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Design of Stilling Basin Model with Impact Wall and end Sill

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Abstract

The stilling basins are used to dissipate the energy of flowing water and protect the downstream structures like spillways, canals, etc. from the scouring. Hence hydraulic engineers need proper attention for the design of stilling basin. The aim of the present experimental investigation is to design the new stilling basin model for non circular pipe outlet using impact wall and end sill only. Performance of outlet basins having impact wall of varying size and location were evaluated based on the performance index (PI), keeping the constant test run time and same base material downstream end sill. Higher values of PI indicate better performance of the basin model. Based on the experimental performance of different stilling basin models are presented and it is concluded that by designing the appropriate impact wall size at suitable location, not only the efficiency of stilling basin model increases but length of basin reduced to 29 % as compared to USBR VI stilling basin.

Keywords: Efficiency, Froude number, stilling basin, scouring.

Introduction

Stilling basins with impact wall along with end sill can be used effectively in dissipating the excessive energy downstream of hydraulic structure like over flow spillway, sluices, pipe outlets, etc. used for irrigation and other purposes. Various types of recommended stilling basins for pipe outlets using impact wall are by Bradely and Peterka[1], Vollmer and Khader[2], Garde et al.[3], Verma and Goel[4], Tiwari et al.[5] and Tiwari[6]. The present research paper investigates the effect of impact wall with end sill in stilling basin on scour pattern downstream of the basin including the maximum depth of scour, the length to the maximum scour from end sill, etc. The jet of water strikes against the vertical impact wall, which distributes the flow of water equally over the full channel width. The flow gets turned toward the upper portion of the impact wall and comes down on the floor of stilling basin after striking the hood portion of impact wall. The dimensions and location of an impact wall is quite important for improving the dissipation of energy. The size of hood should be such that there is no possibility of splashing of water.

Due to the gap at the bottom of the impact wall additional horizontal shear developed by which dissipation of energy enhanced In present work, four impact walls of different size and shape (IW1, IW2, IW3 and IW4) were evaluated at different locations by using performance index as given in table 1. The end sill is a terminal element in the basin, which has a great contribution to promote the reduction of energy of flowing water and assists 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 dissipation of energy of flowing water[6].

Table-1
Details of Impact walls Tested

S. No	Impact wall	Size of Impact wall with hood
1	IW-1	1d × 2.2d
2	IW-2	0.75d × 1.5d
3	IW-3	1.25d × 2.5d
4	IW-4	1.5d × 3d

Material and Methods

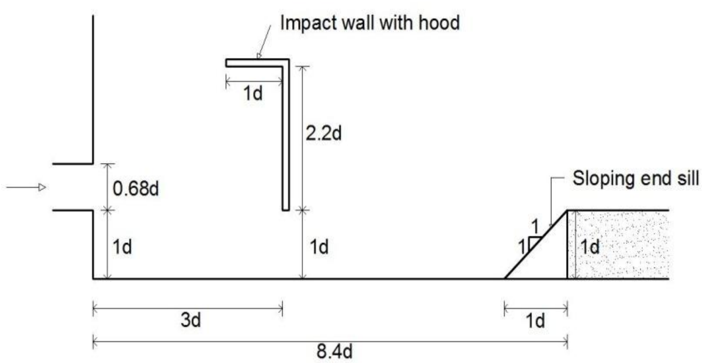
Experimental Programme: To start the experimentation, a stilling basin model was designed for the inflow Froude number (Fr = 3.85) and fabricated in the flume as per USBR impact type VI design. It includes an impact wall of size 1d × 2.2d having bottom gap 1d, located at 3d from the exit of pipe outlet and followed by sloping end sill (1V:1H) of height 1d positioned at 8.4 d, where d is the equivalent diameter of the pipe outlet. The experiments were conducted in a re-circulating laboratory flume of 0.95 m wide 1 m deep and 25 m long. A rectangular pipe having cross section as 10.8 cm × 6.3 cm and 5.75 m long was used as the pipe outlet. This pipe was connected with delivery pipe of the centrifugal pump. The exit of pipe was kept above stilling basin by one equivalent diameter (d = 9.3cm). A wooden floor was provided downstream of the outlet for fixing the appurtenances in the basin. To observe the scour after the end sill of stilling basin, sand bed having properties as given in table 2, was used. The discharge was measured by a calibrated venturimeter installed in the feeding pipe. With the operation of tail gate, the desired steady flow condition with normal depth was maintained. 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 and performance of the models was evaluated by computing the values of performance index. Higher values of PI represent better performance as compared to the model producing lower values of performance index. All the testing were performed for constant running time of one hour and with the same sand bed for three Froude numbers i.e., 3.85, 2.85 and 1.85. Further models were tested by using impact walls of different height kept at the distance of 4d, 3d and 2d from the exit of the pipe with triangular end sill. The impact wall was changed and the models were examined by keeping walls at 4d distances along with the sloping end sill at 7d. The length of basin was reduced further to 6d and model testing was performed with the triangular end sill along with the best impact wall. Arrangements of models are given in table 3 and also shown in figures 1, 2 and 3.

