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Utah State University Stilling Basin Pipe Flow to Open Channels

Hameed Rasheed
Utah State University

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UTAH STATE UNIVERSITY STILLING BASIN

PIPE FLOW TO OPEN CHANNELS

by

Hameed Rasheed

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

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Approved:

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Hameed Rasheed

Hameed Rasheed
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ABSTRACT

Energy dissipation problems are often encountered where pipelines discharge into open channels. Normal pipe flow velocities most often result in super-critical velocities in canals. These high velocities may cause scour, overtopping, and unstable flow in the channel.

The principal objective of the study was to find an efficient and economical design of a stilling basin transition from pipe flow to open channels. Pertinent variables were selected and their effects determined by extensive experimentation.

An efficient stilling basin was developed utilizing a short dissipator pipe on the wall opposite the inflow pipe. The optimum diameter, length, and differential elevation between center lines was determined.
NOTATION

b    Length of dissipation box
b'   Bottom width of trapezoidal channel
d    Width of the dissipation box
D₁   Diameter of inlet pipe
D₂   Diameter of the dissipator pipe
d'   Thickness of concrete wall
ΔE   Energy dissipated, in feet of water
g    Acceleration of gravity
h    Depth of the dissipation box
h'   Depth of the water above the datum in the stilling basin
L    Length of the dissipator pipe
M    Moment in foot-pounds
n    Length ratio
Qₘ   Discharge in model
Qₚ   Discharge in prototype
V₁   Mean velocity in pipe inlet
V₂   Mean velocity in open channel
w    Width of slit in the dissipator pipe
Y₁   Flow depth in open channel
Y₂   Vertical distance from the bottom of the channel to the top of the dissipator pipe
\( \Delta Z \)  The difference in elevation between the mean water level in the stilling basin and the mean water level in the open channel

\( \delta \)  Differential elevation between the center lines of the inlet pipe and the dissipator pipe

\( \lambda \)  Any length dimension
INTRODUCTION

Various hydraulic structures such as spillways, outlet works, and drops require dissipation of the kinetic energy of the flowing water in either a vertical or horizontal direction or both. In the horizontal direction the energy may be dissipated by:

1. Shear drag
2. Pressure drag
3. Increase in piezometric head.

In the vertical direction the energy may be dissipated by:

1. Diffusion of jets vertically upwards
2. Diffusion of jets vertically downwards.

The energy dissipator under study is designed as a transition from full pipe flow to open channel flow. Both vertical and horizontal energy dissipation phenomena are present. Shear drag, pressure drag, and vertical diffusion are the major dissipation mechanisms present.

The basic requirements and limitations of this study are as follows:

1. The pipe outlet is fully submerged at all flow rates
2. The center lines of the inflow pipe, the dissipator pipe, and the open channel are parallel
3. The inflow pipe is the only source of flow to the open channel
4. The dissipator pipe is self cleaning

5. Structural features, shape, and dimensions are so chosen that a workable installation can be achieved with minimal cost

6. The dissipator pipe and the entire installation are designed to be structurally sound under the given flow conditions.

Many variables are important in the design of the proposed energy dissipator. These variables are:

1. The differential elevation between the pipe and the open channel

2. The ratio of the inflow pipe diameter to the dissipator pipe diameter

3. The depth, width, length, and shape of the stilling basin.

The individual effect of any selected variable was determined by holding all other variables constant.

The criteria for evaluating the effect of a particular variable were the roughnesses of the water surfaces in the stilling basin and the open channel. Based on the above analysis the most efficient section was selected for a particular discharge and inflow pipe diameter.

To further verify the design, another model was constructed to a larger scale, and observed. Comparison of the flow profiles in the two models indicated that the proposed design could be extended to actual prototype sizes.
REVIEW OF LITERATURE

Existing stilling basins and energy dissipators can be classified as one of or a combination of the following types:

1. Drop structure basin (2)
2. Free fall basin (7)
3. Roughened channel lining (5)
4. Hydraulic jump basin (12)
5. Diffuser structures (6)
6. Roller bucket (4)
7. Flip bucket (3)
8. Impact structure (8, 11)

Study and analysis of known types of energy dissipators revealed that their application to the problem under study, i.e., pipe flow to open channels, failed to comply with one or more of the basic requirements and limitations previously listed. However, proper combination of the mechanisms involved in Types 5 and 8 proved to give a reasonable solution to the problem.

