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Design Criteria for USU Stilling Basin Pipe Flow to Open Channels

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DESIGN CRITERIA FOR USU STILLING BASIN PIPE FLOW TO OPEN CHANNELS

by

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NOMENCLATURE

Symbol	Definition
b	width of the open channel
d_t	tailwater depth in the open channel outlet
D_1	diameter of the inlet pipe
D_2	diameter of the dissipator pipe
ΔE	dissipated energy
f_b	freeboard
F_1	Froude number
g	acceleration due to gravity
h_b	height of the boil in the stilling basin above the center line of the inlet pipe
H	height of stilling basin
L	length of the dissipator pipe
L_b	length of the stilling basin
n	length ratio
Q_m	discharge in model
Q_p	discharge in prototype
V_1	mean velocity in inlet pipe
V_2	mean velocity in the open channel
W	slot width in the dissipator pipe
W_b	width of the stilling basin

Symbol	Definition
Y_1	elevation of the inlet pipe above the bottom of the stilling basin
Y_2	elevation of the open channel above the center line of the inlet pipe
λ	any length dimension

ABSTRACT

Design Criteria for USU Stilling Basin

Pipe Flow to Open Channels

by

Chi-Yuan Wei, Master of Science

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Department: Civil Engineering

Criterion have been developed in this study for designing a stilling basin to serve as a transition from pipe flow to open channel flow. The purpose of the structure is to prevent erosion in an open channel. The unsteadiness, or smoothness, of the water surface in the model basin was used as the criterion for evaluating the effectiveness of the structure for energy dissipation.

The introduction of a short-pipe energy dissipator in the stilling basin has proven effective in dissipating energy. The stilling basin was designed for a fully submerged pipe outlet. The inflow pipe and the dissipator pipe were designed to be located on the same center line, at $Y_1/D_1 = 1.5$ above the stilling basin floor. The slit-width ratio, W/D_1, yielding the smoothest water surface was 0.5 ($W/D_1 = 0.5$). An optimum dissipator pipe diameter ratio of 2.0 was established ($D_2/D_1 = 2.0$), while the optimum dissipator pipe length ratio was determined to be 1.0 ($L/D_1 = 1.0$).

Three diameters of inlet pipe were used to determine scale effects. Within the accuracy of the measurements used in this study, no scale effects were detected.

The expanding characteristics of a submerged jet were used in establishing the length of the stilling basin. Based on the dissipator pipe diameter ratio of 2.0 ($D_2/D_1 = 2.0$), the stilling basin length ratio is 3.5 ($L_b/D_1 = 3.5$).

Relations among the tailwater depth (d_t), the outlet flume floor elevation (Y_2), the height of boils in the stilling basin (h_b), the width of the stilling basin (W_b), and the amount of freeboard, f_b, have been studied. The interrelationships among F_1, $(Y_2 + d_t)/D_1$, W_b/D_1, and f_b/D_1 have been shown graphically.

INTRODUCTION

To prevent possible erosion below overflow spillways, chutes, and sluices, excess kinetic energy in flowing water needs to be dissipated in either a vertical or horizontal direction, or both. In a horizontal direction the energy may be dissipated by shear drag, pressure drag, or an increase in piezometric head. In the vertical direction the energy may be dissipated by diffusion of jets vertically upward or by diffusion of jets vertically downward.

The energy dissipator under study is designed as a transition from pipe flow to open channel flow. Energy dissipation is performed in both the vertical and horizontal directions by shear drag, pressure drag, and vertical diffusion as the major mechanisms in dissipating the excess energy in the flow.

The study was made under the following conditions:

1. The pipe outlet was fully submerged.
2. The inflow pipe and the dissipator pipe had the same center line, and were parallel to the open channel bed.
3. The inflow pipe was the only source of flow to the open channel.
4. The dissipator pipe was self-cleaning.
5. Structural features, shape, and dimensions were determined by model studies.

The two important components in the design of the energy dissipator

are the dissipator pipe and the stilling basin (i.e., the depth, width, length, and shape of the stilling basin). To find the best design for a stilling basin involving a short-pipe dissipator, the unsteadiness or the smoothness of its water surface was used as the criterion for evaluating the effectiveness of varous sizes and locations of the short-pipe dissipator and the relative dimensions of the stilling basin.

The energy dissipator under study is an impact-type dissipator which requires a relatively small basin. This structure is an effective and economical means of providing a transition from full pipe flow to open channel flow. Unless the kinetic energy of the high velocity jet issuing from the pipe is dissipated within a rigid boundary structure, erosion of the open channel bed and large surface waves would result. A satisfactory energy dissipator is necessary to minimize channel erosion and stabilize the free surface wave fluctuations.

The energy dissipation results from the submerged jet impinging upon a short-pipe energy dissipator and then being turned on itself, along with part of the jet being turned downward through the slot in the bottom of the dissipator pipe. The energy of the flowing water is dissipated by the diffusion of the jet from the inlet pipe into the stilling basin and the shearing action between the jet itself and the water surrounding it.

REVIEW OF LITERATURE

Energy dissipation in some form has been a part of many hydraulic structures throughout the world where the destructive energy in flowing water must be brought under control. Most of the energy dissipators have performed their intended function adequately. Those that received the benefit of model tests have functioned particularly well. Except in unusual circumstances, only larger structures are subjects of individual model studies. However, there are some smaller structures that have been subjected to preliminary model studies to meet particular and rigid requirements.

Although hundreds of stilling basins and energy dissipator devices have been designed in conjunction with spillways, outlet works, and canal structures, it is often necessary to make model studies of individual structures to be certain that these structures will operate as anticipated. The reason for these repetitive tests is that a factor of uncertainty exists regarding the overall performance characteristics of energy dissipators. In important projects, such as those involving a large number of stilling basins, generalized designs for the basins are often necessary for economy and to meet specific requirements. These designs can be developed by model investigations. The basins thus designed are usually provided with special appurtenances, including chute blocks, sills, and baffle piers.

Existing energy dissipator designs are classified as one or a combination of the following types: (a) roughened channel lining (Bradley and Peterka, 1957), (b) drop structure basin (Beichill, 1956), (c) free fall basin (Gnelton, Weingaertner, and Sevin, 1953), (d) hydraulic jump basin (Elevatorski, 1959, and Chow, 1953), (e) diffuser structure (Elevatorski, 1959, and Fiala, 1961), (f) impact structure (Elevatorski, 1959; Keim, 1962; and Peterka, 1957), (g) roller bucket (Bradley and Peterka, 1957), and (h) flip bucket (Elevatorski, 1959).

Hydraulic jump basin

Utilization of the hydraulic jump, whenever possible, to dissipate energy has been an accepted practice. The hydraulic jump is defined as the sudden and turbulent passage of water from a low stage below critical depth to a high stage above critical depth during which the velocity changes from supercritical to subcritical. The jump is accompanied by violent impact and consists of an abrupt rise of the water surface in the region of impact between the rapidly moving stream and the slowly moving water. The water surface at the beginning of the abrupt rise is constantly falling against the oncoming stream, which is moving at a high velocity.

The theory of the hydraulic jump was developed in early days for horizontal slightly inclined channels in which the weight of water in the jump has little effect upon the jump behavior and hence is ignored in the analysis. The results thus obtained, however, can be applied to most channels encountered in engineering problems. For channels of large slope, the weight effect of water in the jump may become so pronounced that it must be included in the analysis.

A hydraulic jump will form in the channel if the Froude number F_1 of the flow, the flow depth y_1, and a downstream depth y_2 satisfy the equation

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 - 8F_1^2} - 1\right) \quad (1)$$

That is, for supercritical flow in a horizontal rectangular channel, the resistance along the channel bed results in a decrease in velocity and an increase in depth in the direction of flow.

A hydraulic jump occurring on a horizontal floor can be classified into several distinct types. According to the studies of the U. S. Bureau of Reclamation (1958), these types can be conveniently classified according to the Froude number, F_1, of the incoming flow as follow:

1. An undular jump for F_1 = 1 to 1.7.
2. A weak jump for F_1 = 1.7 to 2.5.
3. An oscillating jump for F_1 = 2.5 to 4.5.
4. A steady jump for F_1 = 4.5 to 9.0.
5. A strong jump for F_1 = 9.0 and larger.

A steady jump is well-balanced and the performance is at its best. The energy dissipation ranges from 45 to 70 percent. The jump action of a strong jump is rough, but effective, since the energy dissipation may reach 85 percent.