Table-2
Characteristics of sand bed materials

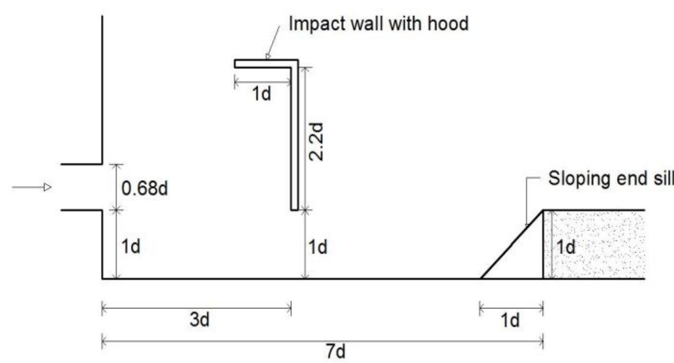
Specific gravity (S)	Density ρ_s (kg/m^3)	Uniformity coefficient c_u	Coefficient of curvature c_c	d_{60} (mm)	d_{50}(mm)	d_{30}(mm)	d_{10}(mm)
2.76	1648	1.57	0.93	2.2	1.9	1.7	1.4

Table-3
Arrangements of Tested Models

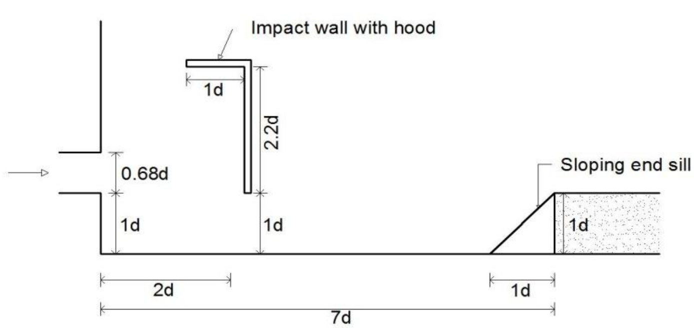
S. No.	Model Name	Impact Wall with hood			End sill			
		Name	Bottom gap with basin floor	Location from outlet exit	Shape	Height	Width	Location from outlet exit
1	MSM-6	IW1	1d	3d	Sloping	1d	1d	8.4d
2	MSM-30	IW1	1d	3d	Sloping	1d	1d	7d
3	MSM-32	IW1	1d	2d	Sloping	1d	1d	7d
4	MSM-33	IW1	1d	4d	Sloping	1d	1d	7d
5	MSM-36	IW2	1d	4d	Sloping	1d	1d	7d
6	MSM-39	IW3	1d	4d	Sloping	1d	1d	7d
7	MSM-42	IW4	1d	4d	Sloping	1d	1d	7d
8	MSM-77	IW4	1d	4d	Sloping	1d	1d	6d



MSM-6 (USBR VI as a base model)

