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CULVERT BAFFLE STUDY

FOR

Rectangular Culverts

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By

W. R. McKinley, Engineer
R. D. Webb, Engineer

State of Washington
Department of Fisheries
Stream Improvement Section

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INTRODUCTION

It has long been realized that there exist conflicts in the design of highway culverts for maximum flow capacity and for the most effective passage of fish life through those structures. On the one hand, greater run-off can be discharged through a smaller and less costly culvert, if it is as smooth as possible and is installed at a maximum gradient. On the other hand, optimum fish passage requires that the culvert be placed at a gradient approaching zero or that velocities be slowed by some type of baffle arrangement.

Recognizing the existence of such opposing design criteria, representatives of the Department of Fisheries and the Department of Highways met in several discussions of the problems involved in fish passage through culverts under state highways. The purpose of these meetings was to develop specifications, to be included in the design of culverts, which would allow the most efficient passage of discharge downstream and fish life migration upstream.

However, past construction had resulted in some state highway culverts which seriously hindered the passage of fish life due to their placement. Correction of these culverts was recognized as entirely possible, but the funds with which to achieve the correction were not available within regular Highway Department maintenance monies. To impose no serious financial handicap on the maintenance funds of the Highway Department, it was suggested that a joint inspection be made of the faulty culverts, tentative plans and cost estimates be formulated for their correction, and a joint bill submitted to the State Legislature requesting funds for improving the fish passage conditions at the culverts. Both Departments felt that this plan would achieve the desired results and to date a joint investigation has been made with preliminary recommendations for the correction of six culverts submitted to the Department of Highways for their further study. This study is to include collection of topographic data and a review of flow records. Such data are to be exchanged with the Department of Fisheries and used in the functional design of fish passage facilities.

Conditions, noted during the field inspection of several of the faulty culverts, indicated that some arrangement of baffles was needed. Steep gradients, causing swift velocities and shallow water depths in these culverts, created serious blocks to fish migration during most water stages.

The engineers of this division, in their search through the available literature, found little reference to experimental or prototype installations of the type needed. Much experimental data may be found concerning fish ladders and fishways; however, we are involved in this case with existing structures which must serve two purposes. These culverts must primarily perform their service of drainage while also, at certain periods of the year, must allow passage of anadromous fish.

Certain barriers must, of necessity, be installed to slow and deepen the flow in the culvert; however, the overall hydraulic efficiency of the culvert cannot be too greatly impaired. To meet these conditions and to supplement the sparse information available from other sources, a model study was initiated.

PURPOSE AND SCOPE

The existing culverts that were found to present a fisheries problem were used as a basis to limit this study. In limiting the scope of this study, it was thought expedient for reasons of time and manpower to explore conditions as heretofore found in the field. The various culverts inspected included a range of slopes up to 3% and widths up to 10 feet. It was decided to extend this range of slope in the model study to a maximum of 5% so that extreme conditions could be studied. The objective in this entire model study was to find a simple effective pattern of flow which would dissipate energy thoroughly at low flows, with high slopes and allow passage of anadromous fish without undue exertion or exposure to harmful effects.

EQUIPMENT

The conditions of this study demanded close control on a variable flow, a precise method for varying slope, and a means whereby the quantity could be measured accurately.

For this study, the facilities of the University of Washington Hydraulics Laboratory were found to be best adapted to our purpose.

The model culvert was constructed on a unit scale; that is, one foot wide; so that it could be easily scaled to any linear ratio on a prototype. To make the slope easily adjustable, the effective length between supports was made exactly 10 feet.

The upstream end of the model was attached by means of a rounded intake to a stilling pool. The quantity of water flowing into the stilling pool was controlled by a six inch valve. The quantity was measured by means of a rectangular tank placed in a sump below the outfall of the model. This tank was one regularly in use by the Hydraulics Laboratory for measurement of water and had an exact horizontal cross section of 2'x3'. A scale was placed vertically on the inside of the tank and the quantity was measured by the time required for a unit change of depth in the tank.

The model culvert was constructed from 1x12 rough cedar lumber. It was made in the form of an open channel for convenience in observing the patterns resulting from different baffle arrangements. The baffles themselves were made of finished lumber which were shaped to the various dimensions used in the study. Rough lumber was used for construction of the model because it most nearly approximated the roughness factor to be found in worn, aged concrete in the existing culverts. Measurements of flow and velocity for the calculation of Kutter's "n" in prototype culverts were available only for Ennis Creek culvert. This "n" was calculated from a depth of flow at which the change in "n", due to change in depth, is not believed to be significant. The relationship between model and prototype when the effects of friction are included is expressed by the formula $\frac{n_m}{n_p} = L_R^{1/6}$ where L_R is the linear ratio of model to prototype. The prototype example used was Ennis Creek culvert, b = 10', h = 8', S = 0.0299. At the time of observation, the discharge was 27.5 c.f.s. and d = 6". The L_R between the model and Ennis Creek culvert is 1/10.