The loss of energy in the jump is equal to the difference in specific energies before and after the jump. It can be shown that the

loss is

$$\Delta E = E_1 - E_2 = \frac{(y_2 - y_1)^2}{4y_1 y_2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

The ratio of the specific energy after the jump to that before the jump is defined as the efficiency of the jump, that is

$$\frac{E_2}{E_1} = \frac{(8F_1^2 + 1)^{3/2} - 4F_1^2 + 1}{8F_1^2 (2 + F_1^2)} \quad \ldots\ldots\ldots \quad (3)$$

The equation indicates that the efficiency of a jump is a dimensionless function, depending only on the Froude number of the approaching flow.

From a practical viewpoint, the hydraulic jump is a useful means of dissipating excess energy in supercritical flow. Its merit is in preventing possible erosion below overflow spillways, chutes, sluices, and other hydraulic structures, for it quickly reduces the velocity of the flow on a paved apron to a point where the flow becomes incapable of scouring the downstream channel bed.

The use of the hydraulic jump for energy dissipation is usually confined partly or entirely to a channel reach that is known as the stilling basin. The bottom of the basin is paved to resist scouring. In practice, the stilling basin is seldom designed to confine the entire length of a free hydraulic jump on the paved apron, because such a basin would be too expensive. Consequently, accessories to control the jump are usually installed in the basin. The main purpose of such control is to shorten the length of channel where the jump will

take place and thus reduce the size and cost of the stilling basin. The control has additional advantages, for it improves the dissipation function of the basin, stabilizes the jump action, and in some cases increases the factor of safety.

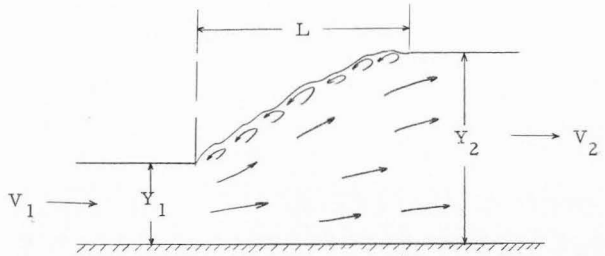


Figure 1. Hydraulic jump in horizontal channels.

Free-jet stilling basin

For the case where the jet discharges into the air and plunges into a pool, it may be desirable to construct a trapezoidal riprap-lined stilling basin. In order for this type of basin to operate satisfactorily, the jet should plunge into the water pool from a point above the maximum tailwater elevation. When the jet is near the tailwater elevation, high velocities will travel along the surface directly downstream from the jet, with stagnation or backflow resulting along the sides of the basin. If the jet is below the tailwater elevation, but not far enough to be submerged, a very unstable hydraulic jump forms downstream from the jet (Gnelton, Weingaertner and Serin, 1953).

Free-jet chutes

If the channel is narrow and erodible, where scouring may be dangerous to the structure, and when the center line of the jet is above the streambed elevation, a free-jet, concrete lined chute extending from the outlet to the stilling basin may be used. The floor of a chute basin is designed to fit the maximum trajectory of the free-jet to prevent subatmospheric pressures and consequent cavitation. To prevent the water from leaving the floor of the drop, the invert curve must not be sharper than the trajectory that would be followed by the high-velocity flow under the action of gravity. The floor profile should be based upon the theoretical equation of the trajectory (Elevatorski, 1959).

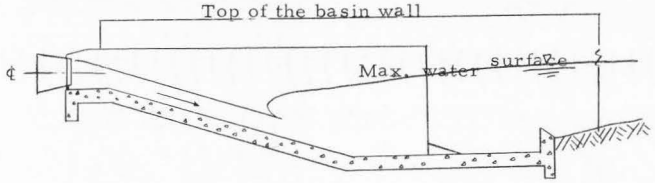


Figure 2. Free-jet chute basin.

Hump stilling basin

When the center line of the jet is below the streambed elevation, but not far enough to be completely submerged by the tailwater, a hump in the stilling basin floor may be provided to spread the jet and permit the formation of a stable hydraulic jump. In designing a hump basin, the chute floor should be shaped in the form of a circular arc at the

upstream end and as a parabola at the downstream end (Elevatorski, 1959). A usual hump stilling basin is shown in Figure 3.

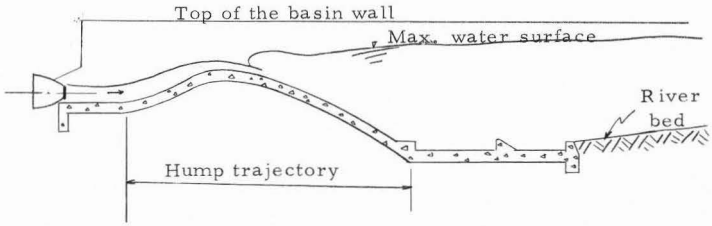


Figure 3. Hump stilling basin.

Jet diffusion and impact stilling basin

The discharge from an outlet--whether from gate, valve, free-flow tunnel, or conduit--usually emerges at a high velocity in a nearly horizontal direction. To prevent or minimize erosion of the outlet channel and structures, it is necessary to provide some means of dissipating a large part of the energy of the high velocity flow as quickly as possible upon its emergence from the outlet. Commonly, when high-velocity jets emerge from the outlet-jet diffusion, free-jet, hump, or impact basins will be required (Keim, 1962, and Peterka, 1957).

Jet diffusion stilling basin

Flow from a valve is usually concentrated into a narrow width as it enters the stilling basin. Engineers of the U.S. Bureau of Reclamation have developed a jet diffusion basin which can be utilized

to reduce the length of basin normally required by a hydraulic jump. Experiments indicated that satisfactory results could be obtained by directing the jets sharply toward the bottom, rather than over the tailwater surface. It was found necessary to protect the inflow water with a hood, or some other device, until it was considerably beneath the tailwater surface. A deflector hood prevented the jet from being torn apart by induced eddies until it was well submerged, thereby accomplishing energy dissipation in a less violent and more efficient manner. It is believed that the effectiveness of this method is due to the small grain turbulence which is created in the basin. Because the outflow is well protected until submerged, it still contains sufficient energy to produce many small, efficient, energy dissipating eddies at the bottom of the basin. From a theoretical standpoint, it has been proven that a large number of small eddies are more efficient in dissipating energy than a few large eddies. A jet diffusion stilling basin was employed for the outlet works at Enders Dam (Tabor and Peterka, 1950), illustrated by Figure 4.

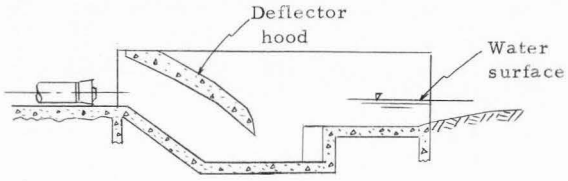


Figure 4. Enders Dam outlet works stilling basin.

Contra Costa energy dissipator

The Contra Costa energy dissipator was developed in 1956 at the Fluid Mechanic Laboratory of the University of California, Berkeley (Keim, 1962). The dissipator is for use in the reestablishment of natural channel flow conditions at culvert outfalls where there are uncontrolled, excessively high, effluent velocities at depths less than half the culvert diameter..

The recommendations regarding the design of the Contra Costa energy dissipator, as shown in Figure 5, are valid for operation at or below the optimum design conditions. In addition to the fixed configuration shown in Figure 5, the dimensions of remaining elements in the approach basin are determined from the relationship

$$\frac{L_A}{h_2 F} = 1.2\left(\frac{h_2}{d_1}\right)^{-1.80} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

where d_1 is the depth of flow at the culvert outfall, F is the Froude number ($F = V_1^2/gd_1$), h_2 is the height of the final baffle, and L_A is the length of approach basin. Satisfactory design of the approach basin is achieved when the values of L_A/h_2 are selected between 2.5 and 7.0, and if the values of h_2/d_1 remain greater than unity.

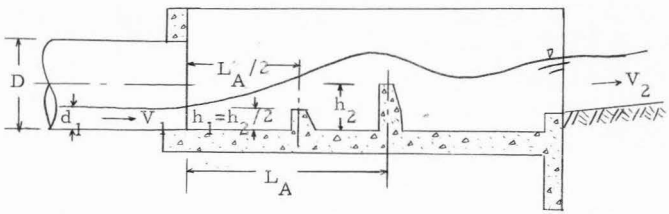


Figure 5. The Contra Costa energy dissipator.

