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EXPERIMENTAL STUDY OF STILLING BASIN MODELS

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Stilling basins with appurtenances can be used effectively in dissipating the excessive energy downstream of hydraulic structure like spillway, sluices, pipe outlets etc. Experimental investigation leading to the development of new stilling basin model design for pipe outlet with different appurtenances is reported in this paper. On the basis of present study, newly stilling basin design has been compared with USBR VI model. The new models were tested in a rectangular shaped pipe outlet for three Froude numbers, namely Fr = 1.85, 2.85, and 3.85 in comparison to USBR VI stilling basin model recommended for the pipe outlets. The scour pattern was measured for each test run and flow pattern was also observed. The performance of the basin was compared by Performance number (PN) as criteria to evaluate the performance of model, using same sand base material and test run time for all the tested models. After test runs, it is found that, for a given Froude number range, the performance of new stilling basin model is improved and also the length of the newly developed basin is reduced as compared to USBR VI stilling basin for a given flow conditions.

Keywords: Appurtenances, Froude-number, Performance-number, Water.

1 INTRODUCTION

Various types of recommended stilling basin models for pipe outlets are by Bradley and Peterka (1957), Keim (1962), Flammer *et al.* (1970), Vollmer and Khader (1971), Garde *et al.* (1986), Verma and Goel (2000), Tiwari *et al.* (2011a, 2011b, 2013a, 2013b), Tiwari and Gahlot (2012), and Tiwari (2013a, 2013b). Appurtenances with proper design and suitable location play an important role for the protection of downstream hydraulic structures by reducing the kinetic energy of flowing water in 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 present research paper investigates the effect of intermediate sill of square cross section having height half of the diameter of pipe outlet with similar end sill along with impact wall as in USBR VI 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 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.

2 MATERIALS AND METHODS

2.1 Experimental Program and Procedure

The experiments were conducted in a recirculating laboratory flume of 0.95 m wide 1 m deep and 25 m long. A rectangular pipe having cross section as 10.8 cm. x 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 = 9.3 cm). 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 1 was used. The discharge was measured by a calibrated venturimeter installed in the feeding pipe. After one-hour test run, 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 number(PN). 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. Arrangements of models are given in Tables 3 and also shown in Figures 1-4.

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

Table 2. Flow parameters.

Inflow Froude Number (Fr)	Av. Velocity (m/sec)	Discharge (m^3/sec.)	Normal Depth (m)
1.85	0.183	0.012	0.114
2.85	0.205	0.018	0.15
3.85	0.295	0.025	0.19

2.2 Scheme of Experimentation

Testing of models in this category, the impact wall of size 1.5d × 3d and square intermediate sill (IS) of size d/2 × d/2 along with the end sill were tested with the variation of location of impact wall and intermediate sill to evaluate the performance of basin models. In model MSM-46, impact wall placed at 4d and IS placed it 3d along with the sloping end sill fixed at 7d. In model MSM-48, intermediate sill was kept at 5d, keeping impact wall at 4d. In model MSM-49, testing was performed by keeping the impact wall at 2d and intermediate sill at 3d. MSM-50 was performed by varying intermediate sill at 4d and the impact wall was kept at 2d. In models, MSM-51 and MSM-52, position of the impact wall was fixed at 3d and location of intermediate sill was varied to 4d and 5d respectively. All these models are shown in Figures 1-4 and also illustrated in tabular form as shown in Table 3.

Table 3. Scheme of experimentation.

S. No.	Model Name	Impact Wall with hood			Intermediate sill			
		Size	Bottom gap with basin floor	Location from outlet exit	Shape	Height	Width	Location from outlet exit
1	MSM-6	1d×2.2d	1d	3d	-	-	-	-
2	MSM-30	1d×2.2d	1d	3d	-	-	-	-
3	MSM-31	1d×2.2d	1d	3d	Square	d/2	d/2	4d
4	MSM-32	1d×2.2d	1d	2d	-	-	-	-