Previous studies have been conducted on energy dissipation at the transition from pipe to open channel flow. These studies will be discussed briefly in this chapter.
A model study of a manifold stilling basin was conducted in the Hydraulic Laboratory at Colorado State University. Figure 1 shows the general layout of the experimental equipment. The width of the model was kept constant (1.0 foot), and the length of the model was set at 8 feet. The depth was varied from one foot at the inlet to zero at the downstream end of the model.

Dimensional analysis was used to determine the pertinent dimensionless parameters. The result was

$$\frac{h}{v_1^{2/3}g} = f\left(\frac{w}{s}, \frac{b}{B_0}\right)$$

where

- $h$ = wave height
- $v_1$ = initial jet velocity
- $g$ = acceleration of gravity
- $w$ = width of the opening
- $s$ = size of the cross bar
- $b$ = tail water depth
- $B_0$ = width of the manifold

A relationship for the boil height was derived from the analytical and experimental work of Albertson et al (14), together with the assumption that the jet velocity causes the boil height at the surface.

The boil height is equal to the velocity head $\left(\frac{v_{\text{max}}^2}{2g}\right)$. 

Manifold stilling basin (6)
Figure 1. General layout of the experimental model used for the manifold stilling basin
\( \frac{a}{v_1/2g} = \frac{c}{b/B_0} \) \[2\]

where

\begin{align*}
a &= \text{boil height} \\
c &= \text{coefficient (expected to be larger than 5.2)} \\
v_{\text{max}} &= \text{maximum velocity}
\end{align*}

Equation 2 represents a manifold stilling basin with numerous jets. However, two limiting conditions were considered:

1. For low tail water, a very small amount of tail water interference was present and the data indicated that \( \frac{v_{\text{max}}}{v_1} \) approached unity for low values of \( \frac{w}{s} \).

2. For high tail water and/or large values of \( \frac{w}{s} \), the manifold behaved as one large jet and the following expression was derived, assuming inflow constant and momentum flux per unit area constant and independent of the number and width of the slots.

\( \frac{a}{v_1/2g} = n_1 B_0 \) \[3\]

where

\begin{align*}
n_1 &= \text{number of slots.}
\end{align*}

Extensive laboratory investigations were conducted, and the validity of the above equation was verified experimentally.
Significant results obtained from these model studies are:

1. The best velocity and pressure distributions were obtained by using square inlet sections

2. As \( \frac{b}{s} \) decreases to about 5, \( \frac{v_1}{v_0} \) becomes smaller

3. As \( \frac{w}{s} \) increases, \( \frac{v_1}{v_0} \) becomes smaller

4. Equation 2 was proved to be valid for \( c \) values greater than 5.2

5. As \( \frac{w}{s} \) becomes larger or smaller, the behavior of the manifold approaches single jet behavior.

A practical field design can be achieved, based on the foregoing results. The discharge and tail water depth must be known. The preliminary geometric design of the manifold is to be based on the equation

\[
\frac{L}{\sqrt{A}} = 8
\]

The design is then checked using design equations 1, 2, and 3, to insure proper hydraulic performance of the stilling basin.

Contra Costa energy dissipator (8)

The Contra Costa energy dissipator was developed at the Hydraulic Laboratory of the University of California. This dissipator is applicable only for flow from culverts where the exit flow depth is less than one-half of the culvert diameter. Figure 2 shows the layout of the Contra Costa energy dissipator.
where

- $D$ = inside diameter of the culvert
- $d_1$ = depth of flow in the culvert
- $h_s$ = height of the stilling basin sill
- $h_1$ = height of the intermediate baffle
- $h_2$ = height of the final baffle
- $L_A$ = length of the approach basin
- $L_B$ = length of the stilling basin

In the early stages of the development of the energy dissipator, some of the geometrical configurations were established. Structural limitations and economic considerations entered into the choice of the final geometry of the basin. The ratio of the height of the intermediate baffle to the height of the final baffle $\frac{h_1}{h_2}$ was fixed at $\frac{1}{2}$; the side slopes of the channel were fixed at 1:1; and the intermediate baffle was placed at the midpoint of the approach basin, $L_A$.

