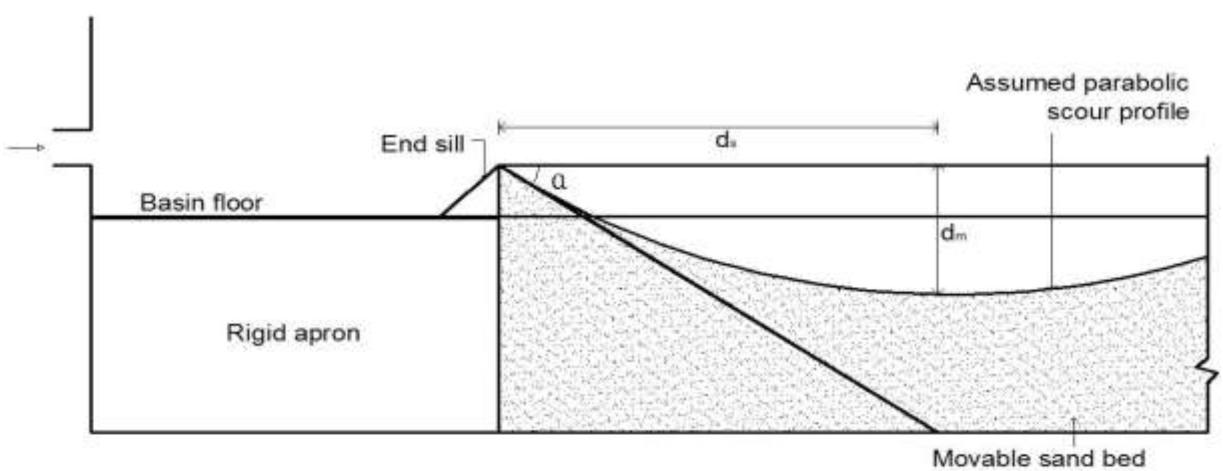


Figure-3
Basin model MSM-6 having sloping end sill with impact wall

Table-2
Scheme of experimentation

Model number	**Stilling basin length**	**USBR Type VI Impact wall**			**End sill of height 1d**
		Size	Location	Bottom gap	
MSM-1	8.4d	-	-	-	Rectangular
MSM-2	8.4d	-	-	-	Square
MSM-3	8.4d	-	-	-	Sloping(1V:1H)
MSM-4	8.4d	1dx2.2d	3d	1d	Rectangular
MSM-5	8.4d	1dx2.2d	3d	1d	Square
MSM-6	8.4d	1dx2.2d	3d	1d	Sloping(1V:1H)
MSM-7	8.4d	1dx2.2d	3d	1d	Sloping (1V:0.5H)
MSM-8	8.4d	1dx2.2d	3d	1d	Sloping(1V:1.5H)
MSM-9	8.4d	1dx2.2d	3d	1d	Sloping(1V:2H)
MSM-10	8.4d	1dx2.2d	3d	1d	Trapezoidal Sloping(1V:1.5H) with top width d/2



Figure–4
Assumed Scour Pattern

Performance Criteria: The performance of a stilling basin model was tested for different outlet Froude number (Fr) which is a function of channel velocity (v), the maximum depth of scour (d_m) and its location from end sill (d_s). A stilling basin model that produces smaller depth of scour at a longer distance is assumed to have a better performance as compared to another stilling basin which results in a larger depth of scour at a shorter distance when tested under similar flow conditions[7,8]. Thus scouring pattern will be better. This criterion was used for comparison of basin models tested.

Results and Discussions

To start the experimental investigations, stilling basin models (MSM-1, MSM-2 and MSM-3) were tested with end sills of shapes namely rectangular, square and sloping (slope 1V:1H) only for Fr = 1.85, 2.85, 3.85, and the values scour parameters (d_m and d_s) obtained are mentioned in the table 3. The model with sloping end sill (1V:1H) is performing better as compared to model MSM-1 and MSM-2. During the experimentation it was observed that for end sills having proper slope, the flow over the bed materials was approaching to tranquilized stage.

Table-3
Scour Pattern

S. No.	Model name	Fr = 1.85		Fr = 2.85		Fr = 3.85	
		d_m	d_s	d_m	d_s	d_m	d_s
1	MSM-1	8.4	17.4	9.7	20.5	12.8	27.6
2	MSM-2	8.6	20.3	10.7	23.7	12.4	28.6
3	MSM-3	4.8	12	5.7	12.9	6.4	17
4	MSM-4	4.3	10.4	4.9	11.6	7.4	19.8
5	MSM-5	3.5	10.3	4.6	12.9	6.4	19.5
6	MSM-6	3.2	10.5	4.4	12.5	4.6	15.5
7	MSM-7	3.9	9.5	5.1	10.8	5.4	14.5
8	MSM-8	3.5	9.6	4.7	11.4	5.1	15.5
9	MSM-9	3.8	11.4	4.7	12.2	4.9	16.1
10	MSM-10	4.0	8.8	5.2	8.6	5.8	9.1

