PRELIMINARY REPORT

ON

INVESTIGATION OF CULVERTS AND HYDRAULIC STRUCTURES

USED FOR FISHWAYS

by

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INTRODUCTION

A brief description of fish blockage problems created by culverts and a review of the state of the art of culvert fishway design is presented. Characteristic features which are necessary for a satisfactory fishway are described. A vertical slot orifice fishway is proposed as an alternate structure which fulfills all the requirements of a fishway.

Problems associated with upstream migration of fish through culverts are well described in "A Proposed Correction of Migratory Fish Problems at Box Culverts", by McKinley and Webb (1) and in "Inland Fisheries Management", edited by Calhoun (2).

Traditionally culverts are proportioned to pass a particular discharge through a barrel of minimum cross-section. During periods of large flow, velocity is too high for successful ascent of fish; during normal or low flow the water may be too shallow. Along steep channels (greater than 1/2% slope), where the culvert is placed on grade, excessive velocity and shallow flow interferes and sometimes totally blocks fish passage.

Both the outfall and inlet of the culvert can be formidable blocks. Under certain flow conditions the contracted accelerating flow at the entrance is the most critical zone. The fish after an exhaustive swim the entire length of the culvert may give up when he meets this final barrier and be swept back through the culvert. Dropoffs at the outlet of the culvert, if of sufficient height, can stop all upstream migration. Dropoffs occur if the culvert outfall is set well above grade or if degradation of the stream bed occurs downstream of the outfall.

Downstream migration of fish through culverts under any flow conditions (other than low flow) is not considered a problem. A study conducted at Glines Dam on the Elwho River in 1952, discussed in Reference 3, indicated a 92% survival rate of yearling silver salmon which passed over a dam crest and free fell 180 feet into a pool. Nothing approaching this type of drop will be encountered at culvert installations.

This research effort is directed toward an economical and reliable solution to the problem of upstream migration through steep box culverts. The characteristics which are necessary for a satisfactory fishway are:

1. Stable low velocity flow in the fishway which will function throughout a wide range of discharges.
2. Self cleaning.
3. Efficient, i.e., does not reduce flow capacity.
4. Simple and economical to construct.

CULVERT FISHWAYS WHICH HAVE BEEN USED

Early efforts to solve the fish barrier problem centered around the use of a pool and baffel fishway. Vertical baffles were placed on the culvert floor perpendicular to the centerline, spaced at regular intervals forming a series of pools and overfall weirs. Two distinct types of flow can occur, "plunging" or "streaming" (Figure 1). When plunging flow occurs the water drops from pool to pool in a step fashion. The kinetic energy content is dissipated in each pool, thus affording the fish a relatively quiescent resting area prior to each ascent of a weir. During streaming flow, water skims over the weir tops at a high velocity with little energy dissipation, a type of flow which is unsatisfactory for fish passage.

Various tests conducted on pool and weir fishladders (Reference 4, 5, 6) with centerline slopes ranging from 5 to 12½%, indicated that plunging flow occurs with depths of flow over the weir up to 1.4'± and streaming flow for any greater depth. If the culvert is to be an effective fishway it must be of sufficient width that flow depth over the weirs does not exceed 1.4 feet for any sustained length of time. This necessitates a wide shallow culvert.

Structural requirements for the culvert roof and floor are a function of the width of the culvert cubed. The bending moments in the roof of a culvert with a span of 10 feet are approximately eight times larger than those for a 5 foot span, thus doubling the span results in a significantly more expensive structure.

Another factor which limits the effectiveness of baffles is bed load deposition in the pools. The material carried in most steep streams rapidly fills the pools between the baffles resulting in streaming flow even at low discharges. It is not economical to clean the pools as the work must be done by hand. Shallow head room and baffles on the floor prohibit any form of mechanical cleaning.

Alternate paired baffles illustrated in Figure 2 have not proven effective. During low flows, depths in successive pools are below minimum depth for fish passage and extremely turbulent unstable flow patterns unsuitable for fish passage occur during high flows (1).

