STILLING BASINS BELOW OUTLET WORKS – AN OVERVIEW

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ABSTRACT

A stilling basin is a transition structure constructed to dissipate excess energy confined by high velocity flow at the outlet of conduit or tunnel so that the flow beyond the basin does not endanger the stability of bed and banks of downstream channel. In a stilling basin kinetic energy causes turbulence and it is ultimately lost as heat and sound energy. There are several types of stilling basins which are used in various hydraulic structures like dam, canal, culvert etc. The type of stilling basin most suitable at a particular location mainly depends upon initial Froude Number and initial velocity of flow. This paper covers design principles and features of various stilling basins used for outlet works.

KEYWORDS – Stilling basin, Froude number, Outlet work, Energy Dissipation.

INTRODUCTION

Stilling basins are used to reduce the high velocity of flow of water from the jet as quickly as possible in order to minimize the scour of downstream river bed. A number of stilling basins like hydraulic jump type, hump type, jet diffusion type, free jet type, impact type and a combination of two or more are employed in most of the hydraulic structures (Mason, 1982). This paper deals with the design principles along with salient features of various stilling basins used for the outlet works. A relative comparison of length of energy dissipators is also presented at the end of the paper.

1. HYDRAULIC JUMP TYPE STILLING BASINS

Earlier hydraulic jump type stilling basins were used as energy dissipators for outlet works. In this type, jet of water is spread laterally by the appurtenances provided inside the stilling basin. The formation of hydraulic jump depends on inflow Froude number and tailwater depth conditions. Various types of hydraulic jump type basins along with details are given in Table 1. It can be seen that in these stilling basins, the L/D ratio varies from 11 to 91, where L = length of stilling basin and D = diameter of outlet. This large variation is due to larger length of stilling basin required for spreading the jet for proper dissipation of energy. These stilling basins have limitations of very large length requiring separate stilling basins for each of the outlets separated by long and high divide walls between them. Some of the hydraulic jump type stilling basins for outlet works as given by Berryhill (1963) are (a) Garrison Dam (b) Coyote Dam (c) Fort Peck Dam.

2. HUMP TYPE STILLING BASINS

As stated by Elevatorski (1959), when centre line of jet is below the stream bed but is not submerged by tailwater, then a hump is used to spread the jet and thus formation of hydraulic jump takes place. In the design of hump type stilling basin, the size and shape of the hump is the most important part. The hump should not be too high otherwise the jet would not spread out completely to the full width of channel. If jet is too low, tailwater for small flows will submerge the hydraulic jump. The level of crest of the hump should be the same as that of the river bed so that the hydraulic jump is formed even at low discharges. The details of hump stilling basin employed for Horsetooth Dam and Heart Butte Dam is given in Table 1.
3. STILLING BASINS FOR PIPE OUTLET DISCHARGING THROUGH VALVES

The details of model studies conducted by the Bureau of Reclamation, Colorado are presented by Peterka and Tabor (1951) with the basic objective of developing cheaper stilling basin structures of better performance for Enders Dam Outlet Works, Boysen Dam Outlet Works and Soldier Canyon Dam Outlet Works as stated below and given in Table 1.

Table 1: Data of Stilling Basins of Hydraulic Jump Type, Hump Type and Outlet Discharging through Valves Type for Outlet Works

