Baffle Type Energy Dissipator for Pipe Outlets

By Vito A. Vanoni and James T. Rostron

The baffle type energy dissipator described in this paper was developed through laboratory experimentation for use in soil conservation work. It is designed to reduce the energy in high velocity pipe flow so that the water may be discharged safely into an erodible channel. This structure can be adapted to meet the many field conditions encountered in erosion control work in agriculture and elsewhere, such as at pipe outlets draining terraces or ditches, highway culverts, and drop inlet spillway outlets. Pipe sizes commonly used in such applications range from 10 to 48 in diameter and have flows from 10 to 250 cfs discharging into channels of various widths.

The design of a baffle type dissipator was first worked out in 1938 by the engineering division of the Soil Conservation Service at Berkeley, California, in an attempt to devise a system of energy dissipation for high velocity flow from pipe outlets that would be more economical than that which makes use of the hydraulic jump. Fig. 1 shows the general appearance of such a structure.

Considerable need for these structures has been encountered in the field and since the originators of the design were not satisfied with it, the Cooperative Laboratory of the Soil Conservation Service and the California Institute of Technology was requested to study the problem and to develop complete design formulas for a structure that could be used generally. The work at the Cooperative Laboratory was undertaken in November, 1941, on a program of laboratory tests which covered the many combinations of discharge, structure width, and pipe size encountered in the field.

Outline of Problem and Scope of Study

Elements of Structure. The baffle structure which was studied and which is shown in Fig. 1 is made up of three fundamental elements: (1) the pipe, (2) the baffle box, and (3) the stilling pool. Each of these elements is made up of parts which are identified in Fig. 1. For instance, the baffle box is made up of the head wall, floor, baffle, cap, and sidewalls. These terms are used in the text without further definition.

Identification of Variables. The variables which completely describe the structure and its performance fall into two classes: (1) independent and (2) dependent. The independent variables are those determined by field conditions including topography and other characteristics of the site, such as (a) the maximum runoff or discharge, \( Q_o \), (b) the length, \( l \), of the pipe, (c) the total head, \( E \), on the system measured by the difference in elevation between the water surface at the entrance to the pipe and the end of the pipe, and (d) the width, \( W \), of the structure. Of these variables all except \( Q_o \) are subject to some adjustment by modifications of the general layout of the system in the field. However, once they are fixed there is only one structure that will fit the conditions, and therefore all dimension are determined. The main dependent variables are the diameter of the pipe, \( D_o \), and the static pressure, \( p_o \), at the end of the pipe, which is referred to as the "back pressure". Other dependent variables are the dimensions of the structure, shown in Fig. 1. Essentially the problem of the laboratory study is to determine the mathematical relationships between these dependent and independent variables.

Similitude Relationships. For convenience in applying laboratory results to full installation rather than to a scale approximation in terms of the diameter of the pipe. Thus, if the structure width is 60 ft and pipe diameter is 1.0 ft, the width is 6.0 pipe diameters and width ratio is 6.0. Therefore, two structures are geometrically similar when their corresponding dimensions, expressed in pipe diameters, are the same. Dynamic similarity obtains when the ratio of the inertia forces to the gravity forces in one structure is the same as in the other. As can be shown readily, this force ratio, \( F_o \), for the pipe outlet structure is given by the dimensionless ratio

\[
F_o = \frac{V_o^2}{g D_o} = \frac{q_o}{\pi D_o^2 g}
\]

where \( V_o \) is the velocity in the pipe, \( g \) is the acceleration of gravity, and \( D_o \) is the pipe diameter. When \( F_o \) has the same value for two geometrically similar structures, dynamic similarity, and therefore complete similarity, will obtain and the flow patterns will be similar.

The ratio, \( F_o \), incidentally, is twice the velocity head of the flow in the pipe divided by the pipe diameter. When such ratios contain the gravity term, \( g \), they are usually called Froude Numbers. However, in this case the ratio is calculated for the closed portion of the system, where the gravity forces have no influence and there is some question regarding the appropriateness of the use of the term, Froude Number. For this reason, and to avoid possible confusion in the use of terms, the ratio, \( F_o \), is called the "velocity head factor."

The use of similarity laws reduces the independent variables to two: (a) \( F_o \), which expresses dynamic similarity, and (b) \( W/D_o \), the width ratio, which expresses geometric similarity. The independent variables are the back pressure ratio, \( p_o/D_o \), and the various dimensionless ratios expressing the proportions of the structure.

