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Experimental Model Studies of Stilling Basin with Some Appurtenances

H L Tiwari[1], Kartikeya Mishra[1], Bikram Prasad[2]

[1]*Professor, Dept. of Civil Engineering, MANIT Bhopal, M.P., India*
[1]*Research Scholar, Dept. of Civil Engineering, MANIT Bhopal, M.P., India*
[2]*Associate Professor, Dept. of Civil Engineering, BIST Bhopal, M.P., India*

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Abstract - *This research paper describes experimental model studies on stilling basin which are performed to develop efficient and economical type stilling basin for non-circular pipe outlets for low Froud numbers. The experimental study was carried out for three Froude numbers, namely 3.85, 2.85 and 1.85 for the exit of the non-circular pipe. Performance of models were compared with non-dimensional parameters Performance criteria named as Performance Index (PI). Flow condition and running test hour was kept constant for all the tested model for particular Froud number. After analyzing eighteen tests, it was observed that the performance of the evolved stilling basin model also improved by reducing the basin length from 8.4d to 7d by introducing an intermediate sill of square section and new design of impact wall as comparison to USBRVI model. This model performed better than the USBR VI impact basin for similar flow conditions at a reduced length of 7d from 8.4d where d is the equivalent diameter of the pipe outlet with significant improved performance.*

***Key Words*: Pipe outlet, Stilling basin, Scour pattern, USBR**

1.INTRODUCTION

The water that comes out of an outlet in the tank, whether it be through gates, tunnels or pipes and over weirs, comes out at high speed, which is generated by varying its height potential drop from reservoir level to downstream river level (Mylvogonan and Rajaratnam 1961). This velocity is much higher than the natural safe velocity of stream at a given site, and causes scouring at the toe of the dam or other hydraulic structures. This scouring, if allowed to continue will undermine the foundation with consequent damage to the outlet structures, the outlet channel and sometimes the dam itself (Gehlot and Tiwari 2014). The hydraulic engineers are, therefore, facing with the problem of minimizing the energy of flowing water having high velocity for reducing the scour below the structure for a long time (Panwar and Tiwari 2014).

The hydraulic jump is an excellent tool for dissipating hydraulic energy, but it requires a greater length of the basin. The length of the hydraulic jump and therefore the length of the basin can be reduced by using devices in the form of baffle blocks, chute blocks, splitter blocks and end sill, etc. According to Murthy and Divatia (1982), hydraulic jump-type stilling basins are the efficient mechanism for dissipating excess energy and the least prone to erosion and cavitation. This type of radiator has been widely used. The hydraulic jump is also assisted by the use of cross jets either from the surface or from the bed. The USBR stilling basins (Bradley and Peterka 1957), S.A.F. stilling basin. (Blaisdell 1948) and I.S. Stilling basins (2004) fall under this category. The designs are modified according to the prevalent site conditions (Mazumdar 2003). The S.A.F. stilling basins are shorter in length and they are mainly used on low head structures. An impact type of stilling basin is contained in a relatively small box type structure which does not have tail water requirements for proper performance. The USBR impact type VI stilling basin was mainly developed for the pipe outlets.

To reduce the high energy of flowing water, stilling basins are normally used (Tiwari et al. 2010). Dams and other hydraulic structures are planned to control large volumes of high pressure water (Sarma et al. 2009). The energies at the base of the structures are often enormous whether the discharge is through outlet conduits or over spillways. Some means of expending the energy of the high velocity flow are needed to prevent river bed runoff, minimize erosion, and prevent dam weakening. This can be achieved by constructing an energy dissipator at the base of the structure to dissipate excess energy from the water and establish safe flow conditions in the drainage channel (Pramanic and Mazumdar 1961). Any hydraulic energy dissipator's ability to function primarily lies on its ability to use one or combination of the techniques recommended by Govinda Rao (1961), Yang (1994), and Vischer and Hager (1995) to consume some of the energy of the high velocity flow. Stilling basins are an integral part of spillways, outlet works, diversion structures and waterfall structures (Tiwari 2013A).