<table>
<thead>
<tr>
<th>Project</th>
<th>Q (m³/s)</th>
<th>V (m/s)</th>
<th>Tunnel Dia (m)</th>
<th>Basin’s Type</th>
<th>Length (m)</th>
<th>L/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Garrison dam USA</td>
<td>992</td>
<td>14</td>
<td>2x6.7</td>
<td>Jump type, 2 divide walls chute, stepped endsill</td>
<td>106.6</td>
<td>13.5</td>
</tr>
<tr>
<td>2. Coyote dam USA</td>
<td>22</td>
<td>-</td>
<td>1x7.93</td>
<td>Jump type, one row baffle, 2.44m end sill,</td>
<td>56.4</td>
<td>15.0</td>
</tr>
<tr>
<td>3. Fort Peck</td>
<td>708</td>
<td>9.1</td>
<td>1x5.39</td>
<td>Jump type 2 rows baffles two rows baffles, end sill,</td>
<td>182.9</td>
<td>22.5</td>
</tr>
<tr>
<td>4. Horse-tooth</td>
<td>42</td>
<td>28.3</td>
<td>2x1.83</td>
<td>Hump type, abrupt step</td>
<td>166.8</td>
<td>91.0</td>
</tr>
<tr>
<td>5. Heart Butte</td>
<td>-</td>
<td>18.3</td>
<td>1x4.27</td>
<td>Hump type, end sill</td>
<td>45.7</td>
<td>11.0</td>
</tr>
<tr>
<td>6. Enders</td>
<td>28.3</td>
<td>17.7</td>
<td>2x1.52</td>
<td>Hooded, diffusion type</td>
<td>22.9</td>
<td>15.0</td>
</tr>
<tr>
<td>7. Boysen</td>
<td>34</td>
<td>20.7</td>
<td>2x1.22</td>
<td>Inclined valves, diffusion</td>
<td>35.3</td>
<td>29.0</td>
</tr>
<tr>
<td>8. Soldier canyon dam</td>
<td>2.83</td>
<td>35</td>
<td>1x0.46</td>
<td>Diffusion type, inclined valves</td>
<td>26.8</td>
<td>58.0</td>
</tr>
</tbody>
</table>

4. USBR IMPACT TYPE VI STILLING BASIN

The impact type stilling basins were developed by Bradely and Peterka, (1957) and U.S. Bureau of Reclamation (1970,1974) in order to meet the need of relatively shorter stilling basins to provide energy dissipation independent of tail water depth. In this type of stilling basins, greater discharges could be handled by constructing multiple units. The efficiency of the stilling basin is achieved by energy losses due to impact in comparison to a hydraulic jump type stilling basins for a given inflow Froude number. The energy dissipation is initiated by flow striking the vertical hanging baffle wall and part of the flow being turned upstream by the horizontal portion in the form of hood of the baffle which produces eddies. It does not require tail water for energy dissipation as required in case of a hydraulic jump. But the efficiency of stilling basin could be increased by providing tail water depth equal to \( d + g / 2 \), (where \( d \) = height of end sill, \( g \) = clear height of hanging baffle wall). The pipe may be tilted downward up to 15° without affecting the performance adversely. It is a simple model having stilling basin floor depressed equal to diameter of outlet below the invert of the outlet with an impact wall and an end sill (vertical or sloping). Notches in the baffle wall could be provided for cleaning purpose. The alternate end sill sloping at 45° improves the performance. This can be used up to discharge of 10m³/s and velocity up to 10m/s. For designing the stilling basin few formulae could also be used as mentioned by Lencastre Armando (1970) and Charles (1991).

Suppose, width of stilling basin is \( W \) and diameter of the outlet pipe is \( D \), then Froude number, \( F_r \) can be calculated by \( W / D = 3 F_r^{0.55} \).

Although length of stilling basin is small, yet it suffers from the following drawbacks:
(i) The Froude number range is very small i.e.1 to 2, which may be due to big size of the outlet used as per the calculations made from the Table (Bradely and Peterka, 1957).
(ii) It is not very useful if velocity is less than 0.61m/s.
(iii) The notches at the bottom of the impact wall provide some concentration of flow passing over the end sill resulting in slight tendency to scour.
(iv) The use of basin is limited to \( Q = 10m³/sec \) and \( V = 10m/sec \).
5. MANIFOLD STILLING BASIN

Manifold stilling basin (Fiala and Albertson, 1961) was designed based on the principle of diffusion of submerged jet. The energy is dissipated with flow in vertical direction by means of a manifold type of structure. One rectangular shape of conduit of constant width and linearly varying height from 0.305m at inlet to zero at the downstream end of model is selected. The jet is made to rise upwards through the rectangular opening by providing adverse slope to the floor meant for entrance. The jet entrains the surrounding fluid due to shear resulting in fine grained turbulence and dissipation of energy. This type of energy dissipator is not suitable for circular outlets and under situations having chances of blockage of openings due to floating debris. The construction of the basin is complicated and requires larger length of the stilling basin.