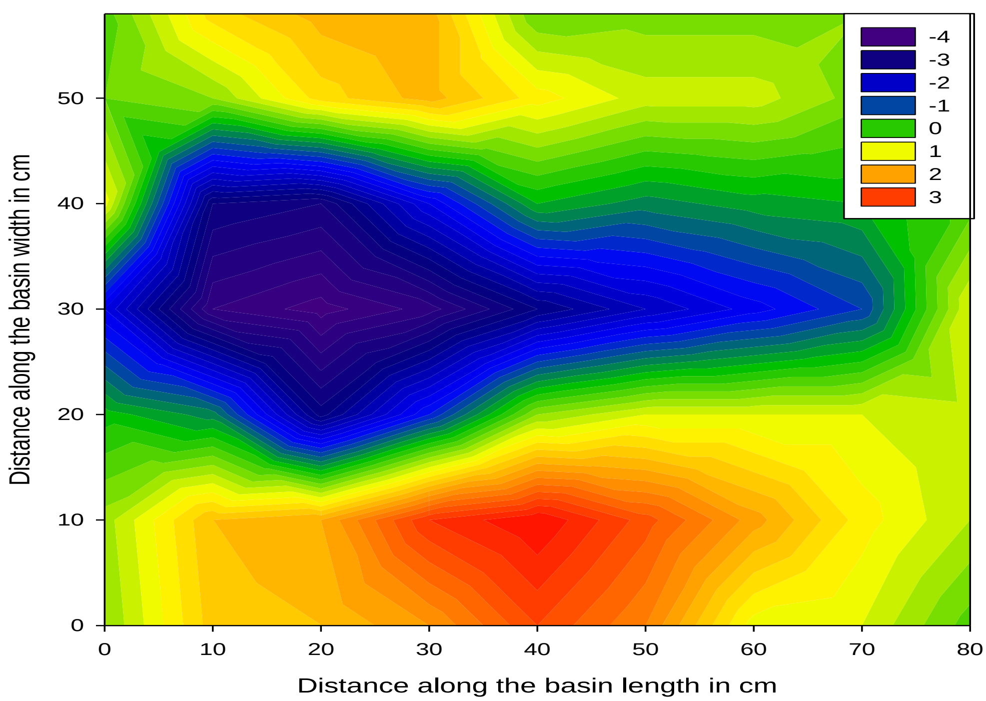
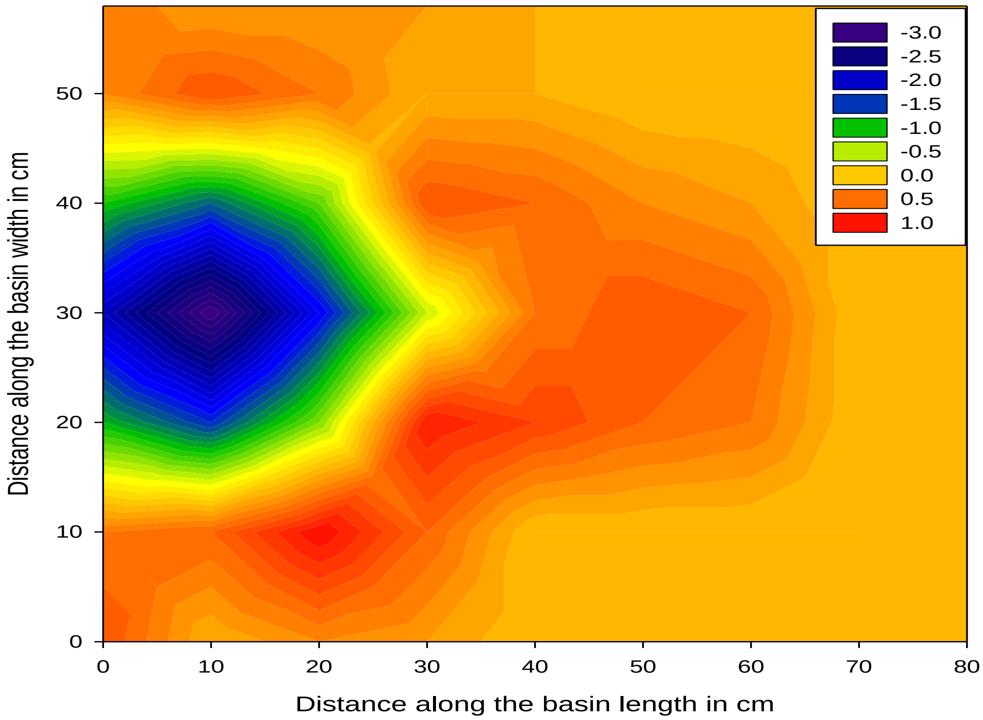