Having established similarity laws, hydraulic model tests were made in which \( F_o \) and \( W/D_o \) were kept constant and the dimensions of the baffle box were varied until satisfactory flow conditions were obtained. This gave one structure which can be fitted to any number of field conditions as long as the values of \( F_o \) and \( W/D_o \) remain the same. The structure is fitted to the field conditions by changing the scale which is equivalent to changing the diameter of the pipe.

Range of Tests. Experiments were conducted over ranges wide enough to include all conditions likely to be encountered in the field. In the studies \( W/D_o \) ranged from 2.0 to 9.5 and \( F_o \) ranged from 1.0 to 190. The diameter of the pipe used in the models ranged from \( \frac{3}{8} \) to 3 in. The other dimensions of the structure were also varied through wide ranges in order to obtain the combination that gave the best overall result.

Apparatus and Procedure

Most of the experiments were carried out in the special flume shown at the right in Fig. 2. This flume is 7 ft long, 4 in wide, with sidewalls about 2 ft high. The near sidewall in the figure contains a large glass window on the face of which is a grid of vertical and horizontal wires spaced at intervals of 0.5 and 0.2 ft, respectively. The window and the grid made possible convenient photographic and visual observation of the flow patterns occurring in the models.

The flow into the model was provided by the portable constant-head water
supply unit shown at the left in Fig. 2. The rate of flow was measured with a venturi meter in the supply unit and regulated by valves. The pipe entered the flume at the lower right corner of the window. By changing the size of the "pipe", actually a hole in a block, the width ratio, \( W/D_0 \), could be varied. Further variation in the width ratio was accomplished by using a half model with the window in the plane of symmetry. Baffles and caps could be installed easily and quickly in the flume, and the length \( L_1 \), of the baffle box could be varied at will. By this convenient means, all the necessary combinations of baffle-box dimensions and width ratios could be represented in a relatively short time.

Flow conditions for each model were studied by observing the motion of entrained air and by probing with a short thread tied to a thin rod. Pencil sketches were drawn for each test condition showing the baffle-box dimension, the back pressure at the pipe outlet, the outline of the flow, and the flow pattern in the box. Notes on each sketch described the general quality of the flow such as steadiness, entrained air, uniformity, etc. Photographs of each test flow furnished a valuable record of performance of the model.

In order to check the results obtained with the small models, tests were made with models having width ratios of 3, 6, and 9, and a pipe diameter of 3 in. These larger scale experiments gave more reliable information on air entrainment, steadiness of flow, ventilation of the overfall, and the adequacy of the stilling pool. By observing these models, information was also obtained on the proper heights of headwall and sidewalls required for safe freeboard. A study also was made to determine the effectiveness of the drains through the baffle on preventing sediment from depositing in the box and clogging the pipe during low flows.

**PERFORMANCE OF THE STRUCTURE**

**Criteria for Satisfactory Performance.** The performance of a structure may be evaluated by measuring its ability to dissipate energy. However, this is only one of many practical requirements which must be met and therefore it was necessary to choose other means of judging performance. After studying the problem in the laboratory, criteria were adopted for selecting those structures which were satisfactory. Listed in the order of their importance, these criteria are:

1. Steadiness of flow whatever the pattern
2. Sufficient energy dissipation to give outlet conditions that will not produce excessive erosion at the structure, or downstream therefrom
3. Minimum air entrainment
4. Uniform distribution of the flow discharging over the baffle
5. Minimum splashing beyond the limits of the structure
6. Minimum structure sizes
7. Minimum back pressure consistent with the preceding factors
8. Proper balance between the above factors to achieve a practical design.

**Regimes of Flow.** For convenience in selecting the desirable structures, the various performances obtained were classified into three types according to the general acceptability of the flow pattern in the light of the established criteria. The pattern resulting from relatively low discharges, which was called Type I flow, gave good performance but resulted in uneconomical structures. Type II flow occurred at much higher discharges, but the flow remained steady and evenly distributed, thus giving good performance with a relatively smaller and more economical structure. As the discharge is increased further, the water rises higher along the headwall, becomes unsteady, and may cascade directly into the stilling pool, without coming in contact with the cap. This unsatisfactory condition was described as Type III flow.

A flow of one type can be changed to either of the other two by changing the dimensions of the baffle box, as well as by changing the flow. Fig. 3 shows that by varying the discharge only, all three types may be obtained in a model designed to meet all of the requirements for performance and economy. The most economical structure that gave Type II, Fig. 3(b), for design discharge was the one selected. Type I flow in Fig. 3(a) is at one-half the design discharge and Type III in Fig. 3(c) occurs at 1.7 times the design flow. As Fig. 3(c) shows, the Type III flow tends to fall clear of the cap and entrains considerable air, thus producing an undesirable condition.