The baffle system which has worked most effectively is the offset baffle design (Figure 3). Throughout a large range of flow depths a counter-clockwise roll of relatively stagnant water forms in the region below the crest of the baffle in the apex between the angled baffle and the wall. This roll affords a resting area for the fish as they make successive advances through the gap between baffles. Another advantage is that the area is parallel to the direction of fish movement.

Testing of the offset baffles (1) indicated good cleaning characteristics. Although this may be so for small sizes of bed material, the strength of circulation required to sweep out material several inches in diameter would surely result in an unsuitable resting area. Mr. Gene Fiolla, Regional Hydraulics Engineer for the Bureau of Public Roads, mentioned that several of these installations in Oregon and Washington have filled completely with bed material and are no longer effective.

Another undesireable feature of any type of floor baffle is the loss of efficiency. Efficiency is defined (1) as the ratio of the depth of flow in a culver operating without baffles divided by the depth of flow for the same discharge and culvert barrel dimensions with baffles in place. Model tests on offset baffles simulating a 10 ft. wide culvert with one foot high baffles indicated an efficiency of 69%. With 1.4 foot high baffles the efficiency was 57%. This is an important consideration when existing culverts are modified. As an example, if a six-foot high box culvert, proportioned to carry a particular discharge with a headwater of 6 feet, is converted to a fishway by installing one foot high baffles, the headwater (backwater) upstream of the culvert would have to be about eight feet in order to drive the same discharge through the culvert (computations shown in appendix). This headwater is about two feet higher than that specified during the original design. In some situations two feet of additional backwater may inundate valuable land or structures, or may overtop the roadway fill resulting in damage to the highway and possible loss of the culvert. This point must be considered when existing structures are modified.

New structures which are to function as fishways, must be designed for a specified headwater with a corresponding increase in structure width and cost.

SUGGESTED STRUCTURE

A structure, which satisfies criteria for the fishway outlined above is shown in Figure 4. The fishway exit (upstream end of the culvert) would be constructed outside the culvert barrel. The critical cross-section for culverts on steep grades is the entrance section thus there would be no decrease in efficiency of the culvert. At a distance downstream of the inlet, such that there is no interference to flow entering the culvert, the fishway would enter the culvert barrel and occupy the region adjacent to a wall. The effect of this is to raise the level of flow in the lower reach of the culvert, however, since this reach is below the contracted entrance section and in the supercritical flow zone, it does not effect the headwater level.

The second major feature of the fishway would be the use of vertical slot orifices the entire length of the fishway. The series of vertical slots extending the full depth of the section would be effective over a very large range of discharges and would provide a suitable environment for fish passage.

A semidment ejector constructed at the upper end of the fishway would flush all bed load onto the smooth floor of the culvert barrel where it would immediately be swept downstream. The invert of the fishway exit would be set at a slightly lower elevation than the culvert inlet invert, thus all of the low flow would be routed through the fishway. Fish passage would be possible even during very low flows.

If degradation is expected at the lower end of the culvert, the fishway invert can be constructed to the elevation of expected degradation. The slot orifice should function well throughout a large range of tailwater depths.

The orifice fishway could be constructed entirely outside of the culvert barrel. However, it appears that this arrangement would be more costly as considerably more material would be required for the roof and floor. From a construction viewpoint forming of the roof in place would be impractical.

Another point against the separage fishway is lack of light. It is generally agreed (though not conclusively proven, see Reference 7) that a lighted fishway is more conducive to fish movement than a dark fishway. When the fishway is constructed within the barrel the lighting condition is fulfilled with the exception of a short reach in the upper portion of the fishway.

HYDRAULICS

Several aspects of the hydraulics of the system cannot be designed with existing criteria. The flow regime at the fishway exit is quite complex. The quantity of inflow through the slot orifice and how the lateral withdrawal distorts the normal flow pattern at the culvert entrance at various headwater stages will have to be determined. The geometry of the entrance slot and sediment ejector, the quantity of flushing water, and the normal weir to weir flow pattern with various orifice opening ratios and longitudinal spacings will have to be examined. Criteria for the longitudinal spacing (as a function of culvert slope) and the ratio of the orifice opening to fishway width will have to be developed. A minimum width of opening will have to be specified depending upon the size and species of fish which will use the structure.

