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 in diameter and have flows from 10 to 250 cfs discharging into channels of various widths.

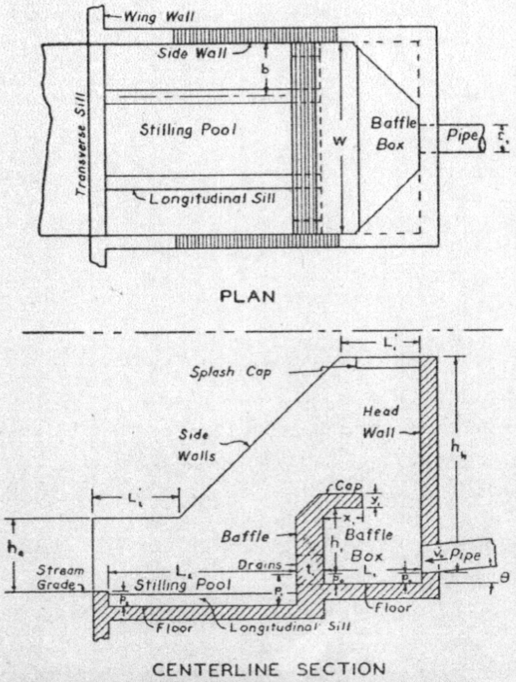
The design of a baffle type dissipator was first worked out in 1938 by the engineering division of the Soil Conservation Service at Berkeley, California, in an attempt to devise a system of energy dissipation for high velocity flow from pipe outlets that would be more economical than that which makes 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_0, (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 at the end of the pipe, and (d) the width, W, of the structure. Of these variables all except Q_0 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_0, and the static pressure, h_0, 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.



PLAN

CENTERLINE SECTION

Fig. 1 Typical baffle structure for pipe outlet

Similitude Relationships. For convenience in applying laboratory results to field installations, all dimensions are expressed in terms of the diameter of the pipe. Thus, if the structure width is 6.0 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_0, for the pipe outlet structure is given by the dimensionless ratio

$$F_0 = \frac{V_0^2}{gD_0} = \frac{Q_0^2}{\dfrac{\pi^2 D_0^5 g}{16}} \qquad [1]$$

where V_0 is the velocity in the pipe, g is the acceleration of gravity and D_0 is the pipe diameter. When F_0 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_0, 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_0, is called the "velocity head factor."

The use of similarity laws reduces the independent variables to two: (a) F_0, which expresses dynamic similarity, and (b) W/D_0, the width ratio, which expresses geometric similarity. The dependent variables are the back pressure ratio, h_0/D_0, and the various dimensionless ratios expressing the proportions of the structure.

Having established similarity laws, hydraulic model tests were made in which F_0 and W/D_0 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_0 and W/D_0 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_0 ranged from 2.0 to 9.5 and F_0 ranged from 1 to 190. The diameter of the pipe used in the models ranged from ¾ 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 over-all 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

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*R. L. Daugherty, "Hydraulics," p. 108, McGraw-Hill, New York, 1937.

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 outflow 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.

