EXPERIMENTAL STUDY OF EFFECT OF END SILL ON STILLING BASIN PERFORMANCE

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Abstract
This research paper presents an experimental study of end sill for new stilling basin models in dissipation of energy for a rectangular shaped pipe outlet of size 10.8 cm x 6.3 cm. The models were tested for three Froude numbers namely 1.85, 2.85 and 3.85 in the laboratory. The new models are developed by changing the shape of end sill. The scour (magnitude and location) after the end sill were measured for each model. The results have indicated that for all flow conditions, the sloping end sill is more effective in lowering the downstream kinetic energy than other end sills tested.

Keywords: Scour, Stilling basin, Froude number, End sill.

Introduction
End sill plays an important role in the design of stilling basin for reducing the length of it and also helps to improve the flow pattern downstream of the channel. End sill may be defined as a vertical, stepped, sloped or dentated/solid wall at the downstream end of the stilling basin, Edward, A (1959). Stilling basins are employed for the purpose of dissipating the excessive energy downstream of hydraulic structures like overflow spillways, sluices, pipe outlets etc. Various types of recommended stilling basin designs for pipe outlets recommended are by Bradely and Peterka (1957), Fiala and Albertson (1961), Keim (1962), Flammer et al. (1970), Vollmer and Khader (1971) Garde and Saraf (1986), Smith (1988), Goel and Verma (1999, 2001) and Goel (2008) etc. In all above mentioned studies, end sills used are either sloping Peterka (1957), or semicircular, Goel and Verma (2000). The previous models developed by past investigators are either too long or not working efficiently except the models developed by Goel (1999, 2001, 2008) which are applicable to circular shaped outlets only. The present research paper concentrates to study the effect of the shape & size of the end sill to develop new models for rectangular pipe outlet stilling basin.

Experimental arrangement
The experiments were conducted in a recirculating laboratory flume of 0.95 meter wide, 1 meter deep and 25 meter long in the hydraulics laboratory 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 as per design considerations suggested by Bradely and Peterka (1957). A rectangular pipe of 10.8 cm x 6.3 cm was used to represent the outlet pipe. This pipe was connected with delivery pipe of diameter of 10.26 cm installed in the centrifugal pump. The exit of outlet pipe was kept above stilling basin by one equivalent diameter (d = 9.3 cm) as per the design. A wooden floor of size 58.8 cm wide and 78.6 cm long was provided, downstream of the outlet for fixing the appurtenances in the basin. Three inflow Froude numbers namely Fr = 1.85, 2.85 and 3.85 were fixed as per discharge consideration in the flume. To observe the scour after the end sill of stilling basin, an erodible bed consisting of coarse sand passing through IS sieve opening size 2.36 mm. and retained on IS sieve opening size 1.18 mm was provided. The bed material size was selected on trial basis in such a way that even for a minimum Fr = 1.85, a measurable scour occurs and for maximum Froude number Fr = 3.85, the bed of flume is not exposed within a stipulated period of running time which was chosen as one hour for each model.
testing. A manual tail gate was used at the end of the flume to control the tail water depth in the flume for experimentation. The time for each test run was kept as one hour. The one hour duration was found to be sufficient as 90% of the scour occurred in 45 min for range of Froude numbers used as observed by experimental run, conducted as a trial at the beginning of the testing. The maximum depth of scour \(d_m\) and its distance from end sill \(d_s\) was measured for each test run after one hour run time. The depth of flow over the erodible bed was maintained equal to the normal depth of flow, which was computed by Manning’s formula corresponding to the inflow Froude number \(Fr = \frac{V}{\sqrt{gd}}\), where \(V\) is the average velocity in the pipe, \(g\) is the acceleration due to gravity and \(d\) is the equivalent diameter of the pipe. The erodible sand bed was leveled up to the top of the end sill for observation of the scour pattern. First of all all bed material was filled up to the height of end sill and get 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. After that centrifugal pump of capacity 20 HP was switched on, keeping the control valve closed, fitted into the feeding pipe. The flow into the flume was increased gradually so as to achieve required Froude number with a minimum possible disturbance to the erodible sand bed. The discharge was measured by a calibrated venturimeter installed in the delivery 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. All the models were tested for constant run time of one hour and with the same erodible material for three Froude numbers namely 1.85, 2.85 and 3.85. Different stilling basin models were tested by changing shape of end sills.

**Scheme of experimentation**

First of all basin floor was designed for the inflow Froude number \((Fr = 3.85)\) and was fabricated in the flume as per USBR impact type model, which consists of an impact wall of size \(1d \times 2.2d\) with a bottom gap \(1d\), located at \(3d\) from exit of pipe outlet and followed by sloping end sill of height \(1d\) positioned at \(8.4d\) where \(d\) is the equivalent diameter of the pipe outlet. Later on, in order to study the effect of end sill shape, new stilling basin models were fabricated by changing shapes of end sills (06 Models) fig. no. 1-2. During the test runs for all the stilling basin models, the grain size of the material forming the erodible bed and test run time were kept the same. The details of new models have been mentioned in Table No 1.