Various devices such as impact wall, intermediate and end sill etc. are used to make the stilling basin more efficient (Tiwari et al. 2014). The effect of the sill on the flow or scour characteristics depends on the configuration of the sill, its geometry and the flow regime, Negm (2004). Various types of stilling basin models recommended for pipeline releases are by Bradley and Peterka (1957), Fiala and Maurice (1961), Keim (1962), Vollmer and Khader (1971), Verma and Goel (2000 and 2003), Goel (2008), Tiwari et al. (2011, 2012, 2013, 2014 and 2015), Tiwari and Gahlot (2012), Tiwari (2013A and 2013B), Tiwari and Goel (2014 and 2016) and Tiwari and Singh (2017). The devices play an important role in reducing the kinetic energy of running water in the design of the stilling basin model. A stilling tank for the outlet of a pipe consists of accessories such as the divider block, the impact wall, the intermediate sill and an end sill, etc (Tiwari et al. 2014). The vertical sill is a terminal element of the still basin, which greatly contributes to reducing the energy of the flowing body of water and helps to improve the flow downstream of the canal thus helping to reduce the length of the stilling basin (Tiwari and Goël 2014). The placement of the sill above the bottom of the stilling basin has a great impact on the formation and control of the hydraulic jump and ultimately leads to the reduction of the kinetic energy of the flowing water (Tiwari et al. 2022). Several researchers, including Negm (2004), Verma and Goel (2003) suggested installing an intermediate sill to enhance stilling basin performance. Also. based on lab testing, the end sill significantly boosts the basin's effectiveness (Saleh 2004, Alikhani et al. 2010). This research paper focuses on improving the performance of the USBR VI Stilling Basin model using the square sill positioned after the impact wall with the end sill and impact wall. The performance of the stilling basin models is compared to the performance index (PI). A higher PI value indicates better performance of the still model for the pipe outlet (Tiwari 2013B and Tiwari et al. 2014).

1.1 Design of appurtenances

Appurtenances are employed to promote the dissipation of energy and thereby making the energy dissipators effective and economical. For energy dissipation of the pipe outlet, appurtenances like splitter block, impact wall, end sill, etc. plays important role to increase the performance of basins by reducing the excess energy of flow within the basin length (Tiwari and Prasad 2017). They not only economize the stilling basin but also help to reduce the scour of downstream channel within a permissible limit with a suitable velocity distribution (Elevatorski 1959). Thus, the appurtenances are important tool to reduce the cost of the stilling basin and also provide safety to the hydraulic structure.

2. Materials & Method

The experiments were carried out in a recirculating laboratory channel 0.95 m wide, 1 m deep and 25 m long. The width of the channel was reduced to 58.8 cm by building a brick wall along its length to maintain the ratio of the width of the basin to the equivalent rectangular outlet diameter of 6.3 according to the drawing by Garde et al. (1986). A 10.8 cm rectangular tube x 6.3 cm. was used to represent the outlet. The outlet of the tube was maintained above the stilling tank of an equivalent diameter (1d = 9.3 cm). To observe the scouring after the final sill of the still basin, an erodible bed of coarse sand was made which passes through the opening of the 2.36 mm screen and held over the opening of the 1.18 mm IS screen. The maximum abrasion depth (dm) and its distance to the end sill (ds) were measured for each test after one hour of operation. The flow depth on the erodible bed was kept equal to the normal flow depth. The USBR Type VI still basin model proposed by Bradley and Peterka (1957) was fabricated with an 8 '' x 23 '' impact wall with a 3.5 '' x 58.8 '' hood cm and an inclined sill with a height of 9.3 cm and a base width of 9.3 cm. The flow was measured by a calibrated Venturi meter installed in the supply line. With the operation of the tailgate, the desired condition of constant flow with normal depth was maintained. After an hour of testing, the motor was shut down. The value of the maximum scouring depth (dm) and its position relative to the threshold (ds) were noted. First of all stilling basin model without impact wall was tested and named as SM-1 then USBRVI impact wall was placed and model (renamed as SM-2) was again tested in a similar flow condition as SM-1. Further length of the basin was reduced to 7d and models were tested without impact wall and with impact wall and they were named as SM3 and SM4. Further to improve the performance of the model square sill was introduced and again model was tested and it was renamed as SM-5. To make the model more efficient impact wall and sill were also introduced and model was tested in similar flow conditions and performance was evaluated and model was re-designated as SM-6. Some models tested with accessories are shown in Figures 1 to 3. All tests were performed for a constant run time of one hour and with the same erodible material for three Froude numbers, i.e. 3.85, 2.85 and 1.85. An additional scouring scheme was also performed and then a total of 18 tests were performed to evaluate the performance of the stilling basin models using the sill as well as the USBR VI impact wall and end sill. The experimental scheme is presented in Table 1.