Attention is called to the mean values of the back pressure, \( b_0 \), shown below each of the views in Fig. 3. They also show the end of the pipe in the headwall.

Although in Fig. 3 the flow patterns above the baffle box are very different, the patterns in the box are alike. Gravity forces do not exist in the baffle box because any filament of flow in the box is buoyed up with a force equal to its own weight since it is submerged in a fluid of like density. This becomes clear when it is realized that a fluid within a fluid, just as a solid submerged in a fluid, is buoyed up by the weight of fluid displaced. Under these conditions, the filament will neither tend to rise nor sink, and hence the force of gravity is cancelled out. Therefore, the pattern is determined practically entirely by the geometry of the system. Since the geometry does not change, the flow pattern can be expected to remain fixed regardless of the rate of flow. On the other hand, above the baffle box where a free surface exists, the gravity forces are obviously important and in this region the pattern is determined by the simultaneous action of the inertia and gravity forces. The pattern will vary as the ratio of these forces varies and since this ratio is expressed by the parameter, \( F_c \), this is equivalent to saying that the flow pattern above the baffle box is dependent on the velocity head factor. That this is true is shown in Fig. 3.

![Fig. 2 Flume in which experiments were conducted for the development of a baffle type energy dissipator](image-url)

![Fig. 3 Effect of discharge on flow conditions. All structures are identical. Only the discharge (velocity head factor, \( F_c \)) is varied. \( D_0 = 0.078 \text{ ft};\) \( W/D_0 = 4.3;\) \( p_1 = 0.32D_0;\) \( L_1 = 3.2D_0;\) \( h_b = 3.0D_0;\) \( x_1 = 1.4D_0;\) \( p_2 = 0.53D_0;\) \( L_2 = 5.2D_0.\) (a) Low flow, \( F_c = 8;\) \( h_b = 4.2D_0.\) Type I Flow — Underload Discharge

(b) Design discharge, \( F_c = 32;\) \( h_b = 5.6D_0.\) Type II Flow — Recommended Performance

(c) High discharge, \( F_c = 96;\) \( h_b = 8.0D_0.\) Type III Flow — Overload Condition

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**Notes on each sketch described the general quality of the flow.**
GLOSSARY OF TERMS

b=distance from sidewalls to centerline of longitudinal sills in stilling pool, ft
w=width of drain opening, ft
C = \left( \frac{\sigma}{4} \times \frac{D_i}{W_i} \right)^{1/3} = \text{a critical depth coefficient}
C_1 = \text{exterior chamfer of baffle, ft}
C_2 = \text{fillet at corner formed by cap and baffle, ft}
C_3 = \text{stilling pool apron length coefficient}
C_f = \text{Coefficient of energy loss}
D_i = \text{Diameter of pipe outlet, ft}
d_1 = Q_1/\pi D_i^2 = \text{crITICAL DEPTH, ft}
E = \text{a specific energy, ft-lb per lb}
E = \text{loss of energy, ft-lb per lb}
f = \text{friction factor for pipes}
F_s = V_1/2g = \text{velocity head of flow in pipe, ft}
h_1 = \text{net height of baffle, ft}
K_e = \text{COEFFICIENT IN BACK PRESSURE EQUATION}
S_e = \text{LENGTH COEFFICIENT FOR ENTRANCE}
S_p = \text{LESS COEFFICIENT FOR PIPE FRICTION}
S_k = \text{LESS COEFFICIENT FOR MISCELLANEOUS CAUSES}
L_1 = \text{length of baffle box, ft}
L_2 = \text{top length of side wall, ft}
L_3 = \text{length of stilling pool, ft}
L_4 = \text{sidewall dimension for stilling pool, ft}
L_e = \text{overall length of structure, ft}
T_d = \text{time of pipe carrying discharge to structure, ft}
D_p = \text{drop in floor of baffle box below pipe invert, ft}
D_i = \text{drop of stilling pool floor below pipe invert, ft}
D_e = \text{depth of stilling pool (height of transverse or end sill)}
Q_1 = \text{discharge through stilling sills, cfs}
t_1 = \text{thickness of baffle, in}
V_c = \sqrt{2g} = \text{critical velocity, ft/sec}
V_f = \text{velocity of flow at pipe outlet, ft/sec}
V_s = \text{velocity of flow discharging from baffle box, ft/sec}
W_e = \text{velocity in downstream channel, ft/sec}
W = \text{width of structure, ft}
D = \text{depth of structure, ft}
D = \text{width of outlet, ft}
S = \text{slope of inlet pipe, deg}