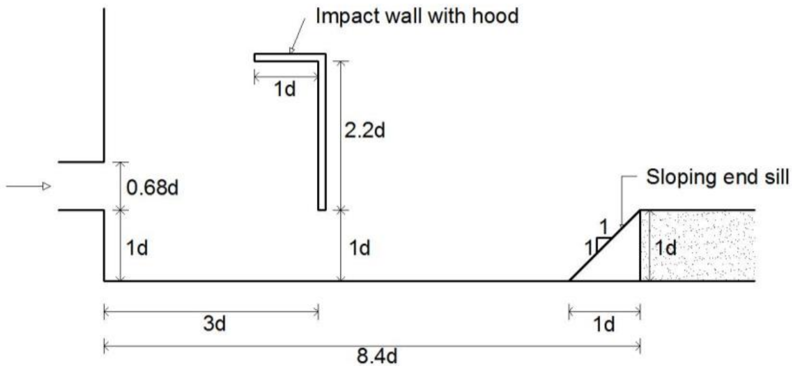
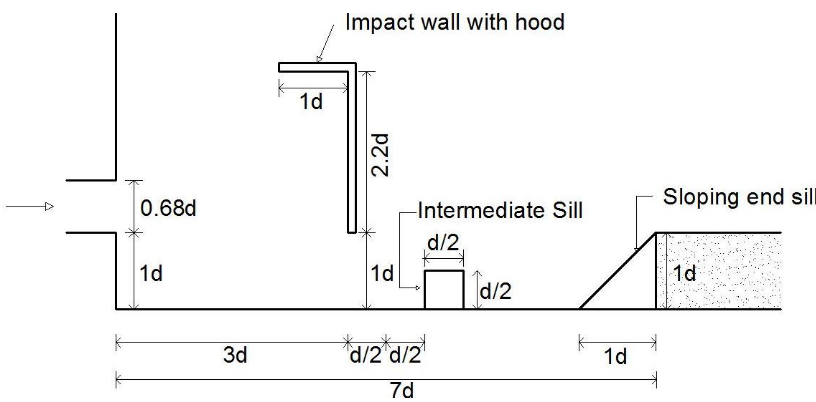


Figure 1. USBR VI stilling basin model (MSM-6).



MSM-31

Figure 2. New model at 7d length of the basin with appurtenances.

2.3 Performance Evaluation

The performance of any stilling basin model, tested for different Froude number (Fr), is a function of channel velocity (V), the maximum depth of scour (d_m) and its location from end sill (d_s) as shown in Figure 3. 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.

Actually, geometry of scour depends upon residual energy of flowing water after end sill. If within the stilling basin energy dissipation is more, then residual energy of flowing water after end sill will be lesser, resulting flatter scour geometry and better performance of model. A non dimensional number called Performance number (PN) used in Tiwari and Gahlot (2012) is considered for the comparison of performance of the stilling basin models. A higher value of performance number shows better performance of stilling basin models. The Performance Number developed by (Verma and Goel 2000), which is the ratio of scour Froude number to the scour index can be represented as

$$PN = \frac{1}{2} * V * d_s / (g * d_m{}^3)^{0.5} \tag{1}$$

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. A higher value of performance number suggests a better performance of a stilling basin model for a given conditions of the channel downstream of the pipe outlet.

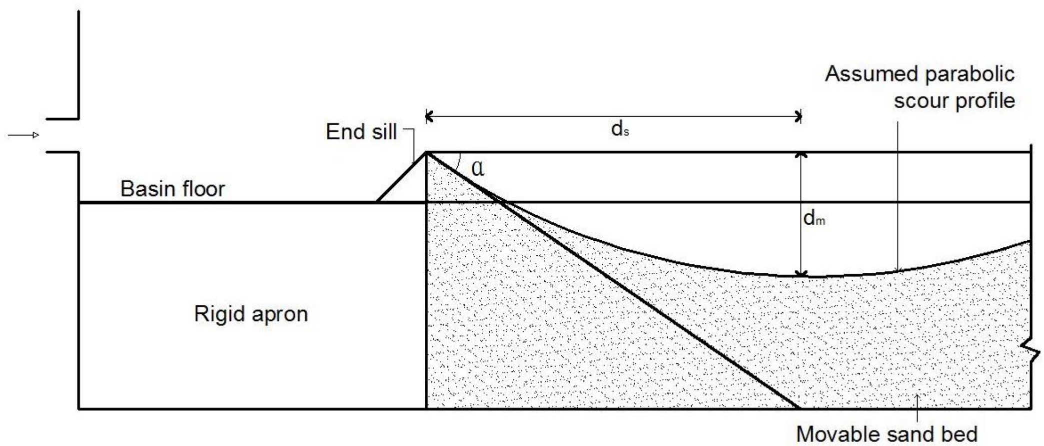


Figure 3. Scour pattern.