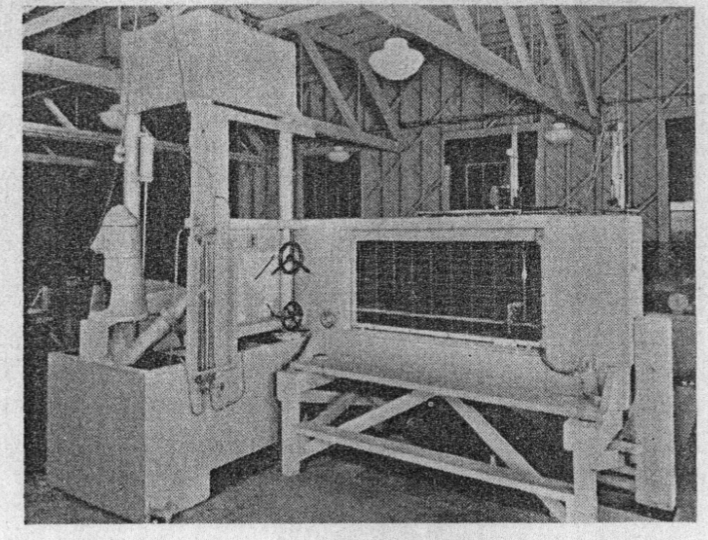
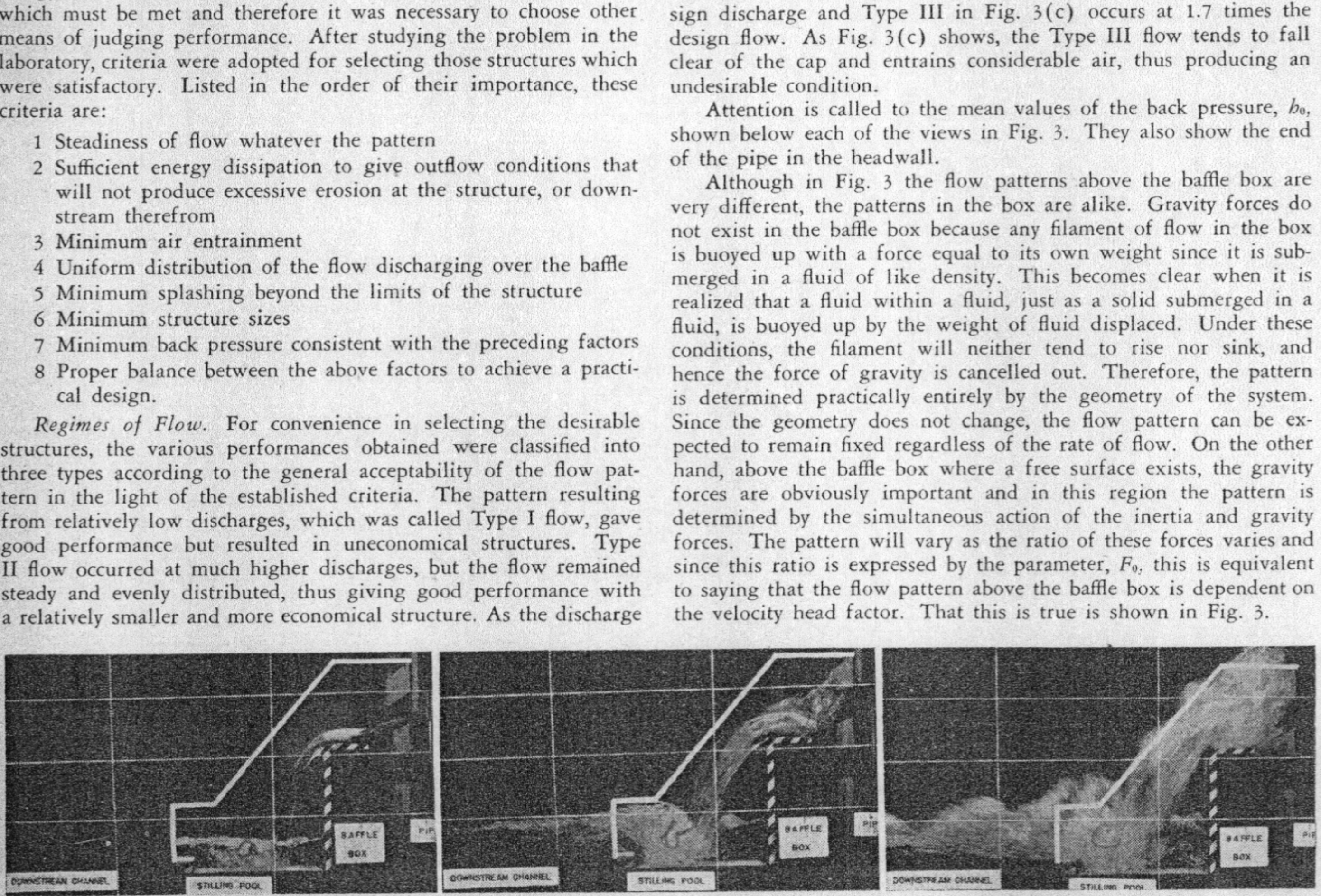


Fig. 2 Flume in which experiments were conducted for the development of a baffle type energy dissipator

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, h_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_0, 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.