Fig. 4 indicates diagrammatically the pattern for a typical case of Type II flow. The flow in the plane of projection is indicated by lines with arrows. Flow normal to this plane is represented by dots and crosses which indicate movement towards and away from the observer, respectively. The center-line section shows the high velocity jet issuing from the pipe outlet, striking the baffle, being deflected upward and then being turned horizontally upstream by the cap. This action produces a roller with a horizontal axis above the pipe and below the cap. Upon reaching the headwall the flow is deflected upward again and rises along the headwall to a height determined by its velocity, whereupon the flow must cascade over the incoming flow, the crest of the baffle, and thence into the stilling pool. As is shown both in the center-line section and in section 1-1, a roller extending across the structure occurs at the upstream face of the cap and under the fall. Section B-B of Fig. 4, which is a plan view taken approximately through the center of the baffle box, shows that the jet also is deflected sideways by the baffle, causing a roller with vertical axis to form on each side of the pipe.

The tortuous path that the flow is forced to take in passing through the structure results in the formation of much turbulence, and hence in high energy dissipation. The energy line for a typical structure operating at design discharge is shown in Fig. 5. This shows that 86 per cent of the total energy existing at the pipe outlet is dissipated by passing the flow through the structure. By far the greater portion of the dissipation occurs in the baffle box although an appreciable amount also occurs in the stilling pool. Fig. 5 also shows the flow over the end sill. This sills deflects the main flow upwards away from the stream bed causing a roller to form at the bed. As may be seen, the direction of flow at the bed under the roller is actually upstream. This tends to move bed material toward the sill and protects the structure against undermining.

Effect of Baffle-Box Dimensions on Flow. In the course of determining the proper size of baffle box, it became necessary to study the effect of flow conditions caused by varying the dimensions of the box. This study yielded not only the proper sizes to use but also furnished some rational basis for these sizes. Flow conditions with baffle boxes that are too short and too long are illustrated in Fig. 6(b) and (c), respectively, and flow with design condition is shown in Figs. 5(b) and 6(a). It will be noted that with the short box the back pressure was high and that the flow rose high along the headwall and appeared to be of Type II. This was due mainly to the throttling of the flow as it passed through the small gap between the cap and headwall. With the long box shown in Fig. 6(c), the back pressure was reduced slightly and the flow was a little quieter than for the shorter and more economical structure shown in Fig. 6(a).

Fig. 6(d) and (e) show the flow patterns with the baffle too low and too high. The low wall causes a very disturbed and unsteady flow pattern that is unsatisfactory. This results because there is not enough space between the floor and the cap to permit the jet from the pipe to hit the baffle and be turned back towards the headwall as in the standard flow pattern shown in Fig. 4. The result is that the entire pipe jet is deflected sideways by the baffle, forming two strong vortices with vertical axes which entrain considerable air and produce an unsteady, non-uniform flow distribution. When the baffle is made too high, as in Fig. 6(e), the flow is very...
satisfactory. However, the back pressure is raised and structure will be higher, longer, and hence more expensive than necessary.

Fig. 6 (f) and (g) show the flow that results when the length of the cap is varied from the design value. The conditions in Fig. 6(a), (f), and (g) are identical except for the cap lengths. The cap in Fig. 6(f) was not long enough to turn the flow in the upstream direction sufficiently to prevent pulsations and the entrainment of considerable air. With the long cap shown in Fig. 6(g), the gap between the cap and headwall constricted the flow, and by causing it to rise higher along the headwall, increased the back pressure. This performance was good, but no better than that of the smaller structure of Fig. 6(a).

In Fig. 6 the floor drop, \( P_o \), i.e., the distance from the invert of the pipe to the floor, was \( 0.3D_o \), since for this case tests showed that this gave approximately the optimum condition. The drop makes it possible for the flow to spread downward as well as upward. Consequently when the baffle is reached the velocity is less than without the drop and the resulting flow is quieter. Increasing this drop by several fold caused no further improvement and is, therefore, uneconomical. The drop in the floor simplifies the construction slightly and provides better protection against clogging the box with debris deposited by the flow.

Experiments in which the slope of the pipe, \( \theta \), was varied showed that the flow was improved by inclining the pipe. This is because the flow which is now directed slightly downward strikes the floor and is spread further before it reaches the baffle, thus producing a more favorable flow condition at the baffle. Experiments with fillets of various sizes under the baffle cap showed that they had practically no effect on the performance as long as they were of reasonable size.