2.1 Arrangement of Appurtenances

Tests on models in this category, an impact wall of size 1d × 2.2d with an inclined end sill and an intermediate sill of size d / 2 × d / 2 square (IS) were tested with an impact of varying the position of the wall while maintaining the position of the impact wall itself. The length of the basin varied from 8.4d to 7d. At the basin lengths of 7d and 6d, the intermediate sill has been introduced to make the model efficient. Models SM1, SM3 and SM6 were tested with end sill at basin length of 8.4d, 7d and 7d respectively. Models SM2 and SM4 were tested with an impact wall with the end sill. Additional SM5 and SM6 models were tested with an intermediate sill with the same impact wall and end sill as the models tested previously. Some of these models are shown in Figures 1 to 3 and all models are also shown in tabular form in Table 2.

2.2 Optimization of Froude Number and Model Parameters

The invert level of the outlet was kept 1d above the basin floor. Models were tested for this design Froude number and two lower Froude number (Fr = 1.85 and 2.85) were selected for model testing based on discharge and other experimental constraints. Flow parameters for different tested Froude numbers are shown in Table 1.

Table -1: Flow Parameters

Froude Number (Fr)	Velocity (m/sec)	Discharge (m^3/sec.)	Normal Depth (m)
1.85	1.75	0.012	0.114
2.85	2.70	0.018	0.15
3.85	3.65	0.025	0.19

2.3 Criteria for the performance of evaluation for a stilling basin model

The performances of the stilling basin models were tested for a different Froude number (Fr) which is a function of the speed of the channel (v), the maximum excavation depth (d_m) and its position from the end sill (d_s). A new dimensionless number, called the performance index (PI) developed by Tiwari et al (2011) was used to compare the performance of calm basin models. This is given as follows:

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

Where, V is the average speed of the channel, ds distance of the maximum depth of scour from the end sill, dm maximum depth of scour, g - acceleration of gravity, s density of sand, ρ_w density of water, d_{50} the particle size distribution such that 50% of the sand particle is finer than this size, a higher value of the performance index indicates better performance of the stilling basin model (Tiwari et al. 2022). The value of the performance index for different runs on each model for different Froude numbers is shown in Table 3.