In addition to the above fixed geometric features, four pertinent dimensionless parameters were selected. The relationships between these parameters were determined as a result of the analysis of data collected from various model setups. The final results were:

\[
\frac{L_A}{h_2F} = 1.2 \left( \frac{h_2}{h_1} \right)^{-1.80} \quad [4]
\]

\[
\frac{L_B}{L_A} = 3.7 \left( \frac{h_2}{L_A} \right)^{0.03} \quad [5]
\]
\[
\frac{Z}{h_2} = 1.3 \left( \frac{\frac{L_A}{h_2}}{h_2} \right)^{0.36}
\]

where

\[F = \text{Froude number} \quad \frac{v_1^2}{g d_1}\]

\[Z = \text{peak depth of water surface above the basin.}\]

Observations were made on different model arrangements, and the results revealed that best hydraulic operation was achieved when

\[\frac{L_A}{h_2} \quad \text{was approximately 3.5, and}\]

\[\frac{W_C}{D} \quad \text{was approximately 2.0.}\]

Field installations are designed by utilizing Equations 3, 4, and 5. Slight changes in the design can be made for purposes of economy.

**Bradley-Peterka energy dissipator (5)**

An impact type stilling basin was developed in the Hydraulic Laboratory of the U. S. Bureau of Reclamation. The purpose of this dissipator was to establish natural flow conditions in open channels where the flow originated from a pipe.

No tail water is necessary for the operation of this stilling basin.

Figure 3 shows a longitudinal section of the final design.

Geometric dimensions are shown in Figure 3, where they are expressed in terms of the pipe diameter. A protective blanket of riprap downstream is suggested for proper operation. The minimum riprap
Figure 3. Elevation view of the final design, Bradley-Peterka basin VI
size is given by the expression \( V_b = 2.6 \sqrt{d} \)

where

\( V_b \) = bottom velocity in feet per second

\( d \) = diameter of the rock in inches.

The pipe inlet may be tilted downward as much as 15° without affecting the operation of the stilling basin.
EXPERIMENTAL PROCEDURES AND RESULTS

Some preliminary work on design of a stilling basin for pipe flow to open channels was conducted by Dr. G. H. Flammer at Utah State University. The study was made for a private concern, and design recommendations were based on limited model studies. Dr. Flammer strongly recommended that a more thorough and comprehensive study of the problem be made. This research results from his recommendation.

Equipment

The first model consisted of a 2-inch inflow pipe flowing into a box stilling basin 8 inches wide and 6 inches long. The stilling basin discharged into a trapezoidal channel with a bottom width of 2.5 inches and side slopes of 1:1. The center line of the inflow pipe was located 3 inches above the bottom of the stilling basin and 2.85 inches below the bottom of the trapezoidal channel.

The discharge measurement device consisted of a manometer connected across a sudden contraction in the supply line. The calibration was made by means of weighing tanks. A short dissipator pipe was placed on the wall opposite the incoming jet. Figure 4 shows an elevation view of the model, and Figure 5 shows a plan view.
Figure 4. Elevation view of the stilling basin

Figure 5. Plan view of the stilling basin
Procedure

Discharges as high as 40 gpm were observed in the model. Preliminary observations indicated that:

1. At low discharges (10-20 gpm), the water surface in the basin and channel inlet was smooth and the box section alone was sufficient to dissipate the energy.

2. At high discharges (20-40 gpm), there was considerable turbulence in the box section and an undesirable velocity distribution in the trapezoidal channel (Figure 6), indicating insufficient dissipation. A short dissipator pipe was then located on the opposite wall with its center line slightly offset vertically from the inflow pipe center line. This arrangement proved to be an effective energy dissipator.

3. For a constant discharge, tail water depths were varied by varying the slope of the outlet channel. Observations showed the performance of the stilling basin to be independent of tail water depth for the limited range of depths possible at maximum discharge in the open channel.

Considerable flow improvement was effected by introducing the short dissipator pipe on the opposite wall from the incoming jet. The jet enters the pipe where its confinement results in very high shear and turbulence between the incoming and outflowing water.
Figure 6. The model operating at a discharge of 35 gpm without the dissipator pipe
Preliminary observations on the first model indicated that a discharge of 35 gpm was maximum without overtopping. The geometry of the stilling basin box was fixed by experimentation at: \( b = 3D_1 \), \( h = 4D_1 \), and \( d = 4.33D_1 \). However, the value of the depth, \( h \), was later reduced. Structural aspects were also considered.