Impact stilling basin

The development of the impact stilling basin was initiated by the need for relatively small basins to provide energy dissipation independent of tailwater variations or any tailwater at all. Impact basins that require no tailwater for their performance have been reported by Peterka (1957).

These basins are recommended only for entering velocities of less than 30 fps. The efficiency of the impact basin as an energy-dissipating device is greater than that of the hydraulic jump for the same Froude number. For velocities of 30 feet per second or less, the basin width W was found to be a function of the discharge, with other basin dimensions being related to the width. To determine the necessary width, erosion test results, judgment, and operating experiences were all used to obtain the finally determined limits. Energy dissipation is initiated by flow striking the vertical hanging baffle and being turned upstream, while the horizontal portion of the baffle directs the flow toward the floor. Tailwater as high as $d + g/2$ will improve the performance by reducing outlet velocities, providing a smoother water surface, and reducing tendencies toward erosion. A protective blanket of riprap downstream from the structure is suggested as a safeguard against erosion.

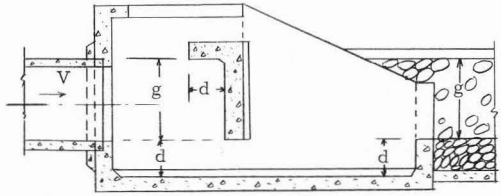


Figure 6. Impact stilling basin design.

Manifold stilling basin

A model study of a manifold stilling basin was conducted in the Hydraulic Laboratory at Colorado State University (Fiala, 1961). Figure 7 shows the general layout of the basin. 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

$$\frac{h}{v_1^2/2g} = f\,(w/s,\ b/B_o) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where

h = wave height

v_1 = initial jet velocity

g = acceleration due to gravity

w = width of the opening

s = size of the cross bar

b = tailwater depth

B_o = width of the manifold

A relationship for the boil height was derived from the analytical and experimental work of Albertson, together with the assumption that the jet velocity causes the boil height at the surface. The boil height is equal to the velocity head ($V^2_{max}/2g$).

$$\frac{a}{v_1^2/2g} = \frac{c}{b/B_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where

a = boil height

c = coefficient (expected to be larger than 5.2)

V_{max} = maximum velocity

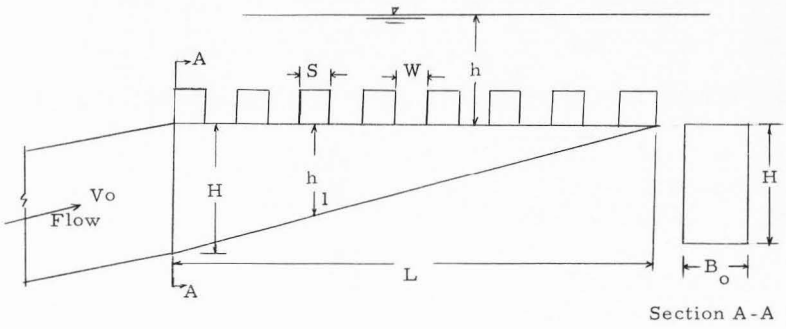


Figure 7. General layout of the manifold stilling basin.

Equation 6 represents a manifold stilling basin with numerous jets. However, two limiting conditions were considered:

1. For low tailwater, a very small amount of tailwater interference was present and the data indicated that V_{max}/v_1 approached unity for low values of w/s.

2. For high tailwater and/or large values of w/s, the manifold behaved as one large jet, and assuming constant inflow and momentum flux per unit area is the same whether the flow is coming through n_1 slots of Bo_1 width, or through n_2 slots of Bo_2 width, and the following expression was derived:

$$\frac{a}{v_1^2/2g} = n_1 B_o \quad \ldots \ldots \ldots \ldots \ldots \quad (7)$$

where

n_1 = number of slots

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 b/s decreases to about 5, v_1/v_o becomes smaller.

3. As w/s increases, v_1/v_o becomes smaller.

4. Equation 6 was proven to be valid for values of c greater than 5.2.

5. As w/s becomes larger, the behavior of the manifold approaches single jet behavior.

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

$$\frac{L}{\sqrt{A}} = 8 \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (8)$$

The design is then checked using Equations 5, 6, and 7 to insure proper hydraulic performance of the stilling basin.

EXPERIMENTAL DESIGN

Theory of jet diffusion

When a steady jet of water impinges on any solid surface there is a rebound following the impact. A thin stream is formed which glides along the surface until it reaches the boundaries, then it leaves approximately tangential to the surface. When the initial and final directions and velocities of an impinging jet are known, the force which it exerts on the solid surface, in any direction, may be calculated by equating this force to the total change in momentum per second of the jet in this direction. When the water is flowing from the inlet pipe to the stilling basin, the flow is subject to an abrupt enlargement in the passage, and is thrown into a state of unsteady motion, with a consequent loss of energy. If the mean velocities before and after passing the enlargement are known, the equations of momentum may be applied to determine the magnitude of this loss (Albertson, Dai, and Rouse, 1950, and Gibson, 1952).

Considerable kinetic energy is also dissipated in the stilling basin by shear between the jet and its surrounding water. As the direct result of turbulence generated at the borders of a submerged jet, the fluid within the jet will undergo both lateral diffusion and deceleration, and at the same time, fluid from the surrounding region will be brought into motion and the kinetic energy of such a jet will

be dissipated through reaction with the surrounding fluid. The difference in velocity between a jet and the region into which it is discharged will give rise to a pronounced degree of instability, the kinetic energy of the oncoming flow steadily being converted into kinetic energy of turbulence, and the latter steadily decaying through viscous shear. Any reduction in kinetic energy necessarily represents a decrease in the velocity of flow, and even the most elementary considerations of continuity indicate that the area of the flow section must become greater as the velocity becomes smaller. In view of the Newtonian principle of action and reaction, moreover, it will be realized that deceleration of the fluid in the jet can occur only through simultaneous accelerations of the surrounding fluid. By referring to Figure 8, it can be seen that an initial zone of flow establishment must exist beyond the efflux section of the three-dimensional submerged jet. Since the fluid discharged from the boundary opening may be assumed to have a relatively constant velocity, there necessarily will be a pronounced velocity discontinuity between the jet and the surrounding fluid. The eddies generated in this region of high shear will immediately result in a lateral mixing process which progresses both inward and outward some distance from the efflux section. Such lateral mixing produces a necessarily balanced action and reaction. The fluid within the jet gradually is decelerated and the fluid from the surrounding region gradually is accelerated.

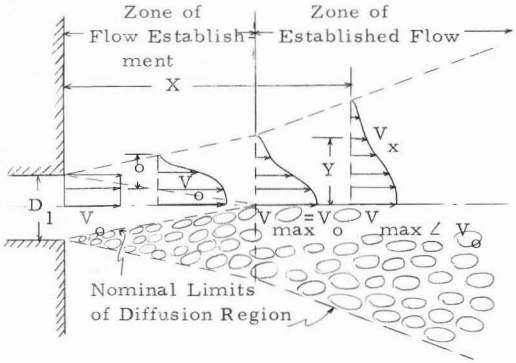


Figure 8. Schematic representation of jet diffusion.

As a result, the constant velocity core of the jet will decrease steadily in lateral extent, whereas the overall breadth of the jet will increase steadily in magnitude with distance from the efflux section. The limit of this initial zone of flow establishment is reached when the mixing region has penetrated to the center of the jet. Once the entire central part of the jet has become turbulent, the flow may be considered as fully established, for the diffusion process continues thereafter without essential change in character. Further entrainment of the surrounding fluid by the expanding eddy region is now balanced inertially by a continuous reduction in the velocity of the entire central region.

If the Reynolds number for fluid efflux from a submerged boundary outlet is not too low, the mean velocity, V, at any point should depend only on the coordinates X, Y, and Z, on the efflux

velocity, V_o, and on a linear dimension, L_o, characterizing the particular outlet form. The variables may be grouped in the dimensionless relationship:

$$\frac{V}{V_o} = f\left(\frac{X}{L_o}, \frac{Y}{X}, \frac{Z}{X}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Viscous action is presumed to have no influence on the mixing process. The diffusion characteristics, and hence the characteristics of the mean flow, should be dynamically similar under all conditions. Thus, in effect, the same velocity function must characterize every section within the diffusion region. As a matter of fact, experimental data follows the general trend of the Gaussian normal probability function,

$$\frac{V_x}{V_{max}} = \exp\left(-\frac{Y^2}{2\sigma^2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where σ is the standard or root-mean-square deviation.