6. CONTRA COSTA STILLING BASIN

It was developed by Keim (1962) for the culverts wherein depth of flow is less than half of the culvert diameter and effluent velocity is high. It is based on concept of energy loss by a combination of hydraulic jump, diffusion and impact inside the stilling basin. Redistribution of jet was obtained by using a barrier which resulted into increased momentum components in the lateral and vertical directions. The mechanism consisted of the production of large scale turbulence during distribution of the jet. The design depends on assumed value of L_A/h_2 where L_A = length of approach basin and h_2 = height of final baffle. Four relationships between dimensional parameters were found to be sufficient for design which are mentioned below:

(i) Approach basin - It provides initial redistribution and dissipation of energy.
(ii) Length of basin - It provides impact and stabilisation of flow.
(iii) Height of side wall - It contained highest water surface with in dissipator.
(iv) Limits of magnitude of variables were also determined for the satisfactory design.

It was designed for the most severe flow conditions expected in terms of maximum Froude number. The Froude number was given by \( F = \left[ \frac{V_1}{\sqrt{gd_1}} \right] \) where \( F = \) Froude number, \( V_1 = \) velocity of flow in culvert outfall, \( g = \) gravitational acceleration, \( d_1 = \) depth of flow in culvert at outfall. If values of \( d_1, F, d_2 \) where \( d_2 = \) depth of tail water in downstream channel are given, other parameters can be obtained by using the equations developed between \( L_A, L_B, F, h_2, d_1 \) and \( Z \) by extensive experimentations as given below.

\[
\begin{align*}
L_A/L_B &= 1.2 \left( \frac{h_2}{d_1} \right)^{1.30} \\
L_B/L_A &= 3.75 \left( \frac{h_2}{L_A} \right)^{0.68} \\
Z/h_2 &= 1.3 \left( \frac{L_A}{h_2} \right)^{0.26}
\end{align*}
\]

But it has following drawbacks:

(i) It is only applicable when depth of flow is half of culvert diameter or less. If depth of flow is more than half the culvert diameter than it can not be used.
(ii) It is based on a hit and trial method.
(iii) The Froude number range is from 4 to 76 and its value is very high. Hence it is not suitable for low Froude numbers.
(iv) Satisfactory design limits are not defined.
(v) The dimensions like width and slope of baffle walls are not defined.
(vi) The side slope 1:1 of channel requires additional cost and labour.
(vii) It requires more length of basin and hence cost of construction is high.

7. UTAH STATE UNIVERSITY STILLING BASIN

It has been designed by Flammer et. al (1970) as a transition from pipe flow to open channel flow. Energy is dissipated by shear drag, pressure drag and diffusion action of submerged jet. The dimensions of a short dissipator pipe introduced opposite to the inflow pipe with common central axis are the most important part. Initially experiments were performed to fix the dimensions of dissipator pipe. Finally taking dimensions of dissipator pipe as \( D_2/D_1 = 2, L/D_1 = 1, W/D_1 = 0.5 \) and other dimensions of stilling basin such as \( Y_1/D_1 = 1.5, L_B/D_1 = 3.5 \) were fixed by considering the jet expansion ratio 1:5 and \( W_B/D_1, Y_2/D_1 \) and \( Y_t/D_1 \) were varied. By using a graph and these standard values of dissipator pipe and other components, the stilling basin could be designed easily, given the data of discharge, outlet diameter and available tail water depth conditions. It is applicable only for fully submerged outlets and can not be used for \( W_B/D = 6 \) more if Froude number is less than 5.5. The depth requirement of stilling basin is too much which may not be possible to be provided physically in many situations. The chances of debris being entrapped in the basin endangering the safety of structure are also there.
8. COUNTER CURRENT STILLING BASIN