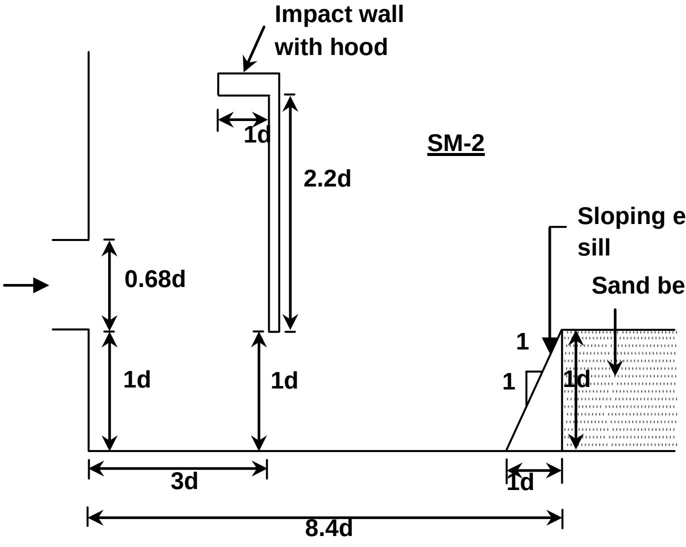

Fig -1: USBR VI stilling basin model at basin length 8.4d

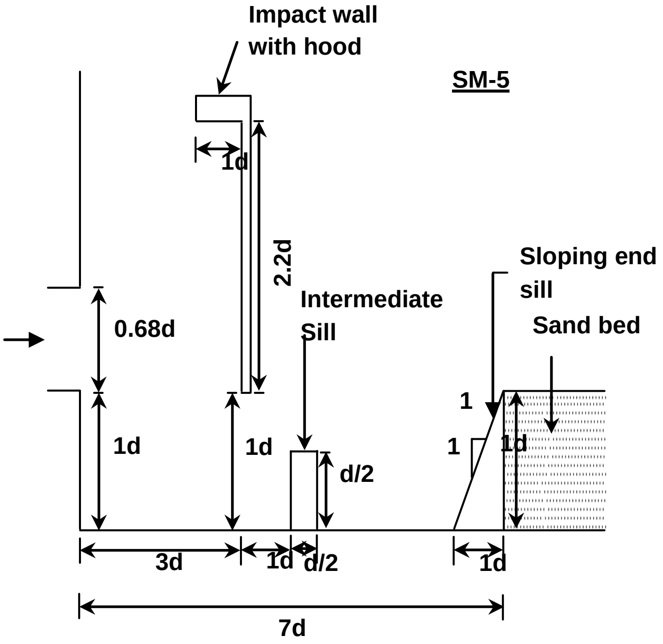

Fig -2: New stilling basin model at basin length 7d with square sill

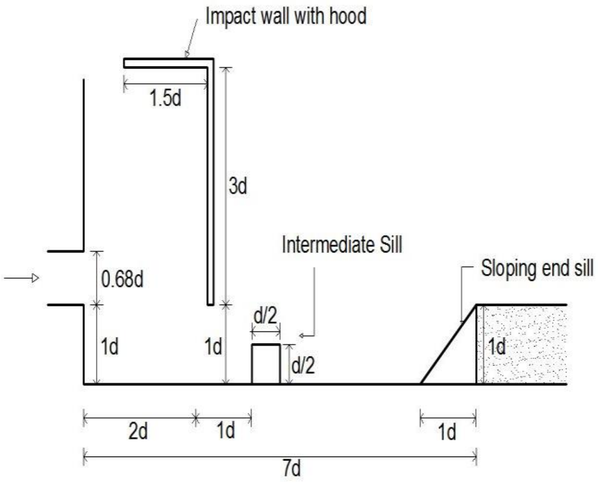

Fig -3: New stilling basin model at basin length 7d with square sill

3. RESULTS

An experimental work was carried out to design efficient new stilling basin model as compared to existing USBR VI design. First of all model (SM-1) was tested with sloping end sill without impact wall and value of PI were found to be 2.03, 2.01 and 2.70 for Froude number 1.85, 2.85 and 3.85 respectively, USBR VI impact wall was placed and again testing of USBR VI model(SM-2) was carried out in similar flow condition as for SM-1 and PI values were obtained as 2.67, 2.63 and 3.42 for Froude number (Fr) =1.85, 2.85 and 3.85 respectively, which are higher than SM-1 stilling basin model. Thus, the performance of SM-2 model is better as compared to model SM1, which includes only end sill. After that stilling basin model length was reduced to 7d from 8.4d and in similar flow conditions model SM-1 and SM-2 were retested and re-designated as SM-3 and SM-4 respectively. Values of PI were computed and mentioned in Table 2. From Table 2, it is obvious that PI values of model SM-3 and SM-4 are reduced as compared to SM-1 and SM-2 respectively as basin length is reduced to 7d from 8.4d. Further to improve the performance of the stilling basin model a square sill was introduced after impact wall at 4d length from exit of the pipe length as shown in Figure 3 and model (SM-5) was tested in similar flow conditions and computed values PI are come out as 2.40, 2.96 and 4.2 for Fr=1.85, 2.85 and 3.85 respectively, which are higher than the values obtained for USBR VI model (SM-2), whose values are 2.67, 2.63 and 3.42 for Fr=1.85, 2.85 and 3.85 respectively, thus performance of model with square sill at basin length 7d is better as compared to USBR VI model of basin length 8.4d. Further to make more efficient model the design of impact wall was changed as given in model SM6 with basin length of 7d and PI values appeared as 6.15, 5.10 and 4.20 for Fr = 1.85, 2.85 and 3.85 respectively, which are still more than values obtained for USBR VI model (SM-2) at basin length 8.4d & SM6 model of basin length 7d. Thus, the performance of new developed model with square sill at basin length 7d is better as compared to USBR VI model of basin length 8.4dwhich is also shown in Table 2. During the test run of this model, it was also observed that flow was very smooth for all Froude numbers and the amount of eroded material of sand bed was also lesser as compared to other models.

After the analysis, it was found that by introducing the intermediate sill with newly designed impact wall, there is an improvement in the performance of the stilling basin model. By designing new impact wall, the area of contact with water during impact action increases by which, a reduction in energy is greater, thus improving the performance of the basin. An intermediate sill of adequate height promotes energy dissipation in the basin by lifting the filaments at high speed from the bed. Undoubtedly, the performance of the calm basin models improves with the inclusion of the square section of the intermediate threshold, which also confirms the results of Negm (2004). A similar result was also reported by Tiwari and Tiwari (2013) and Tiwari et al. (2014).