From the above conditions, it was found that $n_p = 0.0254$.

From data obtained from the model culvert, it was found that $n_m = 0.0173$.

The ratio $\frac{n_m}{n_p} = 0.68$ and the ratio $L_R^{1/6} = 0.68$.

Assuming reasonable accuracy in estimating flow in Ennis Creek culvert, there is no apparent error in the model for the scale value of roughness. Thus this model duplicated as nearly as possible the existing culverts.

PRELIMINARY STUDY

Since most of the culverts which are intended to be baffled are already in place, the difficulty of entering these existing culverts, placing concrete forms or anchoring wood baffles, and in general accomplishing the job, must necessarily restrict the design of the baffles to one of the utmost simplicity. For these reasons, it was decided that any arrangement of baffles finally used must be straight, with no change in cross section, no curves, no re-entrant ends, or other complexities. To avoid the necessity of the fish swimming a curving, torturous path, a straight clear channel through the entire culvert is desirable. Due to the limitations on time available for this study, it was thought best to select a few simple, effective patterns and examine them exhaustively. By such a complete exploration of the possibilities of these patterns, the arrangement which would most successfully allow fish passage, effective use of water at low flows and minimum restriction of the normal culvert cross section could be discovered. With these criteria as guides, many small changes in baffle arrangement were tested until one, Fig. 1, gave a possibility of the desired type of control over the flow of water. Other arrangements were examined for possible good control over the flow of water. These were the paired baffle type and the alternate baffle type shown in Figs. 2 and 3.

EXPERIMENTAL PROCEDURE

A trial series of a particular arrangement of baffles consisted of three different quantities and various slopes. The first quantity flowed only to the top of the baffles, the second quantity submerged the baffle slightly, and the third quantity overtopped the baffle by several inches in model. At each of these quantities, the slope was varied from 1.5% to 5%, the intervals of slope tested were 1½%, 3½%, and 5%. Thus for a particular baffle arrangement, nine runs were made, during which flow was observed, patterns recorded, and any other particulars of these baffles examined at the designated flow and slope. Zero slopes were not examined in this study, since a culvert so placed can be made to create one long pool.

After one series of tests had been run, one of the dimensions of the baffle pattern was changed so as to try and improve the pattern. A new series of tests would then be run using the new arrangement. This procedure of refining the flow pattern was continued until the best arrangement was finally found. An example would be the baffle spacing. The experiment started with 10-3/4 inch spacing which proved to be too close. The spacing was increased in increments to as much as 21 inches which proved to be excessive. The spacing was then cut back down to its final arrangement of 13½ inches. Similar refinement was made in the angle of the baffle with respect to the wall, the lengths of the two baffles, "x" and "y", (See Fig. 4) and the clear opening between baffles.

RESULTS AND CONCLUSIONS

When the series of studies on these baffle arrangements was started it was decided that there must be a basis for comparison between trials. Many trials might consist of the same arrangement but only the slope and quantity going through them to be changed. It was necessary that a grading system be set up that would have its final basis of scoring on effectiveness of fish passage. An arrangement of baffles that is effective at a certain slope and a certain discharge might, at a different slope or discharge, have entirely different properties. The different trials were rated individually without reference to previous runs, expected conditions, or preconceived patterns.

The basic features of a fish passage device that could be rated in effectiveness are as follows: Effective energy dissipation, minimum depth encountered by a fish passing through, the pattern of flow and its effect upon the path a fish would follow through the entrance conditions from pool to pool, the availability of dead or very slow water for resting purposes, and finally to allow for the evaluation of unknown factors such as objectionable whirlpools, hydraulic jumps, excessive standing waves, high turbulence, or other hydraulic peculiarities which were observed, the judgment of the operators was also scored.