All of the information needed to design a pipe outlet structure is summarized in Figs. 7 and 8 by means of graphs, sketches, and formulas. In arranging this information it has been assumed that the design discharge is determined by field conditions only and that the width of the structure is fixed within limits by conditions at the site. The main points in the design are discussed below with a view to clarifying them and facilitating their application.

**DESIGN FORMULAS**

**Fundamental Hydraulic Formulas.** The design formulas are expressed in terms of the two fundamental hydraulic variables, \( F_o \), the velocity head factor, for the pipe flow, and \( d_e \), the critical depth for the width, \( W \). The first of these is expressed by

\[
F_o = \frac{V_o^2}{2g} = \frac{16Q_o^2}{gD_o} \quad \text{[1]} \]

where the expression on the right is obtained by introducing the equation,

\[
V_o = \frac{Q_o}{A_o} = \frac{Q_o}{\pi D_o^2} \quad \text{[2a]} \]

is given by the familiar expression

\[
d_e = \sqrt[3]{\frac{Q_o^2}{W^2 g}} \quad \text{[2b]} \]

Substituting \( Q_o \) from equation [1] into equation [2a] gives

\[
d_e = D_o \left( \frac{\pi D_o}{4 \times W} \right)^{1/3} \quad \text{[2b]} \]

\[
E = (K_r + K_l + K_m + 1) \frac{V_o^2}{2g} + b_0 \quad \text{[3a]} \]

where \( E \) is the total available head, and \( K_r, K_l, \) and \( K_m \) are respectively, the loss coefficients for entrance, friction in the pipe and miscellaneous causes. By substituting \( b_0 \) for \( V_o^2/2g \) and by estimating average values of the loss coefficients and the back pressure, \( b_0 \), equation [3a] becomes

\[
b_0 = 0.5E \quad \text{[3b]} \]

Lacking better information, this is a good value of \( b_0 \), to use in making the first trial calculation to determine \( D_o \). The method of calculation is shown in detail under "Design Example."

**Formula for Baffle-Box Dimensions.** All of the dimensions of the baffle box are defined by Figs. 1 and 7 and their values are given as formulas in Fig. 7. These dimensions have been assigned lower limits that are determined by practical, hydraulic, and structural considerations. For instance, the minimum value of the baffle height, \( h \), is such that sufficient room is allowed to turn the jet issuing from the pipe. It is easy to see that this value must be more than the pipe diameter, and the minimum value of \( 1.5D_o \) determined by experiment, therefore appears reasonable.

**Formula for Back Pressure on the Pipe.** The formula for back pressure is based on the equation

\[
b_0 = b_1 + \frac{V_o^2}{2g} \quad \text{[8]} \]

where $V_s$ is the velocity through the gap between the cap and the headwall. $V_s$ may be taken as

$$V_s = \frac{Q_0}{W'Kd_e}$$ \hspace{1cm} [8a]

where $K$ is a numerical factor which varies with the velocity head factor and the width ratio of the structure. Introducing [8a] into [8b] gives

$$b_o = b_h + \frac{1}{K^2} \times \frac{Q_0^2}{2W'D_o^2}$$ \hspace{1cm} [8b]

Analysis of the data on back pressure showed that the coefficient, $1/K^2$, could be expressed as

$$1/K^2 = 4.0 \times (W'/D_0)^{0.96}$$ \hspace{1cm} [8c]

Introducing this equation into equation [8b] and dividing through by $D_0$ gives

$$\frac{b_o}{D_0} = \frac{b_h}{D_0} + 4.0 \times (W'/D_0)^{0.96} \times \frac{Q_0^2}{2W'D_o^2D_0}$$ \hspace{1cm} [8d]

Introducing equations [1] and [2a] gives

$$\frac{b_o}{D_0} = \frac{b_h}{D_0} + [1.5 + 4.0 \times (W'/D_0)^{0.96}] \times \frac{Q_0^2}{2W'D_o^2D_0}$$ \hspace{1cm} [8e]

The curves of Fig. 8(b) were calculated from this equation.