The above design criteria will be developed by using a combination of hydrualic laws and hydraulic modeling. Several references such as "Flow in Rectangular Channels with Lateral Construction Plates" (8), and "The Vertical Slot as a Flow Measurement Device" (9), will be useful though not directly applicable to the problem.

CONCLUDING REMARKS

A brief review of the state of the art of culvert fishway design and a description of a few shortcomings of existing designs is presented in this interim report. A vertical slot orifice fishway is proposed as an alternate solution which fulfills all the requirements of a fishway without lowering the efficiency of the culvert. If, after review and comment by interested agencies, the vertical slot orifice fishway is considered practical, modeling of the fishway and development of design criteria will commence. The modeling work will be accomplished in the hydraulics laboratory in the new Buchanan Engineering Laboratory at the University of Idaho.

REFERENCES

1. McKinley, W. and Webb, R., "A Proposed Correction of Migratory Fish Problems at Box Culverts," Fisheries Research Papers, Vol. 1, No. 4, Washington Department of Fisheries, March, 1956.

2. Calhoun, A. et al, "Inland Fisheries Management," Department of Fish and Game, State of California, 1966.

3. Regenthal, A., "Downstream Migrant Salmon Survival in Free Fall From a Ski-Jump Spillway," Fisheries Research Papers, Vol. 2, No. 1, Washington Department of Fisheries, June, 1957.

4. Thompson, C. and Gauley, J., "Laboratory Evaluation of the 1-ON-10 Slope Ice Harbor Fishway Design," Special Scientific Report--Fisheries No. 509, U.S. Department of the Interior, June, 1965.

5. Gauley, J. and Thompson, C., "Further Studies on Fishway Slope and Its Effect on Rate of Passage of Salmonids," Fishery Bulletin: Vol. 63, No. 1, U.S. Department of the Interior, February, 1962.

6. Collins, G., et al, "Effect of Fishway Slope on Performance and Biochemistry of Salmonids," Fishery Bulletin: Vol. 63, No. 1, Bureau of Commercial Fisheries, November, 1961.

7. Trefethen, P., "Fish-Passage Research, Review of Progress, 1961-66," Circular 254, Bureau of Commercial Fisheries, U.S. Department of the Interior, October, 1968.

8. Vallentine, H., "Flow in Rectangular Channels with Lateral Constriction Plates," La Houille Blanche, Jan-Feb, 1958, No. 1, p. 75.

9. Hill, H., et al, "The Vertical Slot as a Flow Measurement Device," Presented at ASCE Hydraulics Specialty Conference, Logan, Utah, August, 1969.

OTHER REFERENCES

10. Shoemaker, R., "Hydraulics of Box Culverts with Fish-Ladder Baffles," Vol. 35, Proceedings of the Highway Research Board, Washington, D.C. December, 1956.

11. Thompson, C., et al, "Response of Migrating Adult Salmonids to Vertical and Horizontal Rectangular Orifices at Two Depths," Special Scientific Report--Fisheries No. 547, U.S. Department of the Interior, June, 1967.

12. Weaver, C., "Influence of Water Velocity Upon Orientation and Performance of Adult Migrating Salmonids," Fishery Bulletin: Vol. 63, No. 1, Bureau of Commercial Fisheries, May, 1962.