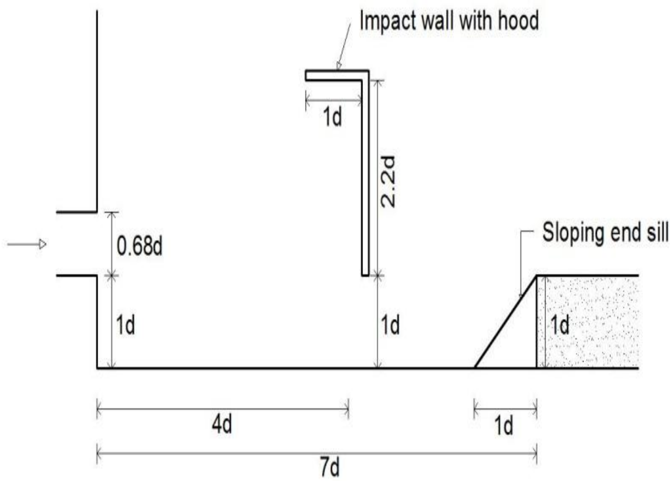


MSM-30

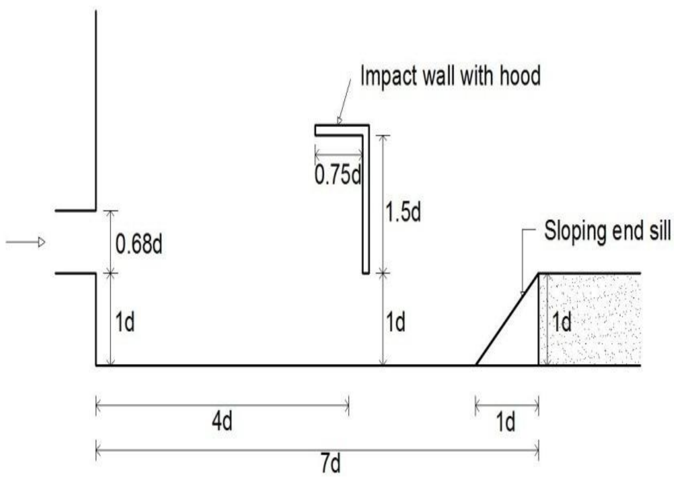


MSM-32

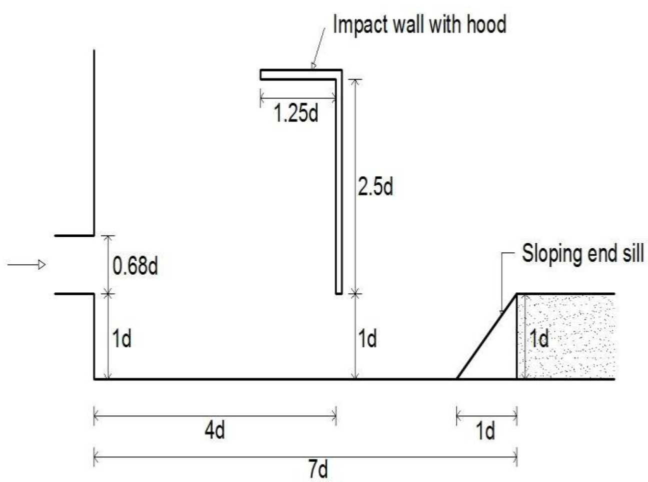
Figure-1
Stilling Basin Models with impact wall at 3d and 2d



MSM-33

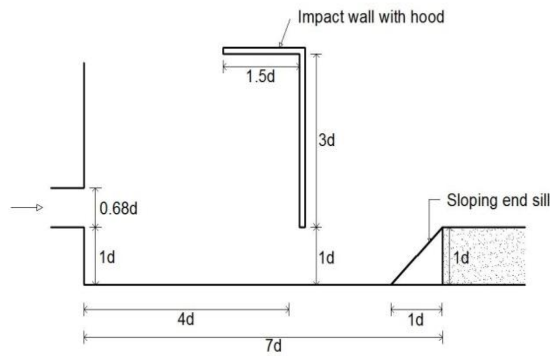


MSM-36

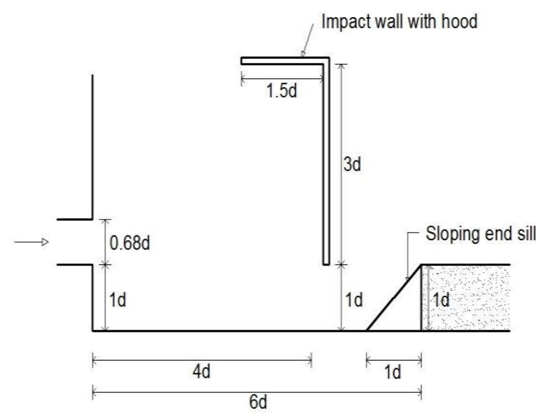


MSM-39

Figure-2
Stilling Basin Models with different Impact wall at 2d and 4d



MSM-42



MSM-77(New Developed Model)

Figure-3
Stilling Basin Models with different Impact walls at 4d

Performance Evaluation: The performance of a stilling basin models were tested for different 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 considered 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 condition[7]. A new non dimensional number, called as performance index (PI) has been used for comparison of performance of stilling basin model[5]. This is given as below:

$$PI = \frac{V x d_s}{2 d_m \sqrt{g \frac{\rho_s - \rho_w}{\rho_w} d_{50}}} \qquad (1)$$

Where, V - the mean velocity of channel, d_s - distance of maximum depth of scour from end sill, d_m- depth of maximum scour, g – gravitation acceleration, $\boldsymbol{\rho_s}$- density of sand, $\boldsymbol{\rho_w}$ density of water, d_{50}- the particle size such that 50% of the sand particle is finer than this size, A higher value of performance index indicates a better performance of the stilling basin model. This performance index takes into consideration of flow, scour parameters (d_m and d_s) and properties of material used in the basin. The value of Performance index for various runs for each model at different Froude numbers are given in table 4.