Formulas for Sidewall Dimensions. The height, $h_o$, of the headwall of any of the walls. However, pressures which must be resisted by the structure were measured in the baffle box. For design purposes it will be satisfactory to assume a uniform pressure over the entire baffle equal to $0.25(h_o + b_h)$, and a pressure head acting over an area of $D_0$ opposite the pipe outlet equal to $0.75(h_o + b_h)$. The pressure head on the headwall and sidewalls may be assumed to vary linearly from $h_o$ at the base to zero at a distance of $b_h$ feet above the base. The resultant unit pressure on the cap may be assumed as $0.25(h_o + b_h)$ acting over the entire underside of the cap in the upward direction. It is probable that most of the structural dimensions will be fixed by earth-pressure loads and by considerations other than water pressure.

To prevent chipping and cracking of the exterior corner at the intersection of the baffle and cap, it is desirable to chamfer the corner. The effect of the chamfer on flow conditions is merely to increase effectively the length of the stilling pool by the amount of the chamfer because the crest of the fall is moved upstream by that amount. Hence, the maximum value of the chamfer, $C_f = 0.5t$, specified in Fig. 7, is based entirely on practical and structural reasons, and therefore this value may be varied. It was shown by experiment that the fillet, $C_f$, at the intersection of the wall and the cap can be made as much as 0.3x, without appreciably affecting the performance of the structure.

**Pipe Outlet Structure - Floor Baffle Type**

(Based on the Laboratory Program, 1942)

**Discussion of Results**

Effect of $W'/D_0$ on Baffle Box Dimensions. The width ratio determines the proportion of the flow which is deflected upward or toward the sidewalls by the baffle and consequently plays an important part in fixing the dimensions of the baffle box. Formulas [4], [5], [6] and [7] show that as the width is increased and more of the flow is turned sideways the baffle can...
be lowered and placed nearer to the outlet. It also may be seen that the structure size increases slowly with an increase in flow capacity. Since the flow pattern is not affected by the velocity head factor until the water has reached the free surface above the baffle cap, the baffle-box dimensions are not strongly influenced by the discharge rate. When the discharge is increased considerably, only a small increase is required in the size of the baffle box to provide satisfactory performance. Consequently a particular structure will operate successfully over a considerable range of discharges, up to the design flow of the structure. Thus in the design equations the baffle-box dimensions are a function of $W$ and $D_0$ primarily and of $F_o$ to a lesser degree. The effect of the width ratio on the flow pattern and design dimensions is illustrated in Fig. 10. Both structures are designed for the same discharge.

In contrast it may be stated that other types of energy dissipation structures, such as those employing the hydraulic jump, require a considerable increase in size when the discharge becomes materially greater, and also require greater structure lengths with increasing values of $W/D_0$ because of the distance required for the spreading of the high velocity jets issuing from the pipe outlets before the formation of a jump is possible.

**Fitting Structure to Field Conditions.** From a study of the design data and charts of Figs. 7 and 8, it becomes clear that this structure is designed to operate under conditions of relatively high velocity discharge. As an example, assume that a structure with a 1-ft pipe is designed for a factor, $F_o$, of 16. Then from equation [1] the velocity head is 8 ft and the velocity and flow in the pipe are 22.7 fps and 17.8 cfs, respectively. Even with this relatively small velocity head factor and small pipe, the velocity and discharge are high.

On the back-pressure chart, Fig. 8(b), the solid lines indicate the range of conditions under which the structure is most efficient and economical. The dashed lines give the back pressure for narrow structures with low velocity head factors. These structures generally are less economical than those in the range covered by the solid lines. For instance, if field conditions indicate that an extremely narrow structure is desirable, it may be possible to effect a saving in total cost by using a wider structure even though the excavation costs may be increased. The main factors in this saving are reductions in wall height and structure length. Structures with width ratios of approximately 6 appear to be the most economical. However, the optimum width depends largely upon field conditions, and therefore must be determined by the designer. Although structures designed according to the charts will operate satisfactorily, it is probable that simpler and cheaper structures can be devised when velocity head factors are below 8.

The pipe size for a system including a baffle-energy dissipator is calculated as it would be for any pipe line which has a submerged outlet. The amount of the submergence is equal to the back pressure created by the installation of the structure, and its value is given by curve (b) in Fig. 8. However, before the back pressure can be determined, $F_o$, and therefore the diameter of the pipe, must also be known. In designing a structure, several trial calculations are usually required before the correct size of pipe is determined. To reduce to a minimum the number of trials required, average probable values of the losses have been assumed and an equation [3b] obtained which gives a value of $h_b$ for the first trial calculation to determine $D_o$. It should be noted that once the pipe diameter is determined, the discharge can be increased on a given installation only by increasing the total head. This can be done only by raising the water level over the inlet to the pipe. Since the inlet is usually a box forebay or small reservoir with limited freeboard, the water surface, and therefore the total head, cannot be raised to any great extent. Practically, this means that it is not possible appreciably to overload a pipe outlet structure and in designing this feature must be kept in mind.