The efficiency of the stilling basin was indicated by the smoothness of the water surface. Water surface elevations were measured at nine locations in the basin. The geometry and the locations of these points are shown in Figure 7. The water levels were measured by a point gage.

Results

In addition to the fixed geometry of the dissipation section, the following dimensionless parameters were found experimentally to have a significant effect on the operation of the stilling basin:

1. \( \frac{D_2}{D_1} \) = ratio of the dissipator pipe diameter to the diameter of the inlet pipe
2. \( \frac{L}{D_1} \) = ratio of the length of the dissipator pipe to the diameter of the inlet pipe
3. \( \frac{S}{D_1} \) = ratio of the differential elevation between inflow and dissipator pipe center lines to the diameter of the inlet pipe.
These variables were changed one at a time to obtain the most efficient basin; that is, the smoothest water surface in the stilling basin and the most symmetrical velocity pattern at the inlet to the trapezoidal flume.

Diameter ratio

Diameter ratios, \( \frac{D_2}{D_1} \), of 0.5, 1.0, 1.5, and 1.85 were tried. The length, \( L \), of the dissipator pipe was fixed arbitrarily at 2.5 inches, and the difference in the elevation of the inlet and dissipator pipe center lines (5) was fixed at 1.25 inches. Data were obtained for various discharges and diameter ratios. The ratio \( \frac{D_2}{D} = 1.85 \) proved best. For this ratio the bottom of the open channel and the top of the dissipator pipe were on the same level. Therefore, higher diameter ratios were not tested.

Figure 8 shows the model operating at a discharge of 35 gpm for the diameter ratio of 1.85. This maximum discharge was the criterion used to select the best diameter ratio. For discharges less than 35 gpm, the following equation can be used to determine the diameter ratio. However, the diameter ratio should not be less than 1.0.

(See Figure 9.)

\[
\frac{D_2}{D_1} = 0.123 (Q-20) \quad \text{ (8)}
\]
Figure 8. Small model operating at a discharge of 35 gpm and a diameter ratio, \( \frac{D_2}{D_1} \), of 1.85.
Figure 9. Plot for determining $\frac{D_2}{D_1}$, $\frac{L}{D}$, for various discharges.
where

\[ Q = \text{design discharge} \]
\[ D_2 = \text{dissipator pipe diameter} \]
\[ D_1 = \text{pipe diameter} \]

Length ratio

After the best diameter ratio was found, the length of the dissipator pipe was varied. Length ratios, \( \frac{L}{D} \), of 1.25, 1.0, 0.75, and 0.5 were used. The best hydraulic performance was achieved when the length ratio was 1.0. Figure 10 shows the model for the best length and diameter ratios at a flow of 35 gpm.

For discharges less than 35 gpm, the following equation can be used to determine the length of dissipator pipe (Figure 9),

\[
\frac{L}{D_1} = 0.067 (Q - 20) \tag{9}
\]

where

\[ Q = \text{design discharge} \]
\[ L = \text{length of dissipator pipe} \]
\[ D_1 = \text{diameter of the inlet pipe} \]

Differential elevation ratio

Differential elevations, \( \frac{\delta}{D} \), of 1.25, 1.00, and 0.75 were tested at various discharges. The best flow profile was achieved for a differential elevation ratio of one-half. Figure 11 shows the model with the differential elevation fixed at 0.5, the length ratio at
Figure 10. The small model operating at a discharge of 35 gpm and with diameter, $\frac{D_2}{D_1}$, and length, $\frac{L}{D'}$, ratios of 1.85 and 1.0, respectively.
Figure 11. The small model operating at a discharge of 35 gpm and with diameter, $\frac{D_2}{D_1}$, length, $\frac{L}{D_1}$, and differential, $\frac{\delta}{D_1}$, ratios of 1.85, 1.0, and 0.5, respectively.
1.0, and the diameter ratio at 1.85, for a discharge of 35 gpm.