Moreover, Equation 9 can be reduced to

$$\frac{V_{max}}{V_o} = f\left(\frac{X}{L_o}, \frac{\sigma}{X}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

but the condition of dynamic similarity simultaneously requires that at all cross sections, regardless of the efflux velocity,

$$\frac{\sigma}{X} = C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

that it, the angle of jet diffusion, must be constant, and the following

relationships can also be found

$$\frac{X_o}{D_o} = \frac{1}{2C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$\frac{D}{D_o} = 1 - \frac{X}{X_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

where D_o is the orifice diameter for a circular orifice, and D is the diameter of the nominal inner border of the diffusion region. The latter equation came from a linear approximation. The quantity C is approximately equal to 0.081.

The region of expansion of a submerged jet is simultaneously the region of appreciable modification of the mean flow pattern and the region of appreciable eddy motion. Under normal circumstances, the jet expands at an angle of 12 to 14 degrees; that is, the expansion ratio is approximately 1:4 or 1:5. The rate of expansion is dependent in part upon the boundary form and in part upon the arbitrary nature of the nominal limits of the diffusion region.

The energy flux passing successive sections beyond an orifice can be expressed as

$$\frac{E}{E_o} = 1 + 2\left(\sqrt{2\pi/3} - 2\right) C \frac{X}{D_o} + 4\left(5/3 - \sqrt{2\pi/3}\right) C^2 \frac{X^2}{(D)_o^2}. \quad (15)$$

where E_o is energy flux for the efflux section. That is, at a certain section the smaller the diameter of the inlet pipe, the greater the energy flux ratio.

For the USU stilling basin, the overall dissipated energy can be calculated as shown below. With reference to Figure 9, the total energy of the flow at the pipe inlet section is

$$\frac{V_1^2}{2g} + h_b \quad \ldots \ldots \ldots \ldots \ldots \quad (16)$$

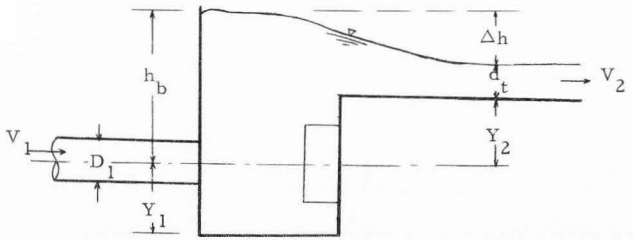


Figure 9. The model basin.

where the centerline of the inlet pipe is used as the datum. The total energy at the downstream section of the flume is

$$Y_2 + d_t + \frac{V_2^2}{2g} \quad \ldots \ldots \ldots \ldots \ldots \quad (17)$$

Thus, the overall energy loss is

$$\Delta E = \frac{V_1^2}{2g} + h_b - Y_2 - d_t - \frac{V_2^2}{2g}$$

$$= \frac{V_1^2 - V_2^2}{2g} + h_b - (d_t + Y_2)$$

$$= \frac{V_1^2 - V_2^2}{2g} + \Delta h \quad \ldots \ldots \ldots \quad (18)$$

Dimensional analysis

For design purposes, dimensional consideration is very important. The flow pattern in the USU stilling basin will depend upon the variables Q, g, D_1, D_2, Y_1, Y_2, h_b, d_t, L, L_b, W, and W_b, where D_1 is the diameter of the inlet pipe, D_2 is the diameter of the dissipator pipe, Y_1 is the height of the inlet pipe above the bottom of the stilling basin, Y_2 is the distance between the centerline of the inlet pipe and the floor of the flume, h_b is the height of water in the basin above the centerline of the inlet pipe, d_t is the depth of tailwater in the open channel, L is the length of the dissipator pipe, L_b is the length of the stilling basin, and W_b is the width of the slot of the short-pipe energy dissipator. These variables can be related by the use of dimensional analysis. The dimensional matrix appears as

	Q	g	D_1	D_2	Y_1	Y_2	h_b	d_t	L	L_b	W	W_b
L	3	1	1	1	1	1	1	1	1	1	1	1
T	-1	2	0	0	0	0	0	0	0	0	0	0

The discharge is allowed to appear in only one dimensionless parameter, and the diameter of the inlet pipe, D_1 is selected as a repeating variable. Dimensional analysis, using D_1 as a repeating variable, yields the functional relationship

$$f\left(\frac{Q^2}{gD_1^5}, \frac{D_2}{D_1}, \frac{Y_1}{D_1}, \frac{Y_2}{D_1}, \frac{h_b}{D_1}, \frac{L}{D_1}, \frac{L_b}{D_1}, \frac{W}{D_1}, \frac{W_b}{D_1}\right) = 0 \quad . \quad . \quad . \quad (19)$$

or

$$\frac{Q^2}{gD_1^5} = f\left(\frac{\lambda}{D_1}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where λ is any length dimension.

Hydraulic model-prototype relations can be obtained and used to scale up the results to the field prototype. According to the geometric similarity, the design condition is

$$\left(\frac{\lambda}{D_1}\right)_m = \left(\frac{\lambda}{D_1}\right)_p \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

or

$$\lambda_p = \frac{(D_1)_p}{(D_1)_m}\,\lambda_m = n\lambda_m \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

where n = length ratio

λ_p = any length dimension in the prototype

λ_m = any length dimension in the model

The prediction equation for discharge is

$$\left(\frac{Q^2}{gD_1^5}\right)_m = \left(\frac{Q^2}{gD_1^5}\right)_p$$

$$\frac{Q_m^2}{(D_1)_m^5} = \frac{Q_p^2}{(D_1)_p^5}$$

$$Q_p^2 = \frac{(D_1)_p^5}{(D_1)_m^5} \qquad Q_m^2 = n^5 Q_m^2$$

$$Q_p = n^{5/2}\, Q_m \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

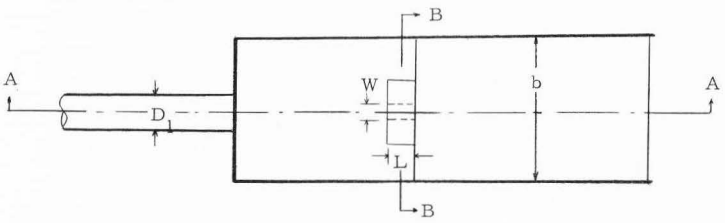
DESIGN OF DISSIPATOR PIPE

The USU stilling basin has been developed as a transition for pipe flow to open channel flow. The dimensions of the dissipator pipe in relation to the stilling basin are of primary importance in dissipating excessive energy in the basin. In the earlier studies by Rasheed (1963), the following dimensionless ratios were used: $D_2/D_1 = 1.85$; $L/D_1 = 1.0$; and $W/D_1 = 0.5$. In order to substantiate Rasheed's work, a comprehensive study regarding the design of the dissipator pipe was undertaken.

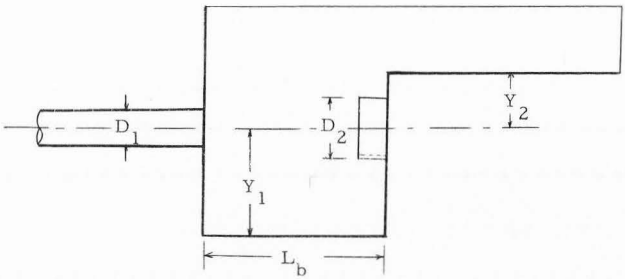
Equipment

The first model consisted of a 3 1/4 inch diameter pipe (D_1) connected to a box-like stilling basin, 18 inches wide and 10 inches long. The stilling basin was connected to a rectangular flume having the same width as the stilling basin. A tail gate was located at the downstream end of the flume to control the tailwater depths in order to evaluate the effect of varying the tailwater depth.

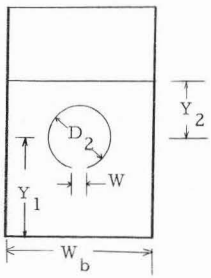
An elbow meter, which consisted of a 90-degree flanged elbow and a manometer, was located upstream from the inlet pipe in order to measure the flow rate, or discharge. A short-pipe energy dissipator was placed on the wall of the basin opposite the incoming submerged jet. The location of the dissipator pipe in the stilling basin is shown in Figure 10.



Plan view



Section A-A



Section B-B

Figure 10. The arrangement of the short-pipe energy dissipator, the inlet pipe, and the stilling basin (first model).