**Construction and Maintenance Considerations.** In fixing the dimensions of the baffle box, it was necessary not only to give consideration to the hydraulic performance of the structure, but also to keep in mind other practical requirements. For instance, the gap between the baffle and the headwall was made sufficiently large so that the flow was not throttled. In the smaller structures this gap may become quite small, making it difficult to build the box and to clean it out if that becomes necessary. Therefore, in order to provide room for construction and cleaning of the box the gap was made 18 in minimum.

The four drains through the baffle are designed to prevent the box from filling up with sediment. Danger of clogging is greatest during the lower discharges when quiet flow in the box permits sediment to deposit. By making the drains as shown in Fig. 7, they will discharge approximately 20 per cent of the flow when the structure is operating at design discharge. Laboratory experiments showed that with drains of this size the box was self-cleaning and could handle heavily laden flows without undue hazard from clogging. Fig. 11 shows the same model structure as in Figs. 9 and 10b operating at a discharge low enough to permit all of the flow to pass through the drains. It is seen that the stilling pool spreads the flow from the jets so that it discharges rather uniformly over the end sill.

Experiments showed that the performance of the baffle box was...
improved by dropping the floor slightly below the invert of the pipe. The dimension, $p_0$ in Fig. 7, is given by the curves of Fig. 8(a). It will be noted that the minimum value of $p_0$, is 0.25 $D_0$. For practical reasons it is recommended that this dimension be made not less than 3 in. This will facilitate the construction and also improve drainage of the pipe and baffle box during low flows.

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### TABLE 1. DESIGN CALCULATIONS

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Design Data</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
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<td>40.0</td>
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<td>ft</td>
<td>26.0</td>
<td>26.0</td>
<td>26.0</td>
<td>26.0</td>
</tr>
<tr>
<td>$W$</td>
<td>'</td>
<td>9.0</td>
<td>9.0</td>
<td>6.0</td>
<td>15.0</td>
</tr>
<tr>
<td>$b_1$</td>
<td>'</td>
<td>[3b]</td>
<td>7.80</td>
<td>7.95</td>
<td>9.95</td>
</tr>
<tr>
<td>$V_1$</td>
<td>ft/sec</td>
<td>22.4</td>
<td>22.6</td>
<td>22.6</td>
<td>23.3</td>
</tr>
<tr>
<td>$A_t$</td>
<td></td>
<td>1.78</td>
<td>1.77</td>
<td>1.77</td>
<td>1.58</td>
</tr>
<tr>
<td>$D_t$</td>
<td>ft pipe diameter</td>
<td>1.51</td>
<td>1.50</td>
<td>1.50</td>
<td>1.42</td>
</tr>
<tr>
<td>$F_r$</td>
<td></td>
<td>19.2</td>
<td>10.6</td>
<td>10.6</td>
<td>11.0</td>
</tr>
<tr>
<td>$W/D_t$</td>
<td></td>
<td>5.56</td>
<td>9.0</td>
<td>4.0</td>
<td>10.6</td>
</tr>
<tr>
<td>$h_1$</td>
<td>ft</td>
<td>5.90</td>
<td>5.59</td>
<td>5.59</td>
<td>4.25</td>
</tr>
<tr>
<td>$h_2$</td>
<td>'</td>
<td>9.30</td>
<td>9.55</td>
<td>9.55</td>
<td>12.6</td>
</tr>
<tr>
<td>$h_C$</td>
<td></td>
<td>0.28</td>
<td>1.55</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>$h' = h_C + h_2$</td>
<td>24.6</td>
<td>25.0</td>
<td>25.0</td>
<td>23.8</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2. TRIAL DESIGN NO. 2

<table>
<thead>
<tr>
<th>$Q$</th>
<th>40 cfs; $W/D_t$=6.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>$D_t$=18 in; $W$=9 ft 0 in; $L$=90 ft</td>
</tr>
</tbody>
</table>

### Design data

- **Baffle box dimensions:** $p_0=0.25D_0=0.25 \times 1.5=0.375$ ft
- **Velocity:** $V_1=Q/A_t=1.77$ ft/s
- **Length of pipe:** $L=3D_0=5.2D_0=0.6D_0=2.55$ ft
- **Velocity at $h_1$:** $h_1=2D_0(W/D_t)=1.5D_0=5.85$ ft
- **Velocity at $h_2$:** $h_2=2D_0(W/D_t)=1.5D_0=5.85$ ft
- **Pressure drop:** $x_0=0.5D_0=1.46$ ft