This differential elevation between the center lines of the inflow pipe and the dissipator pipe gives the best flow dissipation for the following reasons: The inflow jet enters near the bottom of the dissipator pipe. This confinement forces high velocity flow out of the bottom. However, the currents are deeply submerged so their energy is efficiently dissipated as they travel toward the surface. The velocities returning along the top of the dissipator pipe are relatively low in magnitude because of the increased flow area resulting from the offset. The currents occur near the surface but are small enough to dissipate rapidly without causing significant surface disturbance.

Shape factor

Although the differential elevation improved the surface profile considerably and established good flow conditions in the open channel, it was felt that slots or holes in the dissipator pipe at various locations from which small jets could issue would further improve the design.

Numerous hole and slot arrangements were tried. A uniform slit in the bottom of the dissipator pipe over the full pipe length gave the best surface profile. Dimensionless slit widths of 2.0, 1.5, 1.0, and 0.5 were used. The best slit width was

\[
\frac{W}{D_1} = 0.5
\]
where

\[ W = \text{width of the slit at the bottom of the dissipator pipe extending through the entire pipe length.} \]

Figure 12 shows the model at a discharge of 35 gpm with the most efficient length, diameter, differential elevation, and shape factor. When a smaller inlet pipe was used for the same discharge, the surface profile was affected, which indicated that the 2-inch diameter was the minimum size for the discharge under study.
Figure 12. The small model operating at a discharge of 35 gpm with the optimum values of length, diameter, differential elevation, and shape factor of the dissipator pipe
ANALYSIS

Theory

Considerable kinetic energy is dissipated in the stilling basin by shear between adjacent fluid jets. As flow issues from the inlet pipe and enters the dissipator pipe, the jet is deflected 180° and is so confined that the opposing jets are immediately adjacent to each other. A region of extremely high shear with considerable energy dissipation results.

In addition, vertical diffusion is an important dissipation mechanism, particularly for the high velocity flow forced vertically downward out of the bottom slit of the dissipator pipe.

The amount of energy dissipated can be computed by the following simple analysis. (See Figure 5.) The total energy of the flow at the pipe inlet is

\[
\frac{V_1^2}{2g} + h'
\]

Assuming the center line of the inlet pipe to be the datum line, the total flow energy in the entrance of the open channel is

\[
\delta + \frac{D_2}{2} + y_2 + y + \frac{V_2^2}{2g}
\]

Thus

\[
\Delta E = \left( \frac{V_1^2}{2g} + h' \right) - \left( \delta + \frac{D_2}{2} + y_2 + y + \frac{V_2^2}{2g} \right)
\]
\[ \Delta E = \frac{V_1^2 - V_2^2}{2g} + h' - S - \frac{D_2}{2} - y^2 - y \]
\[ \Delta E = \frac{V_1^2 - V_2^2}{2g} + \Delta Z \]

where

\( \Delta E \) = energy dissipated in feet of water

\( V_1 \) = mean velocity in the inlet pipe

\( V_2 \) = mean velocity in the open channel

\( h' \) = depth of the water above the datum in the stilling basin

\( g \) = acceleration of gravity

\( S \) = differential elevation between the center lines of the inlet pipe and the dissipator pipe

\( D_1 \) = diameter of inlet pipe

\( D_2 \) = diameter of dissipator pipe

\( y \) = flow depth in the open channel

\( y_2 \) = the vertical distance from the bottom of the channel to the top of the dissipator pipe

\( \Delta Z \) = the difference in elevation between the mean water level in the stilling basin and the mean water level in the open channel.

An understanding of the dissipation mechanisms involved is important. Geometry and other features were designed accordingly with consideration given to structural aspects.
Comparison of models

To verify the design features of the first model, a second model was constructed to a larger scale. Comparison of the two models indicated the design can be extended to any prototype size. Dimensional analysis was utilized as follows. (Refer to Figures 5 and 6.) The effect of viscosity and surface tension were neglected.

\[
\frac{V_1^2}{gD_1} = f\left[\frac{D_2}{D_1}, \frac{L}{D_1}, \frac{\delta}{D_1}, \text{etc}\right]
\]

\[
\frac{V_1^2}{gD_1} = f\left[\frac{\lambda}{D_1}\right]
\]

where

\(\lambda = \text{any length dimension}\)

design conditions

\[
\left(\frac{\lambda}{D_1}\right)_m = \left(\frac{\lambda}{D_1}\right)_p
\]

\(\lambda_p = \lambda_m \frac{[D_1]_p}{[D_1]_m}\)