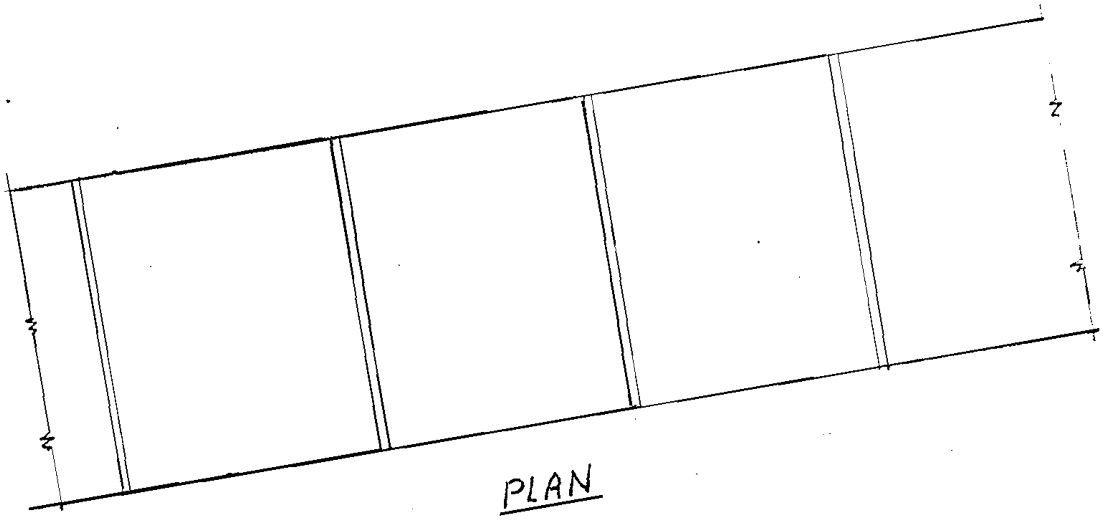
13. Gauley, J., "Effect of Water Velocity on Salmonids in a Transportation Channel," Fisheries Bulletin: Vol. 66, No. 1, Bureau of Commercial Fisheries, March, 1966.

14. Weaver, C., "Progress Report No. 137", Fisheries--Engineering Research Laboratory at Bonneville Dam, U.S. Fish and Wildlife Service, U.S. Department of the Interior, December, 1966.

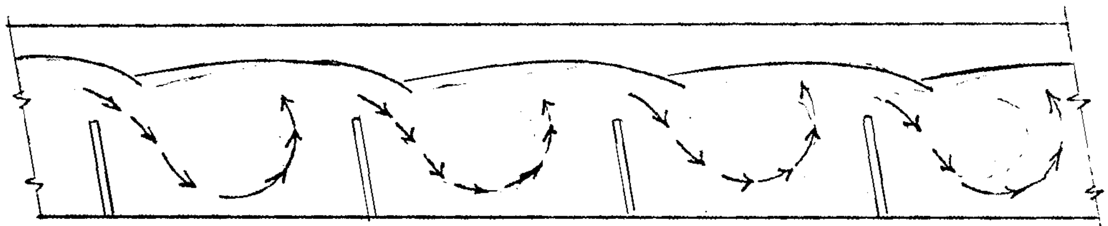
15. Ziemer, G., "Steeppass Fishway Development and Addenda to Information Leaflet No. 12," Information Leaflet No. 12, Alaska Department of Fish and Game, Juneau, Alaska, 1962.