TABLE 1 - GRADING SYSTEM

	Bad				Good
Energy Dissipation	1	2	3	4	5
	< ½"	3/4"	1"	1¼"	1½"
Minimum Depth in Pool	1	2	3	4	5
	Bad				Good
Pattern of Flow in Pool	1	2	3	4	5
	Little				Much
Dead or Slack Water	1	2	3	4	5
	Poor				Good
Judgment	1	2	3	4	5

Add total points and fit into group below:

Points	Grade
1 - 5	5
6 - 10	4
11 - 15	3
16 - 20	2
21 - 25	1

An example of this grading system is trial No. 6 shown on data sheet No. 1. Energy dissipation was given two points due to the fact that a gain in energy was observed through the culvert; the minimum depth was above $1\frac{1}{2}$ inches which is worth five points; pattern was rather confused (no definite stream) and was rated as two points; very little useful dead water was given one point; and judgment of the lack of other detrimental characteristics received four points. The total points received by trial No. 6 was fourteen which rates it as a three or in the middle of the range of grading.

The object of grading each trial or situation was so that any actual arrangement of baffles could be compared at any slope and any discharge. An arrangement that tested with a good grade at all situations of slope and discharge would be the logical choice over one that received a good grade in one or two situations.

As an aid to judgment of flow patterns and paths that fish would follow proceeding through the baffles; small chinook salmon approximately 85 mm. long were introduced into the lower end of the model culvert during many of these trials. No attempt was made to compare these fish with adults going through a prototype culvert. Their presence was significant, however, in that it would tend to show the path most likely to be followed by fish through various arrangements. When the path became obviously very torturous due to velocity or other conditions, it would be deduced that this arrangement of baffles would provide much the same conditions in the prototype. Conversely, when the fish swam through easily with very little weaving and darting, it may again be deduced that the same conditions would prevail in the prototype.

An unanticipated condition was found during higher flows when using the 30° angle between baffle and wall. Along the wall from which the long baffles projected, a counterclockwise roll was observed to form. This counterclockwise roll formed by the deflection of the water by the upstream side of the baffle against the corner fillet and right wall of the culvert was continuous along the wall, and extended approximately 1/3 of the width. This roll tended to maintain the flow pattern below the baffle tops after the baffles were well overtopped. The circular motion of this roll appeared to effectively reduce the direct downstream velocity within the roll as more energy was dissipated within this circular motion. In three instances, small chinook, as were referred to in the preceding paragraph, were introduced into the culvert and were observed to swim the complete length of the culvert within the roll.

As one of the design criteria was the establishment of dead or resting water in line with the slots of the fishway, the preliminary design was evolved with this factor in mind. Changes of overall spacing, moving of the slot nearer to the center of the fishway, and varying the angle of the long baffle with respect to the wall were tried with this object in mind. Actually many of these conditions are interdependent and the final aim is an effective dissipation of energy through the length of the culvert and formation of dead water in line with the slots. This dead water allows a fish to swim in short spurts through the high velocity, proceed straight ahead and enter a resting area which lies very nearly parallel to the jet of high velocity. This parallelism of the jet and the resting area is obtained by varying the angle of the long baffle with respect to the wall. The smaller the angle of the baffle with the wall, the more nearly the line of high velocity was brought directly downstream through the slot. The limiting condition was the dissipation of energy in the pool. Too small an angle could not be used for then the pools would become too long causing an excessive difference in water levels between pools.

The design that is recommended in this report, and which is sutiable for slopes from 0% to 5%, under all but the very lowest of discharges, for which nothing could possibly be effective, is that shown in Fig. 4.

RELATIVE EFFICIENCY

As this study was carried on in an effort to find effective means to allow fish passage through culverts, the other side of the picture must be considered; that of the effect of the baffles upon the overall efficiency of the culvert passing the amount of water for which it was designed. Any intermediate discharge is not as important as the maximum flow when the culvert is full, this being a 50 or a 100 year flood.

As the ability of the culvert to pass water would be somewhat impaired with the installation of baffles, it was necessary to estimate the relative efficiency of the culvert with and without baffles. Calculation of this efficiency is impossible from low flow model data shown due to the fact that the roughness factor "n" in the baffled culvert appears to vary significantly with depth or discharge. As a result of scale agreement in the model and prototype discussed on Pages 4 and 5, efficiency may be calculated at high discharge conditions by scaling model observations to prototype dimensions. To eliminate the chance of error in such calculations, a comparison was made in the model culvert. A high discharge was put through the baffled model and the depth measured. The baffles were then removed and the depth again measured. From the data on these comparative tests, the roughness in each case can be calculated. By assuming the depth in the bare culvert equal to that in the baffled culvert and calculating the discharge required for this new depth, a comparison may be made between the discharge required in bare and baffled culverts to fill the culvert to the same point.