\(\lambda_p = n\lambda\)

where

\(n = \text{length ratio}\)

\(\lambda_p = \text{any length dimension in the prototype}\)

\(\lambda_m = \text{any length dimension in the model}\)
Prediction equations

\[
\left( \frac{v_1^2}{gD_1} \right)_m = \left( \frac{v_1^2}{gD_1} \right)_p
\]

\[
\left( \frac{v_1}{p} \right)_p = \sqrt{n} \left( \frac{v_1}{p} \right)_p
\]

\[
Q_p = n^{5/2} Q_m
\]

Utilizing the above analysis the second model was constructed with a length ratio of \( n = 2.0 \). Figure 13 shows the second model with the pitot tube used for measuring the velocity distribution, and Figure 14 shows the two models side by side. To observe the performance of the second model, the maximum discharge equivalent to 35 gpm in the first model was computed by Equation 11. It was 198 gpm.

The corresponding maximum discharge was observed in the large model, and data were collected for flow both with and without the dissipator pipe (Appendix). Figure 15 shows the water surface condition for maximum discharge through this model without the dissipator pipe, and Figure 16 shows conditions for the same discharge with the dissipator pipe.

For comparison between the two models, the surface profiles in the stilling basin were plotted. Figure 17 compares results from the two models without the dissipator pipe, while Figure 18 compares the two surface profiles when the models were equipped with the dissipator pipes.
Figure 13. The second model showing the pitot tube, which was used for measuring the velocity distribution at the entrance to the open channel.
Figure 14. A comparative view of the two models side by side.

The larger model is twice the size of the smaller model.
Figure 15. The large model operating at the maximum discharge without the dissipator pipe
Figure 16. The large model operating at the maximum discharge, with the dissipator pipe designed on the basis of results from the first model. (The dark, wavy line shows the water surface profile without the dissipator pipe.)
Figure 18. Comparison plot of the surface profiles for the two models with the dissipator pipe.

I  Water surface along points 1, 2, and 3
II Water surface along points 4, 5, and 6
III Water surface along points 2, 7, 8, 9, and 5
These figures verify the dynamic similarity between flow conditions in the small and the large model for the maximum discharge, both with and without the dissipator pipe. Therefore, the following conclusions may be made:

1. The Froude criterion is sufficient for dynamic similarity, and Equation 11 can be used for prototype design.

2. The design can be extended to any practical prototype size.

To further illustrate the effect of the dissipator pipe and its contribution to energy dissipation in the stilling basin, the velocity distribution in the trapezoidal channel was drawn for the large model at a section 6D₁ from the outlet of the stilling basin. Figure 19 compares the velocity distribution in the open channel for the maximum discharge with and without the dissipator pipe. Considerable improvement in the velocity distribution is evident, further indicating the effectiveness of the dissipator pipe. The stilling basin can be designed for open channels other than those of trapezoidal shape since the transition from the stilling basin to an open channel of any shape follows well established design procedures when the flow is subcritical.

**Structural analysis**

Structural analysis must be made to design the walls, the dissipation box, and the cantilever dissipator pipe. Both static and dynamic forces must be taken into consideration. The walls must be
Figure 19. Comparison of the velocity distribution in the trapezoidal channel with and without the dissipator pipe.
designed as concrete retaining walls and the dissipator pipe must be
designed as a thin-wall cantilever pipe. Structural design methods
will be outlined in a design example.

**Design example**

The following sample problem illustrates the use of the design
criteria presented in this paper:

**Given**

- Discharge--110 cfs
- Inflow pipe diameter--36 inches
- Bottom width of the open channel--4 feet
- Side slopes--1:1
- Depth of flow in open channel--44 inches

\[
n = \frac{36}{2} = 18
\]

\[
Q_p = (18)^{5/2} \left( \frac{35}{450} \right)
\]

\[
Q_p = 108 \approx 110 \text{ cfs}
\]

Maximum design criteria are applicable.