16. Clay, C. H., "Design of Fishways and Other Fish Facilities", Ottawa, Canada, Department of Fisheries, Canada, 1961.

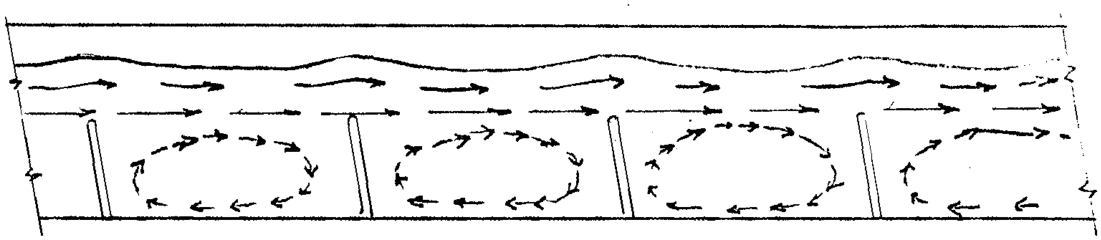
APPENDIX



PLAN



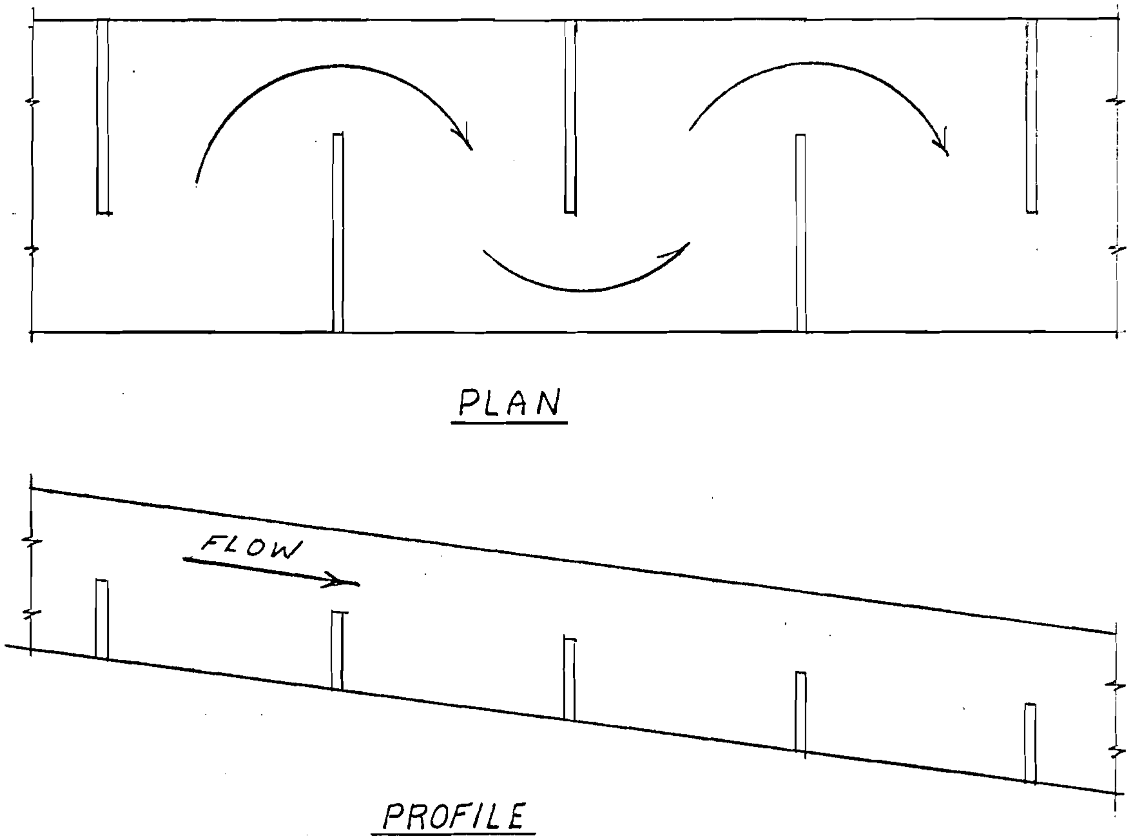
PLUNGING FLOW IN PROFILE



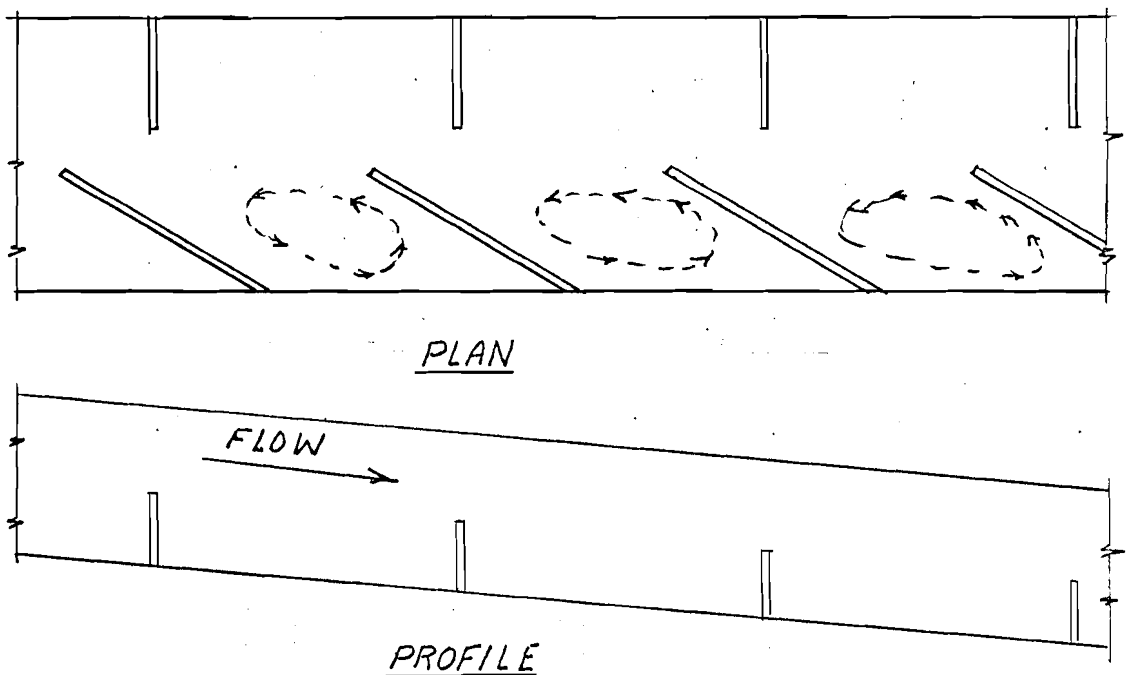
STREAMING FLOW IN PROFILE

FIG. 1

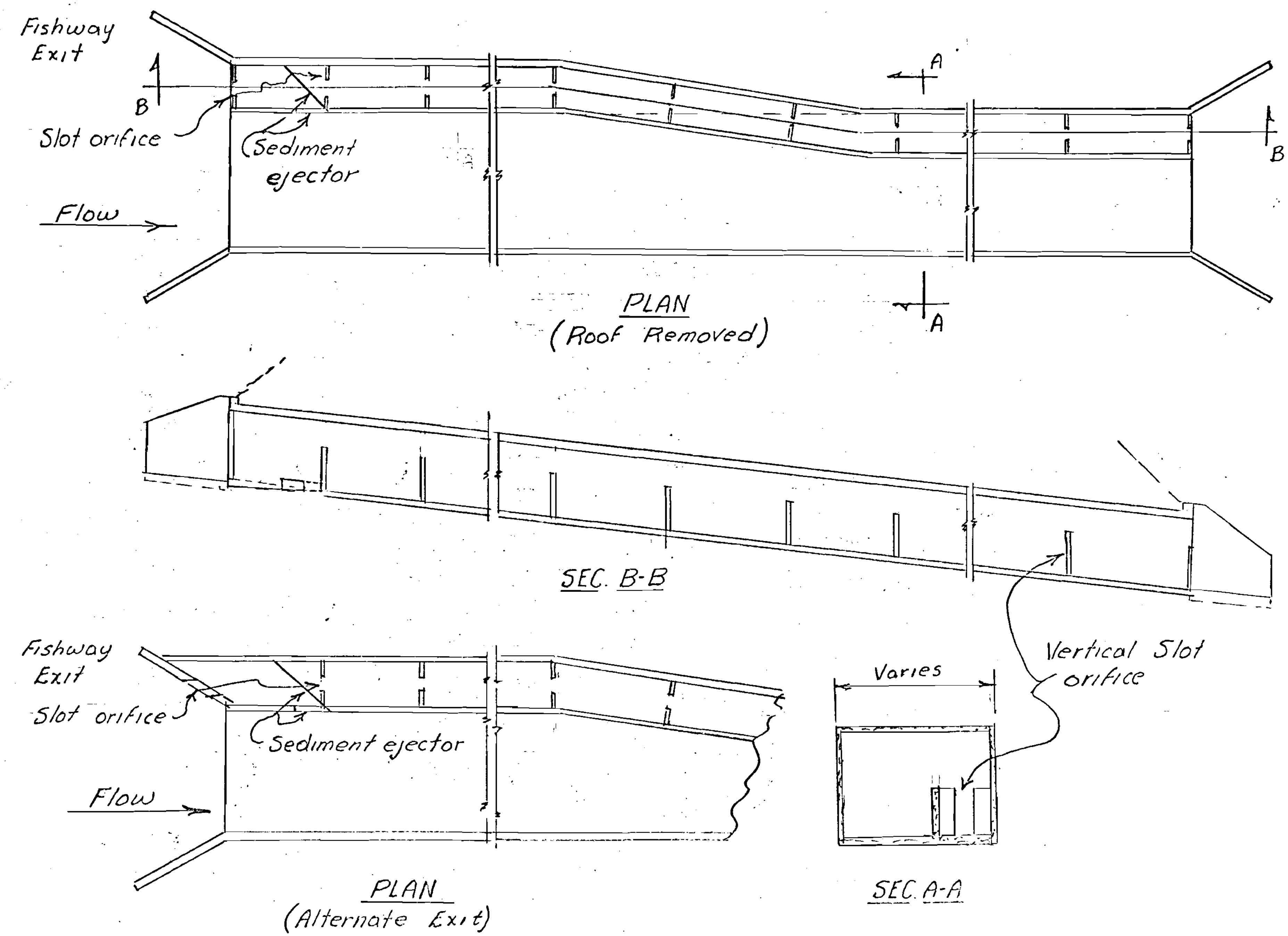
POOL AND WEIR FISHWAY



ALTERNATE PAIRED BAFFLE SPILLWAY — FIG. 2