3.1 Comparison of USBR VI model with new Developed Model

On analyzing the USBR VI stilling basin model (SM-2) proposed by Bradley & Peterka (1957) and new developed stilling basin model (SM-6) for noncircular pipe outlet, it is found that the value of performance index are SM-6 (PI = 6.15, 5.10 and 4.20 for Fr = 1.85, 2.85 and 3.85 respectively,) is higher side as compared to the value of performance index for USBR-VI model (PI= 2.67, 2.63 and 3.42 for Fr = 1.85,2.85 and 3.85 respectively) even at reduced length from 8.4d to 7d. Looking to the performance it is found that efficiency of reduction of flowing energy increases by more than 50 percent. Thus, there is an improvement of performance for the tested Froude number and also the length of the basin for new design model is reduced from 8.4d to 7d. Reduction of the basin length from 8.4d to 7d (17%) makes the new stilling basin model (SM-6) more economical as compared to USBR-VI model (SM-2) with improved efficiency of more than 50 percent. Comparative analysis is also shown in Figure 4.

Table -2: Scheme of Experimentation

Model	Impact Wall with hood			Intermediate sill of square cross section			Basin length
	Size	Bottom gap with basin floor	Location from outlet exit	Cross section	Width along basin width	Location from outlet exit	
SM-1	-	-	-	-	-	--	8.4d
SM-2	1d× 2.2d	1d	3d	-	-	--	8.4d
SM-3	-	-	-	-	-	-	7d
SM-4	1d× 2.2d	1d	4d	-	-		7d
SM-5	1d× 2.2d	1d	3d	0.5d x 0.5d	6.3d	4d	7d
SM-6	1.5d ×3d	1d	3d	0.5d x 0.5d	6.3d	4d	7d

Table -3: Performance index for different models tested with ES, IW and IS

Name of model	Fr = 1.85			Fr = 2.85			Fr= 3.85		
	d_m	d_s	PI	d_m	d_s	PI	d_m	d_s	PI
SM-1	4.8	12.0	2.03	5.7	12.9	2.10	6.4	17.0	2.70
SM-2	3.2	10.5	2.67	4.4	12.5	2.63	4.6	15.5	3.42
SM-3	8.8	17.8	1.64	9.8	19.6	1.85	11.2	25.8	2.34
SM-4	3.4	9.5	2.27	6.4	14.8	2.14	6.8	20.4	3.05
SM-5	1.1	4.6	3.40	2.6	8.3	2.96	2.9	12.6	4.42
SM-6	0.9	6.8	6.15	1.8	9.9	5.1	4.4	18.2	4.2

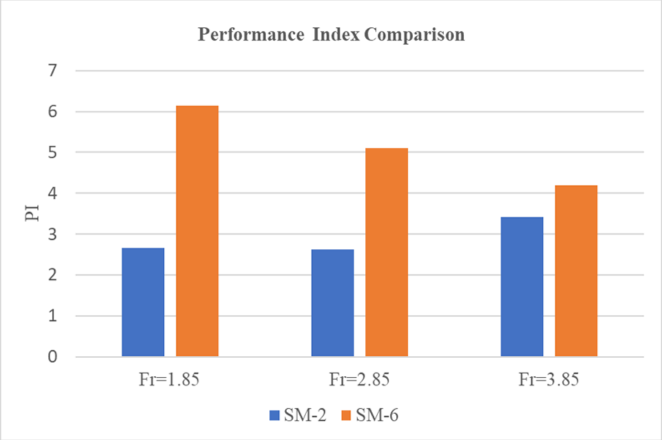

Fig -4: Comparison of new developed model

4. CONCLUSIONS

An experimental study was carried out in the laboratory by designing suitable physical models for the development of a new model of non-circular pipe outlets using the square sill as well as the end sill and appropriately designed impact wall according to the USBR VI existing model. The investigation was carried out at two basin lengths (8,4d, 7d) for the outlet of the rectangular pipe with 18 test run for the Froude numbers 3.85, 2.85 and 1.85. Scouring is reduced there by increasing the performance index for the square intermediate sill placed at a distance of 4d from the outlet of the outlet pipe. It was found that the intermediate square sill of height 0.5 d and base width 0.5 d, used in the SM6 model, produced higher performance indices (6.15, 5.10 & 4.20 for Fr = 1, 85, 2.85 and 3.85 respectively) which are even higher than the values obtained for the USBR VI (SM2) model of short length of 7d from 8.4d and therefore the performance of the new model developed (SM6) are better than the USBR VI (SM2) model for all Froude numbers tested. Based on the results of the experimental studies on the stilling basin models, it can be concluded that there is an improvement in performance for the Froude number tested and that the basin length for the new design model is also reduced by 8.4d to 7d. Reducing the basin length from 8.4d to 7d (17%) makes the new stilling basin model (SM6) less expensive than the USBR-VI (SM2) model.

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