3 RESULT AND DISCUSSIONS

First of all, model was tested as per design of USBR VI stilling basin model and named as MSM-6. Computed values of performance numbers are 0.523, 0.440 and 0.559 for Fr =1.85, 2.85, and 3.85 respectively as shown in Table 4.

After experimentation of USBR VI stilling basin model testing for non-circular pipe outlet, length of basin was reduced and model testing was carried out for all three Froude numbers and values of PN were computed as mentioned in Table 3. These values are 0.432, 0.297, and 0.410 for Fr= 1.85, 2.85, and 3.85 respectively. Model tested was renamed as MSM-30. A as length was reduced to 7d from 8.4d, residual energy seems to increased leading to generate lesser values of performance numbers as compared to model tested in basin length of 8.4d. Model-31 was tested with inserting of intermediate sill of square cross section and PN values were computed and found as 1.136, 0.643 and 0.908 for Fr = 1.85, 2.85, and 3.85 respectively. Another model, namely MSM-32 was also tested but values of PN were found to be lesser than the values of model MSM-31 as mentioned in Table 3. On analyzing the results it is conclude that by inserting the square cross sill before end sill dissipation of the energy is more there by residual energy reduces and hence PN values were increase, which indicates that model with square sill perform better even at reduced length. Intermediate sill promotes the dissipation of energy in the basin by lifting high velocity filaments from the bed. The sill height, configuration and position have great impact on the dissipation of energy of flowing water (Tiwari and Gahlot 2012). No doubt performance of the stilling basin models improves with the inclusion of intermediate sill, which also confirms the findings of Negm (2007). Similar results were also found by Tiwari and Goel (2014), in which different geometry of sill were tested in stilling basin model. Thus as compared to MSM-6 model, values of PN for new developed model MSM-31, increases from 0.523, 0.440 to 1.136, 0.643, and 0.908 for Fr = 1.85, 2.85, and 3.85 respectively, and at the same time length of the basin is also reduced from 8.4d to 7d. Comparative study is mentioned in Table 5.

Table 4. Performance number (PN) for all tested models.

Sr. N0.	Model name	Fr = 1.85	Fr = 2.85	Fr = 3.85
		PN	PN	PN
1	MSM-6	0.523	0.440	0.559
2	MSM-30	0.432	0.297	0.410
3	MSM-31	1.136	0.643	0.908
4	MSM-32	0.485	0.53	0.441

Table 5. Comparison of new model (MSM-31) with USBR VI (MSM-6).

Name of Model	1.85		2.85		3.85		Length	Remark
	PN	Performance improvement	PN	Performance improvement	PN	Performance improvement		
MSM-6	0.523		0.440		0.559		8.4d	USBR VI Model
MSM-31	1.136	More than two times as compared to USBR VI	0.643	More than 1.5 times as compared to USBR VI	0.908	More than 1.6times as compared to USBR VI	7d	New Developed Model. Length reduced about 17%

4 CONCLUSIONS

An experimental study was conducted in the laboratory to design and develop new stilling basin model in comparison of USBR VI model developed by Bradley and Peterka (1957) by using intermediate sill with same impact wall and end sill as suggested by Bradley and Peterka (1957) for rectangular shaped pipe outlet for Froude numbers 3.85, 2.85, and 1.85. After experimentation of USBR VI stilling basin model testing for non-circular pipe outlet, length of basin was reduced and model testing was carried out for all three Froude numbers and values of PN were computed and found as 0.432, 0.297, and 0.410 for Fr= 1.85, 2.85, and 3.85 respectively. Model-31 was tested with inserting of intermediate sill of square cross section and PN values were computed and found as 1.136, 0.643, and 0.908 for Fr= 1.85, 2.85, and 3.85 respectively. Based on the experimental results, it is found that the square intermediate sill affects the performance of stilling basin significantly due to change in the flow patterns. During the study, it was found that intermediate sill affects the flow conditions and ultimately scour pattern downstream of the stilling basin. Similar finding was also reported in Tiwari *et al.* (2014a, 2014b). It is also found that by using only suitable square intermediate sill with same impact wall and end sill was used in USBR VI, efficiency of stilling basin models improves more than two to three times as compared to USBR VI stilling basin model and at the same time length is also reduced to 17%.

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