**Dissipation box dimensions**

\[
\frac{b}{D_1} = 3
\]

\[
b = 3 \times \frac{36}{12} = 9 \text{ ft}
\]

\[
\frac{h}{D_1} = 4
\]

\[
h = \frac{36}{12} \times 4 = 12 \text{ ft}
\]
\[
\frac{d}{D_1} = 4.33
\]
\[d = 4.33 \times \frac{36}{12} = 13.0 \text{ ft}
\]

Dissipator pipe dimensions

\[
\frac{D_2}{D_1} = 1.85
\]
\[D_2 = 1.85 \times 36 = 66.6 \text{ inches}
\]
\[
\frac{L}{D_1} = 1
\]
\[L = 36 \text{ inches}
\]
\[
\frac{\delta}{D_1} = 0.5
\]
\[\delta = 0.5 \times 36 = 18 \text{ inches}
\]
\[
\frac{W}{D_1} = 0.5
\]
\[W = \frac{1}{2} \times 36 = 18 \text{ inches}
\]

Structural design

The side walls of the dissipation box must be designed to stand the static pressure of the water for the maximum discharge. However, the wall to which the dissipator pipe is attached must be designed to stand both static and dynamic pressures.
Side wall dimensions

\[
\frac{12^2 \times 62.5}{2} = 4500 \text{ pounds per foot of length of the wall}
\]

\[
M = 4500 \times 3 = 13,500 \text{ foot-pounds}
\]

\[
M = R \frac{bd^2}{2} \quad (R = 236 \text{ for } 3000 \text{ psi concrete})
\]

\[
12 \times 13,500 = 236 \times 12 \times d'^2
\]

\[
d'^2 = 57.2
\]

\[
d' = \sqrt{57.2} = 7.56
\]

\[
d' = 7.56 + 2 \text{ inch cover} \approx 10 \text{ inches}
\]

\[
A_s = \frac{M}{f_{s}d} = \frac{12 \times 13,500}{20,000 \times 0.866 \times 7.56} = 0.124 \text{ in}^2\text{in}
\]

\[
A_s = 0.124 \times 12 = 1.49 \text{ in}^2\text{ft}
\]

Use No. 8 bars at 6-inch spacing.

For the dissipator pipe wall, the design strength must be increased by about 25 percent to insure stability against dynamic as well as static forces

\[
d' = 10 \times 1.25 = 12.5 \text{ inches}
\]

\[
A_s = 1.49 \times 1.25 = 1.86
\]

Use No. 9 bars at 6-inch spacing.

Dissipator pipe design

The dissipator pipe must be properly anchored to the stilling basin dissipation wall. The thickness of the dissipator pipe will be determined according to the material of the pipe. For this example, if corrugated pipe is used, it should be 8-gage. A bar or band should
be used around the upstream end of the dissipator pipe to prevent the slit from spreading. This end should also be vertically supported by legs anchored to the floor of the dissipation box.
SUMMARY AND CONCLUSIONS

1. An economical stilling basin for changing high velocity pipe flow to subcritical open channel flow has been studied and the most efficient design found. Prototype structures can be designed utilizing Equation 11. The following ratios may then be used for design purposes when the discharge, the inflow diameter, and the geometry of the open channel are known.

\[
\frac{b}{D_1} = 3
\]
\[
\frac{h}{D} = 4
\]
\[
\frac{d}{D_1} = 4.33
\]
\[
\frac{D_2}{D_1} = 1
\]
\[
\frac{6}{D_1} = 0.5
\]
\[
\frac{W}{D_1} = 0.5
\]

However, for discharges less than maximum \( \frac{D_2}{D_1} \) and \( \frac{L}{D_1} \) may be adjusted according to Equations 8 and 9, respectively.

2. In general, the energy dissipation is caused by high shear between incoming and outgoing jets in the dissipator pipe and by vertical diffusion of the jet from the slit at the bottom of the dissipator pipe.
3. The performance of the stilling basin is independent of the tail water depths in the trapezoidal channel for the limited range of variation expected.

4. The stilling basin gives a satisfactory velocity distribution in the channel with no high velocity currents. The water surface in the channel entrance is free of waves.

5. Two important requirements must be fulfilled to secure proper performance:
   a. The pipeline outlet must be submerged at all flow rates, and
   b. The center lines of the inflow pipe, the dissipation box, and the channel must be parallel.

6. The walls of the dissipation box, the dissipator pipe, and all other structural features must be designed to withstand the dynamic and static forces.

7. The stilling basin can be designed for open channels other than those of trapezoidal shape since transition design for subcritical flows follows well established design procedures.
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LITERATURE CITED (cont.)