### Dimensions

- **Minimum width:** $W/D_t=6.0$
- **From chart (b) Fig. 9:** $h_1=3D_0=3.00$ ft
- **From chart (b) Fig. 9:** $h_2=3D_0=3.00$ ft
- **$L'=L_1=3.00$ ft
- **$L''=W/D_t=6.00$**

### Design Example

- **1 Structure to be constructed at pipe outlet of an earth dam.**
- **2 Design discharge, $Q_t=40$ cfs**
- **3 Total available head, $E$ = height of reservoir water surface above center of pipe outlet = 26 ft**
- **4 Field conditions permit structure width from 6 to 15 ft**
- **5 Length of pipe connecting reservoir and structure, 90 ft.**

Following the procedure normally used for computing the size of a pipe line, the total available energy is equated to all of the losses in the system. Assumptions for values of the loss coefficients usually have to be made in the first trial calculation. In computing the pipe size when a baffle-outlet structure is included, the back pressure or static head loss must also be considered. The energy equation for the system.
is given in Fig. 8 of the design charts, and a value of $h_e$ for the first trial calculation of $D_0$ is given by equation [3b].

A structure width of 9.0 ft, well within the limits stated in the assumption of field conditions, is chosen for the first trial design and a friction factor, $f$, of 0.02 is assumed for the pipe. The entrance loss is considered to be $0.24h_e$. To simplify the example, all other pipe line losses, such as those due to valves, elbows, etc., are neglected.

In Table 1 are listed some of the possible designs for a structure which will meet the above specified field conditions and in Table 2 complete computations are shown for the design listed as Trial 1. Photographs of models similar in appearance to the structures obtained in Trial Designs 2 and 3 are shown in Fig. 10.

In reference to these designs (Table 1), several points may be mentioned. In Trial 1 the assumed velocity head was slightly low, and consequently a larger pipe was obtained than was necessary to discharge the flow. However, its value was nearly correct so that the nearest smaller standard pipe size was used for Trial 2 and the hydraulic gradient was recalculated. This gave a satisfactory solution for the hydraulic design which utilized all but 1.00 ft of the total available head, $E$. Therefore, the design of the structure was completed by following the equations and charts of Figs. 7 and 8. Experiment showed that 87 per cent of the energy existing at the pipe outlet is dissipated in passing the flow through this structure.

Since the total available head was not entirely utilized, it is possible to make an alternate solution using a narrower structure, which will have a higher back pressure. The design listed as Trial 3 is one based on a structure width of 6.0 ft and a pipe diameter of 1.5 ft which gives a width ratio of 4.0 for the structure. In this design, the hydraulic gradient was checked exactly, i.e., the sum of the losses of the system was equal to the total available energy.

Trial 4 design was made assuming that a 17-in diameter pipe was available. Hence, to design a structure which will best fit the existing field conditions, it will be necessary to reduce the back pressure to a minimum since all other losses will be increased by using the smaller pipe. Therefore, 15 ft, the maximum possible structure width, is chosen for calculating the design. In this solution it was found that for design discharge the losses exceeded the total available head by 2.8 ft so that the dam height must be raised by that amount unless the freeboard is to be reduced. It is possible that the design discharge could be carried by a 17-in pipe if one having lower friction losses and an improved entrance could be used. The system as originally assumed will discharge 37.6 cfs, or 0.94Qo, under a head of 26 ft.

From the number of designs given to fit the assumed field conditions, it is evident at once that there is more than one satisfactory solution to the problem. Therefore, the design which must ultimately be chosen will be determined by an economic comparison, or by other considerations that are affected by the local conditions.

SUMMARY AND CONCLUSIONS

The pipe outlet structure described in this paper and developed through laboratory experiment is designed to dissipate high velocity flow from a pipe outlet so that it can be discharged safely into an erodible channel. A general design has been developed that will cover all combinations of rate of discharge, pipe diameter, and width of structure likely to be encountered in practice. Performance of the structure is such that flow discharging from the stilling pool is uniformly distributed across the width, thus presenting favorable condition for erosion control at this critical point.

The dimensions of the baffle box in particular and the structure as a whole were worked out very carefully to determine the smallest possible structure that would give satisfactory performance. Changing any one or several of the dimensions results either in poorer performance or in increased cost. All the information necessary to design a structure is given by the drawing, formulas, and charts of Figs. 7 and 8.

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