A Sonic Surface-wave transducer connected to a Texas X-Y recorder was used to record the fluctuations and the profiles of the water surfaces in the stilling basin and the flume. The Sonic Surface-wave Transducer is a device to assist in recording the profile of surface waves. It operates by measuring the time of propagation of a sonic pulse from a transmitter to the changing surface and return, timing the duration of travel of the sonic pulse, and converting these time samples into a stepped voltage output which will closely approximate the form of the surface profile.

Experiments

In the design of the short-pipe energy dissipator, the variables involved are the diameter of the dissipator pipe, D_2, the length of the dissipator pipe, L, and the slit width, W. In order to see how each variable effects the overall performance of the stilling basin, one of the three dimensions was varied while the other two remained fixed. At the same time, the geometry of the stilling basin was fixed.

An extensive study was then made with the aid of the Sonic Surface-wave transducer, which was connected to a Texas X-Y recorder (Figure 11). The effectiveness of various sizes and locations of the short pipe energy dissipator was observed and measured by utilizing the unsteadiness of the water surface in the stilling basin as a criterion.

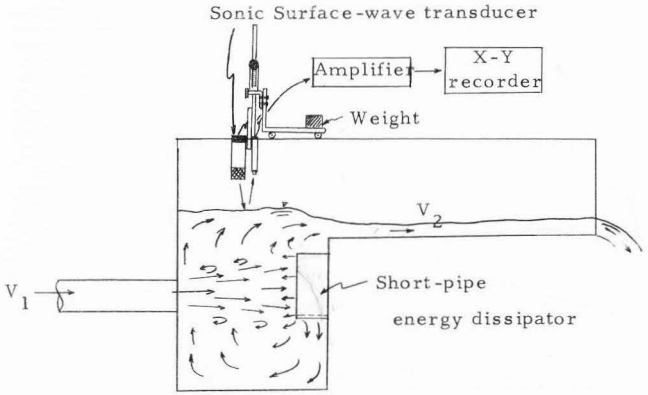


Figure 11. The recording system and the flow pattern in the stilling basin (first model).

To determine the slit-width ratio, W/D_1, which would give the best hydraulic performance of the stilling basin, the ratio was varied without changing the remaining dimensions. This was done by fixing the dimensions, D_1 = 3 1/4 inches, D_2 = 6 1/2 inches, L_b = 10 inches, L = 3 1/8 inches, Y_1 = 4 3/4 inches and width of open channel = 20 inches. The W/D_1 ratios, 0.310, 0.460, 0.615, 0.770, 0.924, and 1.000 were tested. Judging from the fluctuations of the recorded water surface profiles, the ratio yielding the best hydraulic performance was determined as 0.46, say 0.5.

To determine the optimum dissipator pipe length ratio, L/D_1,

the ratios 0.90, 1.10, 1.15, and 1.39 were tested. The dimensions D_1 = 3 1/4 inches, D_2 = 6 1/2 inches, W = 1 1/2 inches, and Y_1 = 4 3/4 inches were fixed. Thus, lengths of dissipator pipe of 3.825, 4.675, and 4.888 inches were used. The best results, using the roughness of the water surface as the criteria, was obtained at ratios in the vicinity of 1.0. Consequently, for practical design purposes, a value of 1.0 can be used for the ratio L/D_1.

To determine the optimum diameter ratio, D_2/D_1, values of 1.45, 1.69, and 1.77 were tested. The dimensions, L = 3 1/8 inches, W = 1 1/2 inches and Y_1 = 4 3/4 inches were fixed. The highest ratio of L/D_1 used in the tests, 1.77, appeared to give the best results. According to Rouse (1950), under normal circumstances the expansion ratio of the region of expansion of a submerged jet is approximately 1:4 or 1:5. Since the length of the stilling box is 10 inches, the diameter of the expanding jet will be approximately 6 inches when it reaches the short-pipe energy dissipator. Accordingly, a dissipator pipe with a diameter of 6 inches will cover the whole portion of the jet. Consequently, a diameter ratio of 2.0 is suggested.

DESIGN OF STILLING BASIN

Model basin

Using the demensionless ratios obtained from the previous study regarding the dissipator pipe, the second phase of this research effort, which is concerned with optimizing the design of the stilling basin structure, was undertaken. To facilitate this phase of the study, a steel box was fabricated having a height of 6 feet, a length of 4 feet, and a width of 4 feet. Steel guides were welded on the inside of the steel box to form vertical and horizontal rows of guides to facilitate changing the dimensions of the stilling basin. A wooden flume, 22 inches wide, 6 feet long, and 20 inches high served as the outflow channel for the stilling basin structure. Figure 12 shows the dimensions of the stilling basin. In Figure 13 the entire structure is shown, while Figure 14 shows the inside view of the stilling basin.

The height of the floor of the flume and the width of the stilling basin could be adjusted. The length of the basin could be adjusted from 6.5 inches to 24 inches, the width of the basin could be adjusted from 14 inches to 48 inches, and the height of the flume could be adjusted from 9.75 inches to 37 inches. Three inlet pipes with inside diameters of 3 1/4 inches, 6 inches, and 10 inches were used in the study. To measure the flow rate, a 12-inch Parshall flume was installed and calibrated.

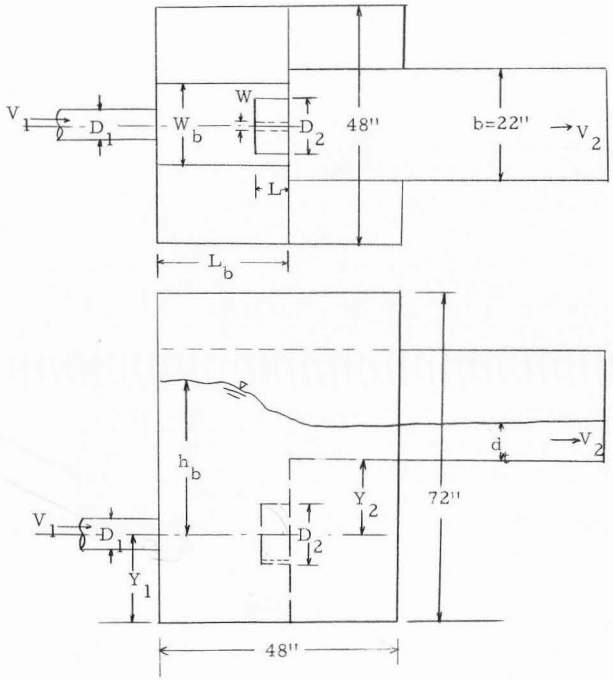
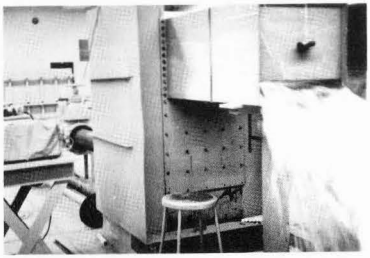
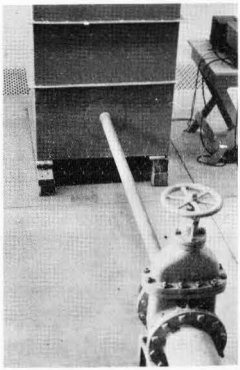


Figure 12. Top view and side view of the stilling basin.

(a) Front view of stilling basin.





(b) Rear view of the stilling basin.

(c) The adjustable structure of the stilling basin.

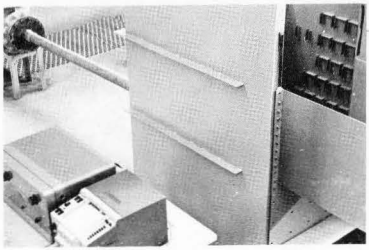
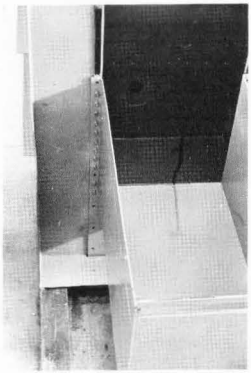
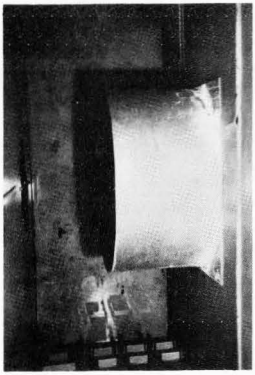


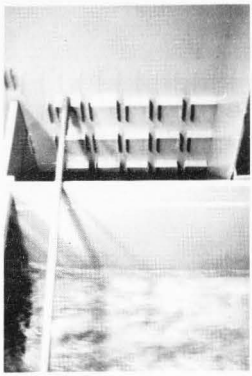
Figure 13. The general layout of the stilling basin.