(a) Low flow, $F_0 = 8$; $h_0 = 4.2D_0$
Type I Flow — Underload Discharge

(b) Design discharge, $F_0 = 32$; $h_0 = 5.6D_0$
Type II Flow — Recommended Performance

(c) High discharge, $F_0 = 96$; $h_0 = 8.0D_0$
Type III Flow — Overload Condition

Fig. 3 Effect of discharge on flow conditions. All structures are identical. Only the discharge (velocity head factor, F_0) is varied. $D_0 = 0.078$ ft; $W/D_0 = 4.3$; $p_0 = 0.3D_0$; $L_1 = 3.2D_0$; $h_1 = 2.8D_0$; $x_1 = 1.4D_0$; $p_2 = 0.53D_0$; $L_2 = 5.2D_0$

GLOSSARY OF TERMS

b = distance from sidewalls to centerline of longitudinal sills in stilling pool, ft

b'_1 = width of drain opening, ft

$C = \left(\frac{\pi}{4} \times \frac{D_0}{W}\right)^{2/3}$ = a critical depth coefficient

C_e = exterior chamfer of baffle, ft

C_i = fillet at corner formed by cap and baffle, ft

C_L = stilling pool apron length coefficient

C_l = Coefficient of energy loss

D_0 = Diameter of pipe outlet, ft

$d_c = \sqrt[3]{Q_0^2/W^2g}$ = critical depth, ft

E = a specific energy, ft-lb per lb

ΔE = loss of energy, ft-lb per lb

f = friction factor for pipes

$F_0 = V_0^2/gD_0$ = velocity head factor

g = gravitational acceleration, ft/sec²

H = net drop from baffle crest to stream bed, ft

h_E = entrance head loss, ft

h_f = friction head loss, ft

h_L = total losses in pipe leading to structure, ft

h_e = height of end wall, ft

h_h = height of head wall, ft

h_0 = back pressure head on pipe outlet, ft

$h_v = V_0^2/2g$ = velocity head of flow in pipe, ft

h_1 = net height of baffle, ft

K = coefficient in back pressure equation

K_e = loss coefficient for entrance

K_f = loss coefficient for pipe friction

K_m = loss coefficient for miscellaneous causes

L_1 = length of baffle box, ft

L'_1 = top length of side wall, ft

L_2 = length of stilling pool, ft

L'_2 = horizontal sidewall dimension for stilling pool, ft

L_s = overall length of structure, ft

l = length of pipe carrying discharge to structure, ft

p_0 = drop in floor of baffle box below pipe invert, ft

p_1 = drop of stilling pool floor below pipe invert, ft

p_2 = depth of stilling pool (height of transverse or end sill)

Q_0 = design discharge, cfs

Q_1 = discharge through baffle drains, cfs

t_1 = thickness of baffle, in

$V_c = \sqrt{d_c g}$ = critical velocity, ft/sec

V_0 = velocity of flow at pipe outlet, ft/sec

V_2 = velocity of flow discharging from baffle box, ft/sec

V_3 = velocity in downstream channel, ft/sec

W = width of structure, ft

x_1 = overhang of baffle cap, ft

y_1 = thickness of cap, ft

θ = 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 sill 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 on 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. 3(b) and 6(a). It will be noted that with the short box the back pressure was high and that the flow rose high up along the headwall and appeared to be of Type III. 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) flow is very