This type of energy dissipator has been designed by Vollmer and Khader (1971). It is based on the principle that the dissipation of energy is brought about due to impact of opposing jets. The flow is divided in two parts by a V-shaped structure placed on the floor of the basin known as splitter block. The major portion of divided flow is directed into the flow direction and are joined by a circular arc structure so as to meet in opposite direction which creates a heavy loss of energy due to impact. The remaining parts of the divided flow are directed in the opposite direction forming small vortices at upstream corners of the basin which properly utilises complete basin area in front of the circular arc like structure for energy dissipation. A gap of 0.2D is provided below the impact wall of circular arc shape to pass low discharges (D = diameter of the outlet). Here flow meets the water cushion provided by end sill which provides energy dissipation. In high discharge, mainly the energy dissipation is by direct impact of divided stream and same energy is dissipated by water cushion behind this circular arc shaped impact wall. The length and the width of stilling basin are 7.3D and 4D respectively. In this stilling basin, appurtenances such as a diffuser of triangular wedge shape, an impact wall of circular shape having bottom gap equal to 0.2D and one rectangular end sill are recommended. The drain holes provided in the end sill would help in removing the sediments at low discharges. All the dimensions of stilling basin are in terms of diameter of the conduit.

9. GARDE’S STILLING BASIN

The energy dissipator designed by Garde and Saraf (1974,1986) is based on the principle that the jet is made to spread over the width of stilling basin and then made to split into number of smaller jets which further diffuse thereby dissipation of energy takes place in the shortest possible length. The energy dissipator evolved has been recommended for circular outlets whose invert level is near the river bed into which it is discharging. Based on the detailed model studies, following appurtenances along with their locations have been recommended for circular pipe outlets:
(i) a single curved splitter at x = 1D
(ii) an overflow vertical grid at x =3D
(iii) a solid rectangular sill at x =8D
(iv) a rounded (R = D/2) step at x =12D
where x is the distance from exit of outlet along the axis of the flume indicating the location and D is the diameter and R is the radius of the outlet. The detailed arrangements of the basin along with recommended grid. This design has been found to be quite useful for Froude number ranging from 1.7 to 7.0. All the dimensions of the stilling basins are in terms of diameter of the outlet. So there is no difficulty in designing the stilling basin. The length of stilling basin is too large and the construction of splitter block and grid with openings is not easy.

10. SMITH’S STILLING BASIN

The design as given by Smith (1988) consists of a transition and a hydraulic jump stilling basin with straight diverging side walls. Design values of stilling basin were determined for both circular and square conduits. The design criteria is based on effective position of HGL (Hydraulic gradient line) at outlet, head losses in transition, depth and velocity distribution in transition, stability of hydraulic jump, downstream velocity distribution and scour tendencies in the discharge channel.

The pressure distribution in the jet at the outlet is non hydrostatic. The effective position of HGL will be below the top of pipe. It can be determined by installing piezometers upstream of outlet where pressure is hydrostatic. Then this line can be extrapolated to the plane of outlet locating a vertical intercept y above the invert of pipe (where y = position of HGL above the invert of pipe).

The transition curve is used to connect straight parallel side of conduit to straight diverging walls of transition. It is intended to avoid complete separation from side walls at the start of transition and can be achieved by a simple curve with a tangent length equal to Bw/2 where Bw = width at the start of transition.

The position of jump should be near the end of transition to avoid possibility of unsymmetrical flow. This is achieved by giving a slope on the floor slab at the end of transition and a drop in the elevation from the invert of the conduit to the floor of stilling basin equal to Bw/2.