These measurements for efficiency comparison were made with the model on a slope of 0.035. The efficiency resulting from scaling to a 10 foot culvert with one foot high baffles was 69%. The efficiency for the same arrangement but with baffles 1.4 feet high was 57%. A third arrangement was tried, as shown on Page 22, with only half of the width of the culvert baffled which resulted in an efficiency of 80.5%.

BAFFLE ARRANGEMENTS

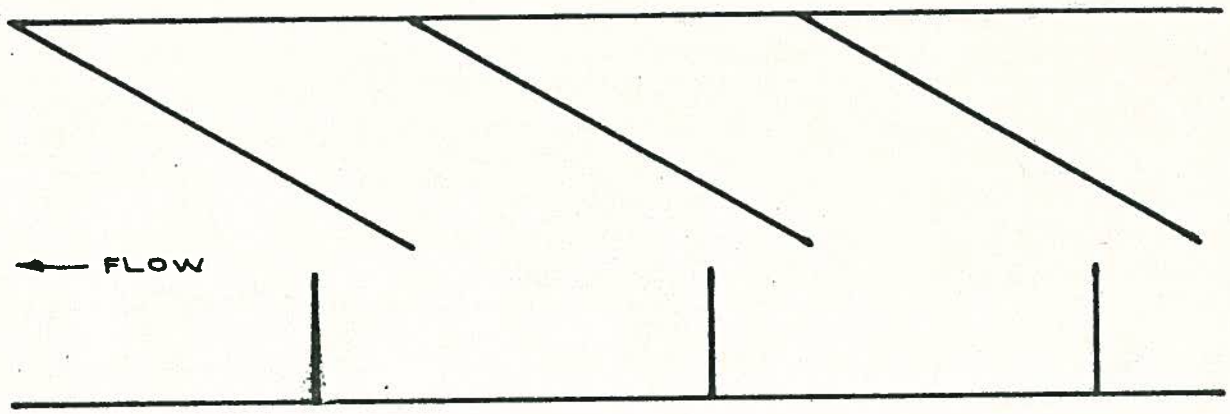

FIG. 1

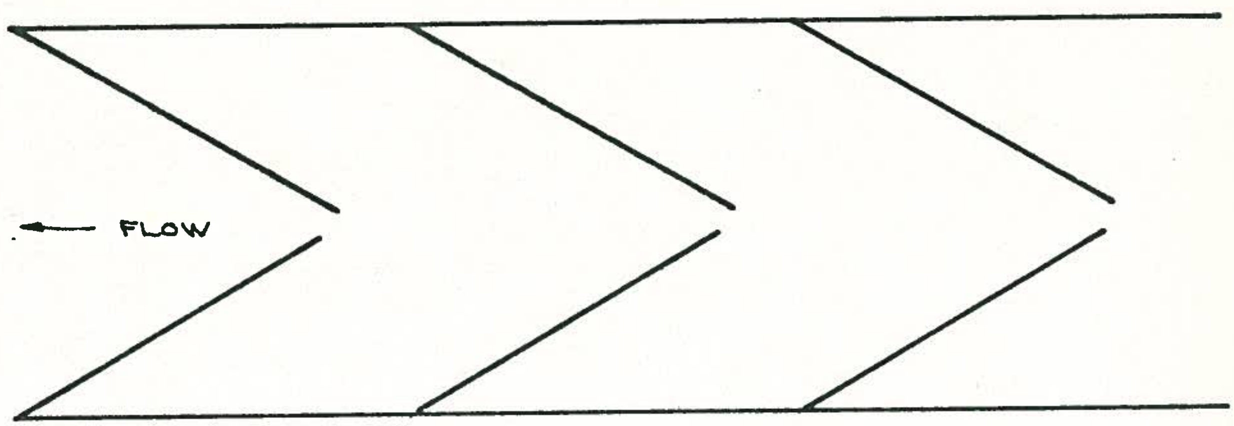

FIG 2.