<table>
<thead>
<tr>
<th>Model number</th>
<th>Stilling basin length L</th>
<th>Impact wall with hood</th>
<th>End sill shape with height d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size</td>
<td>Location from outlet exit</td>
<td>Bottom gap with basin floor</td>
</tr>
<tr>
<td>MSM-1</td>
<td>8.4d</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MSM-2</td>
<td>8.4d</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MSM-3</td>
<td>8.4d</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MSM-4</td>
<td>8.4d</td>
<td>1dx2.2d</td>
<td>3d</td>
</tr>
<tr>
<td>MSM-5</td>
<td>8.4d</td>
<td>1dx2.2d</td>
<td>3d</td>
</tr>
<tr>
<td>MSM-6</td>
<td>8.4d</td>
<td>1dx2.2d</td>
<td>3d</td>
</tr>
</tbody>
</table>
Figure No. 1, New Stilling Basins with end sill only
Fig. 2 Variation of shapes (Rectangular (MSM-4), square (MSM-5), triangular (MSM-6)) of end sill with USBR type impact wall

MSM-4

MSM-5

MSM-6

Fig. 2 Variation of shapes (Rectangular (MSM-4), square (MSM-5), triangular (MSM-6)) of end sill with USBR type impact wall
Performance evaluation

The performance of stilling basin tested for different Froude number (Fr) is a function of channel velocity (v), the maximum depth of scour (dm) and its location from end sill (ds). 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 conditions. Verma & Goel (2003). A non-dimensional scour index (2dm/ds), Goel & Verma (2001), has been considered for comparison of performance of stilling basin models. A smaller value of scour index shows better performance of stilling basin models. The values of scour indices for various runs on each model for different Froude numbers are given in Table No. 2.

<table>
<thead>
<tr>
<th>S No.</th>
<th>Model No.</th>
<th>Fr = 1.85</th>
<th>Fr = 2.85</th>
<th>Fr = 3.85</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSM – 1</td>
<td>0.965</td>
<td>0.946</td>
<td>0.927</td>
<td>Scour Index higher side</td>
</tr>
<tr>
<td>2</td>
<td>MSM -2</td>
<td>0.847</td>
<td>0.903</td>
<td>0.867</td>
<td>Scour Index higher side</td>
</tr>
<tr>
<td>3</td>
<td>MSM - 3</td>
<td>0.800</td>
<td>0.883</td>
<td>0.757</td>
<td>Better performance</td>
</tr>
<tr>
<td>4</td>
<td>MSM-4</td>
<td>0.826</td>
<td>0.844</td>
<td>0.747</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>MSM-5</td>
<td>0.680</td>
<td>0.710</td>
<td>0.656</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>MSM-6</td>
<td>0.609</td>
<td>0.705</td>
<td>0.593</td>
<td>Better performance than all above</td>
</tr>
</tbody>
</table>

Result and discussion

In the beginning stilling basin models (MSM-1, MSM-2 and MSM-3) were tested with end sills of rectangular, square and sloping only for Fr = 1.85, 2.85, 3.85, and values of scour indices were mentioned in the table no. 2. It was found that without impact wall scour indices were on higher side as shown in bar chart in figure no. 6. The USBR impact type VI model (MSM-6) as shown in Fig. 2 for Fr = 1.85, 2.85, 3.85 was tested and the values of scour indices are mentioned in Table 2. The impact wall of height 2d2 with a bottom gap of 1d was placed at 3d from the exit of the pipe outlet. Although USBR model was designed for Fr = 3.85, tests were also conducted for Froude numbers 1.85 and 2.85 for rectangular pipe outlet. Keeping in view the performance of USBR model (MSM-6), the new models were tested by changing shape of end sill while keeping impact wall at same place. Models MSM-4, a square size of 1dx1d and in model MSM-5 a rectangular end sill of size (d) were tested and values of scour indices are mentioned in the Table 2. Comparison of performance of models
MSM-4 to MSM-6 shows that sloping end sill performs better as shown in figure no.4. The model MSM-4 having rectangular end sill further goes down as compared to model MSM-5 with square end sill and far inferior as compared to model MSM-6 as shown below.

**Conclusions**

An experimental investigation was conducted in a laboratory to study the effect of shape of end sill for rectangular pipe outlet basin. It was concluded that the shape of end sill in a basin affects significantly the maximum scour depth and hence scour index. The reduction rate depends upon the type of end sill geometry. The shape of end sill also affects the flow pattern and scour pattern downstream of pipe outlet basin. Experimental study reveals that the sloping end sill(1V:1H) with vertical face upstream dissipates more kinetic
energy for all flow conditions as compared to other end sills tested for rectangular pipe outlet basin. There is a scope to reduce the length of pipe outlet stilling basin by way of experimentations.

References