However, it has got following drawbacks:
(i) The drop height should be at least Bw/2 which may not be available all the time.
(ii) The length of stilling basin is nearly 9Dw.
(iii) It is not easy to construct as it requires side transition walls.
Goel & Verma (2000) used the wedge shaped splitter blocks having a vertex angle of 150° in the stilling basin for pipe outlets. This splitter block found to be very effective in spreading the jet of water over the width of the stilling basin within a shorter length and has better energy dissipation. They had also found that the performance of the stilling basin improves by using rounded end sill instead of rectangular or sloping one.

Goel and Verma (2001) further reduced the length of the stilling basin as suggested by Garde to 8 times and 6 times of the pipe diameter by replacing the grid type of baffle wall with solid one and a curved splitter with wedge shaped splitter block. The performance of the stilling basin improved significantly.

Goel and Verma (2003) carried out study of stilling basins for pipe outlets for the Froude Number range of 1.7-5.5. By using different appurtenances such as splitter block, impact wall, baffle blocks and end sill there is a reduction in stilling basin length up to the extent of 25% of the original and at the same time there is improvement in the performance of the basin. In this study the basin floor is kept at the invert level of the pipe.

COMPARISON OF LENGTH OF DIFFERENT STILLING BASINS FOR OUTLETS

After discussing about various types of stilling basins for outlets, efforts are made to summarize their length as stated in Table 2. It is clear from the Table 2 that hydraulic jump type stilling basins are the longest due to the fact that main portion of length of stilling basin is used by spreading of the jet. The other stilling basins are more or less same in length because they are either impact type or diffusion type or combination of two. In U S U energy dissipator, depth of basin is very large. The Contra Costa stilling basin is used only for culverts where depth of flow is less than half the diameter of the culvert. Mostly used stilling basin for outlets is a recommended by USBR type VI stilling basin with extensive laboratory investigation. The stilling basin suggested by Garde (1986) is also large in length.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Name of Stilling Basin</th>
<th>Length</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Hydraulic Jump Type</td>
<td>11d-91d</td>
<td>Longest</td>
</tr>
<tr>
<td>2.</td>
<td>USU Energy Dissipator</td>
<td>3.5d</td>
<td>Depth is very large</td>
</tr>
<tr>
<td>3.</td>
<td>Manifold Stilling Basin</td>
<td>--</td>
<td>Not for circular outlets</td>
</tr>
<tr>
<td>4.</td>
<td>Garde’s Stilling Basin</td>
<td>12d</td>
<td>Developed in India</td>
</tr>
<tr>
<td>5.</td>
<td>USBR Impact Type VI Stilling Basin</td>
<td>8d</td>
<td>Mostly used</td>
</tr>
<tr>
<td>6.</td>
<td>Smith’s Design of Energy Dissipator</td>
<td>9d</td>
<td>--</td>
</tr>
<tr>
<td>7.</td>
<td>Counter Current Type Energy Dissipator</td>
<td>7.3d</td>
<td>--</td>
</tr>
<tr>
<td>8.</td>
<td>Contra Costa Energy Dissipator</td>
<td>6d - 22d</td>
<td>Depends on dia,Fr and for culverts only.</td>
</tr>
<tr>
<td>9.</td>
<td>Goel Stilling Basin</td>
<td>6d to 8 d</td>
<td>For circular pipe outlet</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The paper reviews several types of stilling basins for circular shaped outlets used in water resources projects. As clear from the present literature, design of none of these energy dissipators have been standardized and most of them are larger in length. Hence, In the light of present knowledge of the energy dissipation, there is an ample scope for evolving a shorter and simple design of an effective stilling basin based on systematic, rigorous
and extensive experimental study. The new designs of shorter basins would save cost of construction of these basins to a great extent.

REFERENCES