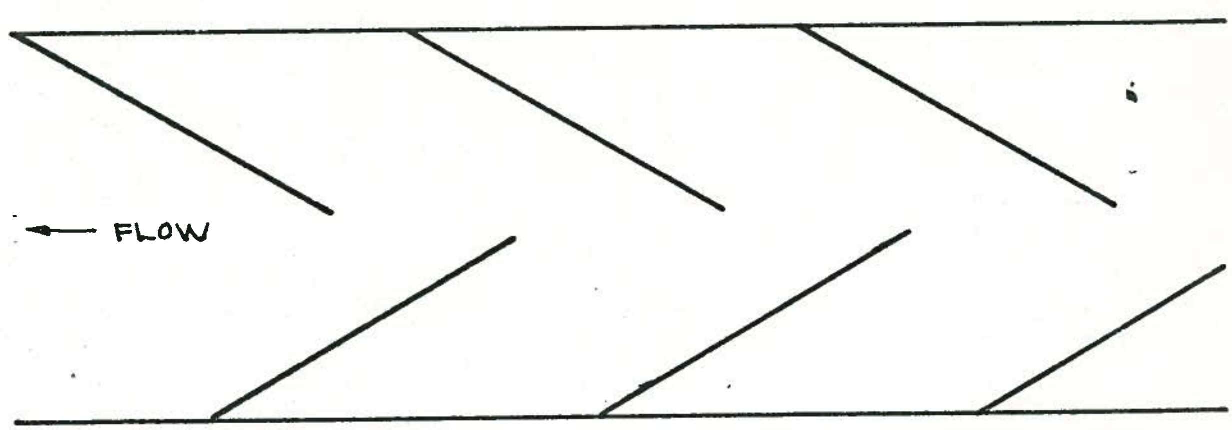

FIG. 3

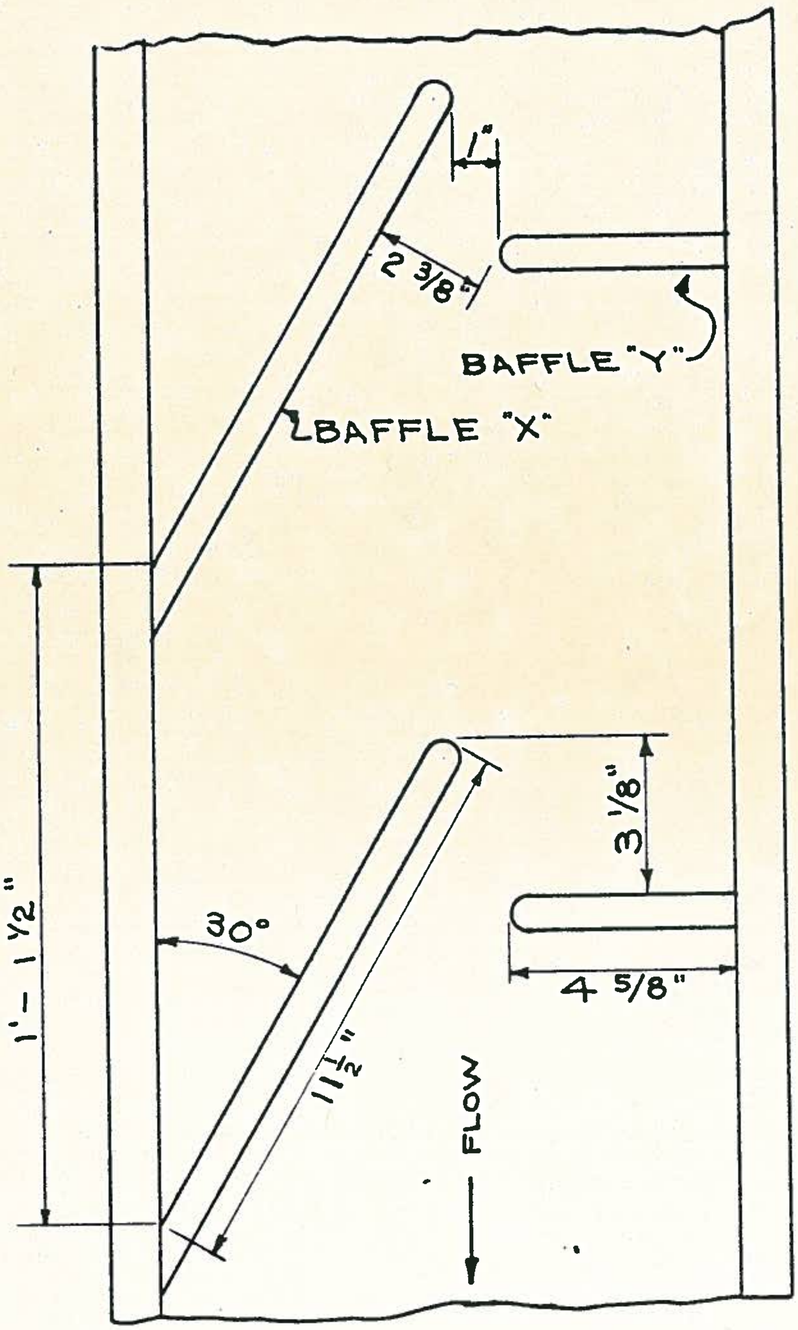

FIG. 4

SELECTED MODEL ARRANGEMENT