(a) The stilling basin and the flume with a control gate at the downstream end.



(b) Short-pipe energy dissipator



(c) Open channel flow in the flume

Figure 14. The inside view of the stilling basin.

Experimental design

The initial tests were conducted using a 3 1/4 inch inlet pipe connected to the stilling basin. A range of discharges between 1.33 cfs and 0.48 cfs was determined by taking into account the maximum discharge available for the largest inlet pipe used (10 inches) and the minimum value at which an energy dissipation structure might be desirable. An intermediate discharge of 0.80 cfs was also used in this study. The proper discharge to be used for other inlet pipe sizes can be obtained from Equation 23.

According to some preliminary observations, as the flow entered the stilling basin from the inlet pipe, the jet impinged upon the short-pipe energy dissipator, was turned upon itself and then rose to the surface in turbulent "boils," which caused surging of the water surface in the stilling basin. In the case of rough turbulent boils, the Sonic Surface-wave transducer could not be used. Under these conditions, the surging or the boiling action of the water surface in the stilling basin was visually observed and the fluctuation of the water surface was recorded.

Each test was conducted using $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, and $Y_1/D_1 = 1.5$. The remaining dimensionless ratios, W_b/D_1, L_b/D_1, and Y_2/D_1 were systematically varied throughout the testing program. In addition to varying W_b, L_b, and Y_2, the inlet diameter, D_1, was also varied in order to evaluate scale effects.

For each physical condition, the hydraulic performance was observed using three values of discharge. For each discharge, the tailwater depth was varied over as large a range as possible in the outlet flume, thereby allowing a variation of the ratio d_t/D_1.

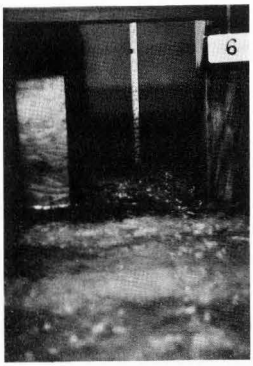
Width of stilling basin

In searching for an acceptable stilling basin width ratio, W_b/D_1, width ratios of 4.0 and 6.77 were used. A discharge of 0.48 cfs and an inlet diameter of 3.25 inches were used. Thus, the Froude number, F_1, which is defined as $V_1/\sqrt{gD_1}$, was 2.8. The tailwater depth was controlled to give a ratio of d_t/D_1 equal to 1.54. Observations were also made at $F_1 = 4.7$ and $F_1 = 7.7$. It appeared that $W_b/D_1 = 6.77$ resulted in a better hydraulic performance in the stilling basin than $W_b/D_1 = 4.0$. The improvement can be seen by comparing Figure 15 (a) with Figure 15 (b). The greater basin width increased the flow path in the lateral direction, thereby resulting in energy dissipation by shear action.

The width of the stilling is dependent upon F_1, and $(Y_2 + d_t) / D_1$. The relationship between these dimensionless ratios and W_b/D_1, which has been determined qualitatively, is shown later (Figure 22).

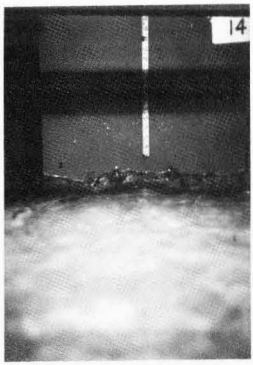
Length of stilling basin

To observe the effect of stilling basin length, the L_b/D_1 ratio was varied from 2.0 to 3.3. For each discharge, flow patterns in



(a) $W_b/D_1 = 4.0$

$[h_b - (Y_2 + d_t)] / D_1 = 0.40$



(b) $W_b/D_1 = 6.77$

$[h_b - (Y_2 + d_t)] / D_1 = 0.35$

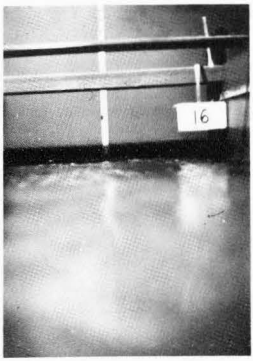
Figure 15. Comparison of stilling basin performances at different width ratios ($F_1 = 2.80$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $Y_2/D_1 = 3.0$, $L_b/D_1 = 2.0$, $d_t/D_1 = 1.54$, and $D_1 = 3.25$ inches).

the stilling basin were compared using the same tailwater depth. For each L_b/D_1 ratio, different tailwater depths were tested, and the flow patterns were observed.

In the initial tests, a 3 1/4 inch inlet pipe was used, with $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $W_b/D_1 = 6.77$, and $Y_2/D_1 = 3$. Keeping F_1 at 2.8, flow conditions resulting from d_t/D_1 ratios of 0.615, 1.54, 2.77, and 4.61 were compared. When $d_t/D_1 = 4.61$ and $L_b/D_1 = 3.3$, the water surface was very smooth, (Figure 16b). The water surface became somewhat wavy as the L_b/D_1 ratio was reduced to 2.0 (Figure 16a). Observing the flow at $d_t/D_1 = 2.77$ and $L_b/D_1 = 2.0$, a small scale boiling action formed in the stilling basin, but, when L_b/D_1 was increased to 3.3, the boiling action decreased (Figures 16a and 16b). The indications were observed for $d_t/D_1 = 1.54$.

Later, the Froude number F_1 was increased to 4.7, while the other ratios were left unchanged. When $L_b/D_1 = 2.0$, the surface of the flow was wavy and appreciable surge and boiling action appeared. There was no such action when L_b/D_1 was increased to 3.3 due to the fact that there was longer distance for the incoming jet to travel before it impinged on the short-pipe energy dissipator, and more kinetic energy was dissipated by the shear action of the water surrounding the jet.

$d_t/D_1 = 2.77$



$d_t/D_1 = 4.62$

(a) $L_b/D_1 = 2.0$

$d_t/D_1 = 2.77$

$d_t/D_1 = 4.62$

(b) $L_b/D_1 = 3.3$

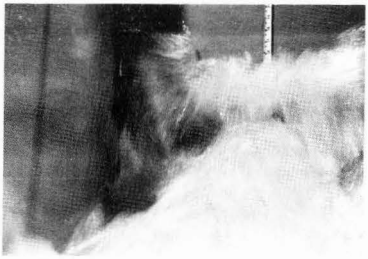
Figure 16. Comparison of flow patterns at different stilling basin length ratios for a low Froude number ($F_1 = 2.8$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1/5$, $W_b/D_1 = 6.67$, and $D_1 = 3.25$ inches).

As the Froude number was increased to 7.7, the flow conditions were very rough for both ratios of stilling basin length. When $L_b/D_1 = 2.0$, violent boiling action occurred in the stilling basin (Figure 17a). When the depth of the tailwater was 5 inches ($d_t/D_1 = 1.54$) the height of the boiling water in the stilling basin, h_b, was 15 inches above the center line of the inlet pipe, i.e., about 5 inches above the surface of the tailwater in the flume ($[h_b - (Y_2 + d_t)]/D_1 = 1.42$), which is shown in Figure 17b. Then, L_b/D_1 was increased to 3.3 with the result that the water surface was still very rough (Figure 18b). As soon as the tailwater depth ratio, d_t/D_1, was increased to 2.77, or more, the flow condition was improved. Water in the basin was still rough, but the boils did not jump too high above the tailwater surface.