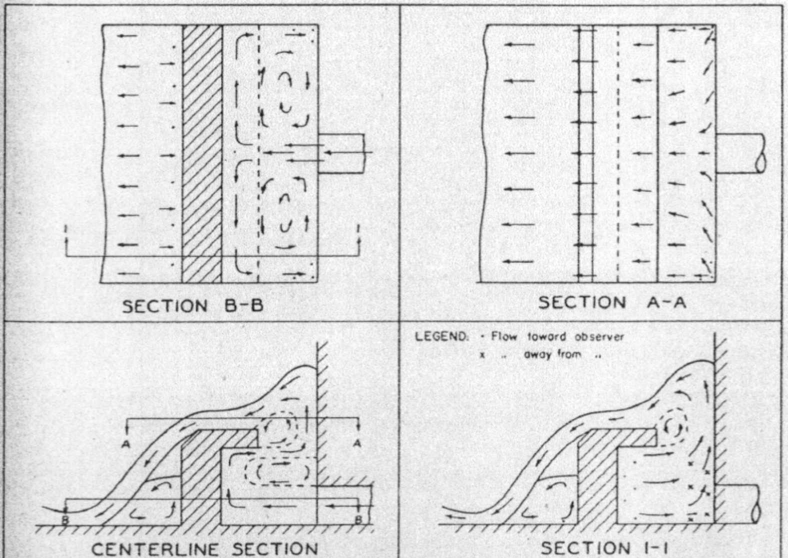


Fig. 4 Sketches of the flow pattern of recommended performance — Type II flow $F_0 = 32$; $W/D_0 = 6.7$; $L_1 = 2.5D_0$; $h_1 = 2.0D_0$; $x_1 = 1.0D_0$

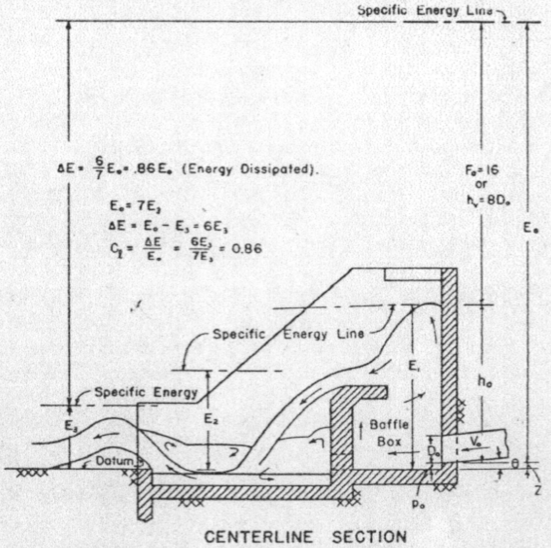


Fig. 5 Typical pipe outlet structure showing energy line $W/D_0 = 5$; $p_0 = 0.3D_0$; $L_1 = 2.5D_0$; $h_1 = 2.0D_0$; $x_1 = 1.0D_0$; $L_2 = 5.0D_0$; $p_2 = 0.4D_0$; $d_c = 0.8D_0$; $F_0 = 16$; $h_v = 8.0D_0$; $h_0 = 4.7D_0$