Table-4
Performance Index for Models Tested

S. No.	Model name	Fr=1.85	Fr=2.85	Fr=3.85
		PI	PI	PI
1	MSM-6	2.671	2.636	3.427
2	MSM-30	2.274	2.146	3.051
3	MSM-32	2.358	2.91	2.978
4	MSM-33	2.724	3.736	4.259
5	MSM-36	2.532	3.592	4.231
6	MSM-39	4.424	4.305	5.08
7	MSM-42	4.884	7.822	7.862
8	MSM-77	5.094	6.220	6.680

Results and Discussions

For evaluating the role of impact wall on the design of stilling basin model, after testing the basic model MSM-6 (USBR VI) at basin length 8.4d, the location of same impact wall (IW-1) at basin length of 7d was varied as 3d, 2d and 4d and models were named as MSM-30, MSM-32 and MSM-33 and observations were recorded after test run for Froude number range and values of performance were computed as given in the table 4. On analyzing the values of Performance index (PI), it is found that the model (MSM-33) with impact wall located at 4d performs better as compared to basic model (MSM-6) and other models (MSM-30 and MSM-32) with impact wall located at 3d and 2d, since values of PI (2.724, 3.736 and 4.259) are higher side for all Froude number tested as shown in Table 3. Further with the variation of the size of impact wall (IW-2, IW-3 and IW-4), models were tested at basin length 7d keeping the location of impact wall as 4d and they were names as MSM-36, MSM-39 and MSM-42 respectively. After computing the values of performance index as shown in table 3, it found that model (MSM-42) with impact wall IW4 immersed as best performing models as compared to other tested models. Further this model was tested at basin length 6d (MSM-77). On comparing the performance of Basic model (MSM-6) newly developed model (MSM-77), it is found that only by changing the impact wall size and location, not only the performance of newly developed model improved significantly (PI = 5.094, 6.220 and 6.680) but length is also reduced to 6d (29 %) as compared to basic model (PI = 2.671, 2.636 and 3.427) at tested Froude numbers. Table 3 illustrates the performance of the models for different wall size at different basin length. On analyzing the table 4 and the figure 4, it is concluded that the impact wall of size 1.5d × 3d (IW4) performs better as compared to other size of the walls. This may be because, by increasing the surface area skin friction increase, by which dissipation of energy enhanced in the basin enabling the higher values of performance index as shown in tables 4 and figure 4.

Conclusion

An experimental study was conducted in the laboratory to study the role of impact wall in the design of stilling basin for varying length (8.4d, 7d and 6d) for rectangular shaped pipe outlet with 24 test runs for Froude numbers 3.85, 2.85 and 1.85. Based on the experimental results, it is found that the size and location of impact wall affect the performance of stilling basin significantly due to change in the flow patterns. During the study it was found that the location, size and gap of impact wall affects the flow conditions and ultimately scour pattern downstream of the stilling basin. This study also revealed that the higher values of performance indices indicate that the impact wall of size 1.5d×3d dissipates more energy of flow and found to perform better for all flow conditions as compared to other impact walls (showing lower values of performance indices) tested for rectangular pipe outlet basin. This may be because by increasing the surface area, skin friction increase, by which dissipation of energy enhanced in the basin enabling the higher values of performance index. It is also found that by using only suitable impact wall at appropriate location, the length of basin can be reduced to 29 % as compared to USBR VI stilling basin with improved performance by which irrigation projects may become economical.

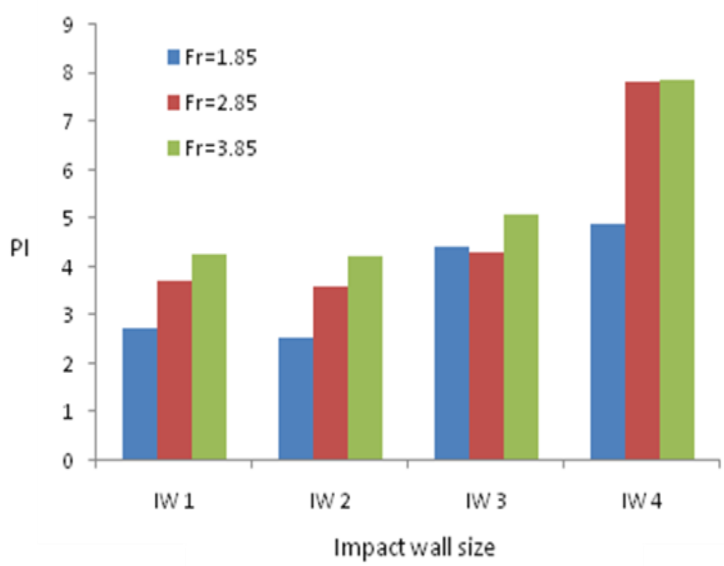


Figure-4
Variation of Performance Index with Impact Wall Size at 4d and basin length 7d

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