According to the expanding characteristics of a sumberged jet, the stilling basin length ratio is a function of the diameter ratio. The expansion ratio of the nominal boundary of the jet is approximately 1:5 under normal circumstances (Rouse, 1950). Thus, in order for the jet to expand to D_2, the length ratio can be obtained from the diameter ratio by the following equation

$$L_b/D_1 = 2.5\,(D_2/D_1 - 1) + 1.0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

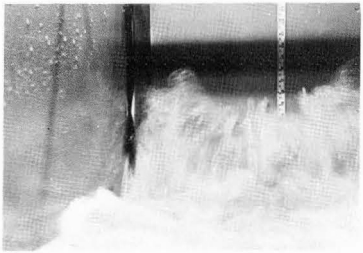
If too large a value of length ratio is used, a larger depth ratio, or higher elevation of the open channel, must be selected to avoid jumping action of the jet onto the flume. And if a length ratio is obtained according to the above equation, the depth of tailwater



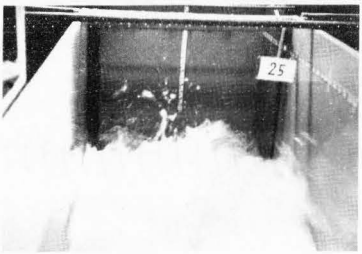
(a) $d_t/D_1 = 1.54$

(b) $d_t/D_1 = 2.77$

Figure 17. Effect of tailwater depth on stilling basin performance at a high Froude number ($L/D_1 = 2.0$, $F_1 = 7.7$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $W_b/D_1 = 6.77$, and $D_1 = 3.25$ inches).



(a) $L_b/D_1 = 2.0$



(b) $L_b/D_1 = 3.3$

Figure 18. Comparison of stilling basin performances at different length ratios for a high Froude number ($F_1 = 7.7$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $W_b/D_1 = 6.77$, $d_t/D_1 = 1.54$, and $D_1 = 3.25$ inches).

required to achieve a certain degree of energy dissipation is primarily a function of the Froude number, F_1. Since the diameter ratio has already been selected as 2.0, the stilling basin length ratio becomes 3.5.

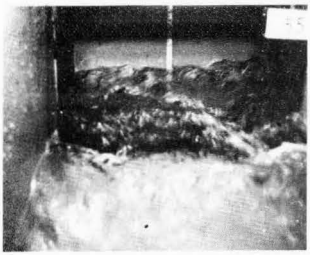
Tailwater elevation

The tailwater elevation, which has a pronounced effect on energy dissipation in the stilling basin, is a combination of the floor elevation of the outlet flume, Y_2, plus the depth of flow in the outlet flume, d_t, which is often referred to as tailwater depth. To test the effect of the flume floor elevation, a 6-inch inlet pipe was installed and the following dimensionless ratios were used in initial tests: $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $W_b/D_1 = 4.0$ and $L_b/D_1 = 2.0$. The Y_2/D_1 ratio was varied from 1.50 to 3.00, while $F_1 = 3.5$ (Q = 2.73 cfs) was maintained for the initial tests. By increasing the relative height of the wall opposite to the incoming jet in the stilling basin, it was found that the difference between elevations of the water surface in the basin and the tailwater surface in the flume could be reduced, as would be expected, and a more uniform flow in the flume could be obtained. The difference can be seen by comparing the flow patterns for different values of Y_2/D_1 as shown in Figure 19. The schematic profiles for both cases of Y_2/D_1 are shown in Figure 20. Then, keeping $Y_2/D_1 = 1.50$ and using the 3.25-inch inlet pipe, the Froude number was increased to 4.70.

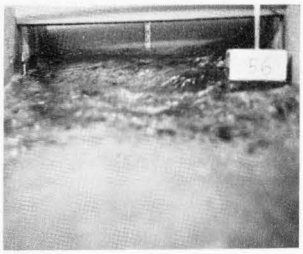
$d_t/D_1 = 1.50$

$d_t/D_1 = 2.80$

(a) $Y_2/D_1 = 1.50$



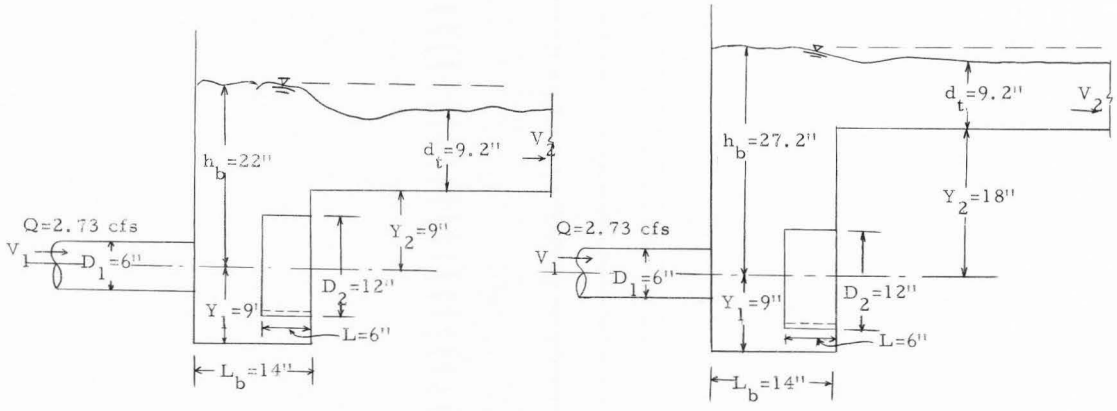
$d_t/D_1 = 1.50$



$d_t/D_1 = 2.80$

(b) $Y_2/D_1 = 3.00$

Figure 19. Comparison of stilling basin performances at different open channel elevations ($F_1 = 3.50$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 1.5$, $W_b/D_1 = 4.0$, $L_b/D_1 = 2.0$, and $D_1 = 6$ inches).



(a) $Y_2/D_1 = 1.50$

(b) $Y_2/D_1 = 3.0$

Figure 20. Schematic profiles of the flow patterns at different Y_2/D_1 ratios. (D_1 = 6 inches, $F_1 = 3.50$, $\frac{D_2}{D_1} = 2.0$, $\frac{L}{D_1} = 1.0$, $\frac{W}{D_1} = 0.5$, $\frac{Y_1}{D_1} = \frac{Y_2}{D_1} = 1.5$, $\frac{W_b}{D_1} = 4.0$ and $\frac{L_b}{D_1} = 2.0$).

(a) $d_t/D_1 = 0.61$

(b) $d_t/D_1 = 1.54$

(c) $d_t/D_1 = 2.77$

(d) $d_t/D_1 = 4.61$

Figure 21. Comparison of stilling basin performances at different tailwater depth ratios with $Y_2/D_1 = 1.5$ ($F_1 = 4.7$, $D_2/D_1 = 2.0$, $L/D_1 = 1.0$, $W/D_1 = 0.5$, $Y_1/D_1 = 6.77$, $L_b/D_1 = 3.3$, and $D_1 = 3.25$ inches).

Flow conditions or flow patterns at different tailwater depths were observed. The effect of varying the tailwater depth is dramatically shown in Figure 21.

To evaluate the relation between the tailwater depth ratio, d_t/D_1, and the outlet flume floor elevation ratio, Y_2/D_1, the heights of the boils in the basin were recorded, and denoted by h_b. It was found that the elevation difference between the top of the boil and the surface of the open channel flow is a function of $(Y_2 + d_t)/D_1$. The relationship is shown in Figure 22 with $[h_b - (Y_2 + d_t)]/D_1$ versus F_1 at different values of $m = (Y_2 + d_t)/D_1$.

In a practical situation, the tailwater elevation will be dictated by downstream conditions. For any selection of Y_2, the height of the boil can be predicted from Figure 22. When the inlet pipe diameter, the discharge, and the tailwater depth are known, the height of the boil can be minimized by increasing Y_2. For design purposes, the required freeboard in the stilling basin needs to be specified. The amount of freeboard has been related in a qualitative manner, to the boil height of the water in the stilling basin, and is shown in Figure 22.

Design example

The following sample problem illustrates the use of the design criteria presented in this thesis.

Maximum discharge, Q, is 100 cfs.