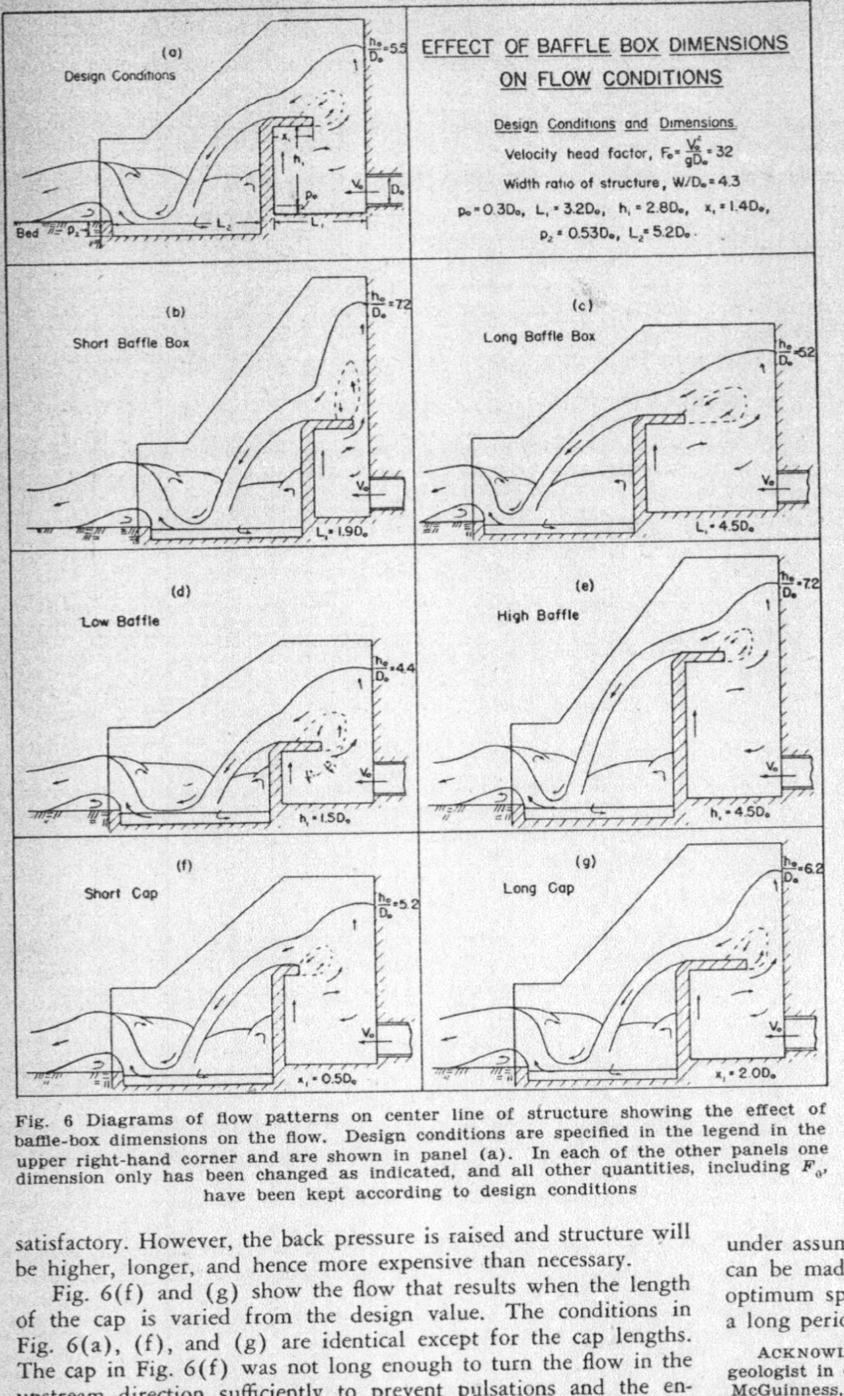


Fig. 6 Diagrams of flow patterns on center line of structure showing the effect of baffle-box dimensions on the flow. Design conditions are specified in the legend in the upper right-hand corner and are shown in panel (a). In each of the other panels one dimension only has been changed as indicated, and all other quantities, including F_0, have been kept according to design conditions

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_0, i.e., the distance from the invert of the pipe to the floor, was $0.3D_0$, 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 severalfold 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, θ, 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.

(Concluded in the September issue)

Weed Control with Chemicals

(Continued from page 298)

Being in common use in agriculture for a number of years, it is also known as a contact killer and soil sterilant. At 1 lb per sq rd contact kills have been satisfactory but larger quantities are needed for appreciable sterilizing effects.

Time of application has been important in securing best results. Applications between June 15 and July 15, after weeds have germinated and made some growth, have been more satisfactory.

The use of chemicals for weed control will probably increase because of the desire and necessity of doing a better job of control, the introduction of new weed-killing chemicals, and the interest in labor-saving methods.

The agricultural engineer is the person to whom we look for the development, manufacture, servicing, and distribution of such machinery. The up-to-date farm of tomorrow may have as a part of its regular equipment some sort of chemical weed control equipment. There is a possibility that there may be a more widespread use of community equipment for the spraying or distribution of chemicals for this purpose. There is currently a trend developing in the direction of weed control in cultivated crops by these methods. Perhaps such tools can be regular equipment for tractors, or adapted from such tools as potato sprayers, etc. With the trend toward the mechanization of all farm operations and raising the working standards of the farmer, the scythe may hang in the tree more of the time in the future.

Water Transmissibility and Storage Coefficients

(Continued from page 300)

been given, and three examples of the application of such coefficients have been discussed. The coefficients have been used to determine the source of water supply, the quantity to be expected from each source, and the minimum yield to be expected from a well field under assumed conditions of operation. Additional applications that can be made with the knowledge of these coefficients include the optimum spacing of wells and the prediction of water levels over a long period of time to prevent obsolescence of equipment.

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