Figure-5(a)
Scour Pattern of Sand Bed for Model MSM-6 (USBR-VI) at Fr = 3.85 (Left to right) after one hour Test Run at Normal Depth



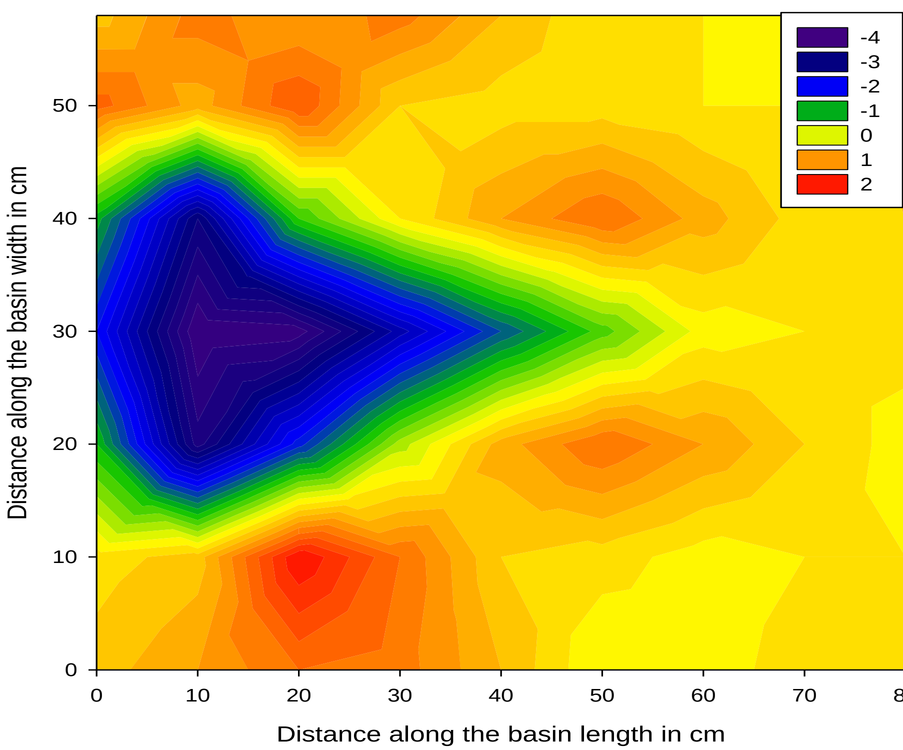


Figure-5(b)

Scour Pattern of Sand Bed for Model MSM-6 (USBR-VI) at Fr = 1.85 and 2.85 (top to bottom) after one hour Test Run at Normal Depth

The models having rectangular or square shaped end sill generates more undulated flow over the bed materials by which scour depth reported higher side as compared to sloping end sill. Further impact wall at 3d was secured in basin and basin was tested with varying end sill from rectangular, square and sloping (1V:1H) for Fr = 1.85, 2.85, 3.85 and the values of scour parameters obtained are mentioned in Table- 3. The models tested were named as MSM-4, MSM-5 and MSM-6. The comparison of scour parameters indicate that there is improvement in the scour pattern of each of the models MSM-4, MSM-5 and MSM-6 as compared to the corresponding models MSM-1, MSM-2 and MSM-3. However, with the model MSM-6, scour pattern is best in series MSM-1 to MSM-6 as shown in the table- 3. Keeping in view the performance of USBR model (MSM-6), the new models were fabricated and tested by changing shapes of end sill while keeping impact wall at same place. Firstly slope of end sill was changed to (1V:0.5H), (1V:1.5H), and (1V:2H) as shown in figure 1 in models MSM-7, MSM-8 and MSM-9 respectively. While in models MSM-10, a sloping end sill of trapezoidal shape (1V:1.5H) with top width d/2 was tested, and the values of scour parameters obtained are mentioned in the Table 3. Comparison of performance of models MSM-7 to MSM-9, the model MSM-9 is performing better in series MSM-7 to MSM-9. But when working of the model MSM-9 is compared with the model MSM-6, it is clear that the model MSM-6 is performing even better as scour depth is minimum as shown in figure-5. The model MSM-10 with a wider top has shown worst performance in this series MSM-4 to MSM-10 as shown in Table 3 with minimum value of scour distance (d_s).

Conclusion

An experimental study was conducted in the laboratory to study the stilling basin performance with end sill for rectangular shaped pipe outlets. Based on the experimental results, it is concluded that the shape of end sill affects the scour pattern downstream of the stilling basin significantly due to change in the flow conditions. This study also revealed that the sloping vertical end sill(slope 1V:1H) dissipates more energy of flow as it gives the minimum value of scour depth and found to perform better for all flow conditions as compared to other end sills tested for rectangular pipe outlet basin. The variation of scour parameters is due to the variation in flow geometry because of varying the shape of end sill and discharge rate.

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