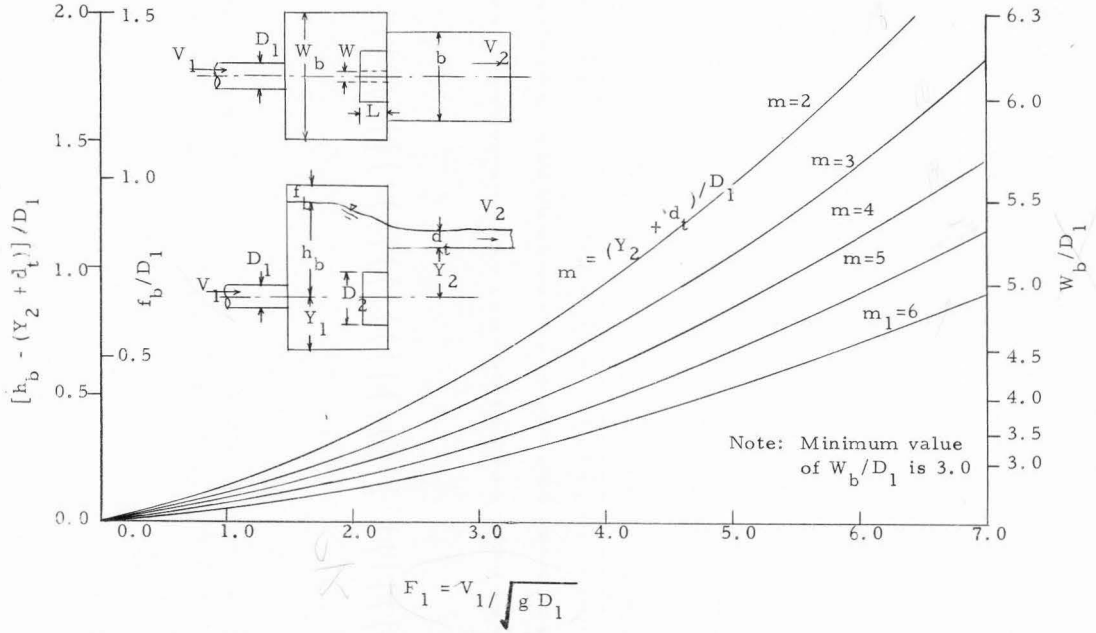


Figure 22. Relationship between boil height and Froude number.

Inlet pipe diameter, D_1 is 24 inches.

Width of open channel is 6 feet.

Tailwater depth at maximum discharge in the open channel is 3.0 feet.

The dimensions of the short-pipe energy dissipator are determined from D_1, alone,

$D_2/D_1 = 2.0$ $\qquad$ $D_2 = 48$ inches

$L/D_1 = 1.0$ $\qquad$ $L = 24$ inches

$W/D_1 = 0.5$ $\qquad$ $W = 12$ inches

$Y_1/D_1 = 1.5$ $\qquad$ $Y_1 = 36$ inches

Solving for V_1

$$V_1 = \frac{Q}{\pi D_1^2/4} = \frac{100 \text{ cfs}}{\pi (2\text{ft.})^2/4} = 31.8 \text{ fps}$$

Since the discharge and the diameter of the inlet pipe are known, the Froude number , F_1, can be computed.

$$F_1 = \frac{V_1}{\sqrt{gD_1}} = \frac{31.8 \text{ fps}}{\sqrt{32.2 \text{ ft./sec}^2 (2 \text{ ft.})}} = 3.96, \text{ say } 4.0$$

Now, the dimensions of the stilling basin can be determined. If $m = 3$ (i.e. $(1/2 + d_t)/D_1 = 3.0$) is chosen, then $1/2$ can be computed since d_t and D_1 are known.

$$(Y_2 + 3.0 \text{ ft}) / 2 \text{ ft} = 3.0$$

therefore,

$$Y_2 = 3.0 \text{ ft.}$$

To determine the boil height in the stilling basin enter Figure 22 with $F_1 = 4.0$ and $m = 3.0$, which gives

$$[h_b - (Y_2 + d_t)] / D_1 = 0.65 \quad \text{i.e. } h_b = 87.6 \text{ inches, say 88 inches.}$$

Also for $F_1 = 4.0$ and $m = 3.0$, the freeboard ratio, f_b/D_1, is obtained from Figure 22.

$$f_b/D_1 = 0.5 \qquad \text{i.e. } f_b = 12 \text{ inches}$$

The height of the stilling basin box, H, will be

$$H = Y_1 + h_b + f_b = 136 \text{ in.} + 88 \text{ in.} + 12 \text{ in.} = 136 \text{ inches}$$

The length of the stilling basin is dependent upon D_1.

$$L_b/D_1 = 2.5 (D_2/D_1 - 1) + 1.0 = 3.5$$

$$\text{i.e. } L_b = 84 \text{ inches}$$

Entering Figure 22, again, with $F_1 = 4.0$ and $m = 3.0$, the stilling basin width ratio, W_b/D_1, is 4.5. Therefore

$$W_b = 4.5 (24 \text{ inches}) = 108 \text{ inches}$$

A drawing of this design is shown in Figure 23.

In conclusion, it should be pointed out that the choice of m in this example was arbitrary. In an actual field situation the value of m may be fixed by existing physical conditions. If this is not the case, then preliminary designs should be computed for a number of m values and the most economical design would be chosen.

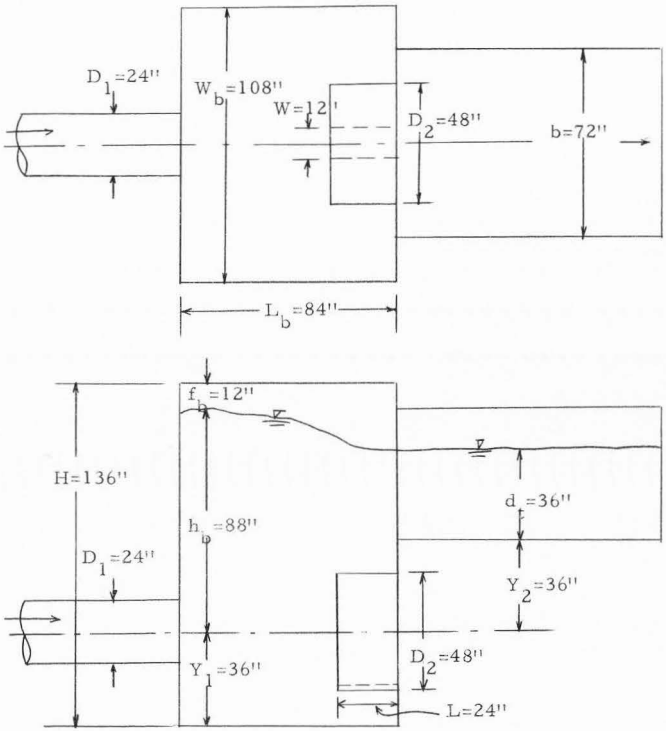


Figure 23. Design example of USU stilling basin.

SUMMARY

Criterion have been developed in this study for designing a stilling basin to serve as a transition from pipe flow to open channel flow. The purpose of the structure is to prevent erosion in an open channel.

The introduction of a short-pipe energy dissipator in the stilling basin has proven effective in dissipating energy. The energy is dissipated mainly by shear drag, pressure drag, and the diffusion action of the submerged jet in the stilling basin. The unsteadiness, or smoothness, of the water surface in the model basin was used as the criterion for evaluating the effectiveness of the structure for energy dissipation.

The stilling basin was designed for a fully submerged pipe outlet. The inflow pipe and the dissipator pipe were designed to be located on the same center line, at $Y_1/D_1 = 1.5$ above the stilling basin floor. To determine the slit-width ratio, W/D_1, the rest of variables were fixed, and water surface fluctuations were recorded for different W/D_1 values. Examining these fluctuations, the ratio yielding the smoothest water surface was 0.5 ($W/D_1 = 0.5$). Following the same approach, an optimum dissipator pipe diameter ratio of 2.0 was established ($D_2/D_1 = 2.0$), while the optimum dissipator pipe length ratio was determined to be 1.0 ($L/D_1 = 1.0$).

In the studies which optimized the design, or dimensions, of the stilling basin structure, three diameters of inlet pipe were used, namely 3 1/4, 6, and 10 inches. The purpose in using three different values of D_1 was to determine scale effects. Within the accuracy of the measurements used in this study, no scale effects were detected.

The expanding characteristics of a submerged jet were used in establishing the length of the stilling basin. Based on these characteristics, a relationship between the stilling basin length ratio (L_b/D_1) and the dissipator pipe diameter ratio (D_2/D_1) was established (Equation 24). When $D_2/D_1 = 2.0$, the stilling basin length ratio was 3.5 ($L_b/D_1 = 3.5$).

An intensive investigation was made to observe the relation among the tailwater depth (d_t), the outlet flume floor elevation (Y_2), the height of boils in the stilling basin (h_b), and the width of the stilling basin (W_b). The boil height above the tailwater surface in the outlet open channel was found to be a function of the Froude number (F_1) and the relative elevation of the tailwater surface above the center line of the inflow pipe ($Y_2 + d_t$). In addition, the width of the stilling basin and the amount of freeboard, f_b, have been related to the Froude number and the relative elevation of the tailwater surface. The interrelationships among F_1, $(Y_2 + d_t)/D_1$, h_b/D_1, W_b/D_1, and f_b/D_1, are shown in Figure 22.

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