OFFSET BAFFLE SPILLWAY — FIG. 3



BOX CULVERT WITH VERTICAL SLOT ORIFICE FISHWAY

FIG. 4

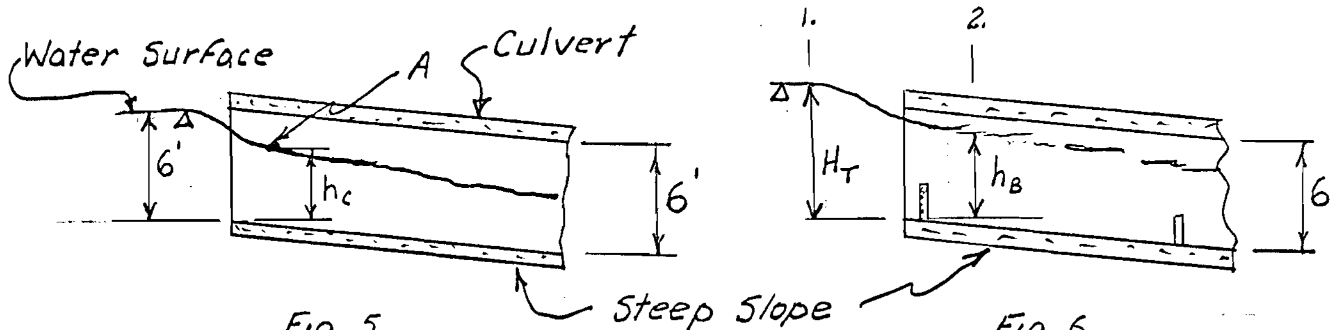


Fig. 5

Fig. 6

℄ SECTION

1. Assume flow passes through Critical Depth at point A, Fig. 5.
2. Given: Allowable depth of headwater is 6'.
3. Compute approximate discharge per foot of culvert width for culvert without baffle.

$h_c = 2/3 \times 6' = \underline{\underline{4'}}$; V = Velocity @ point A $= \sqrt{g\,h_c} = \sqrt{32.2 \times 4} = \underline{\underline{11.4 \text{ fps}}}$

q = discharge per ft of barrel width $= h_c \times V = (4)(11.4) = \underline{\underline{45.6 \text{ cfs}}}$

4. For culvert barrel with 1' baffle, efficiency = 69%, 30% loss of Kinetic energy at the culvert entrance due to high level of turbulence created by baffle; compute the Headwater depth (H_T Fig. 6) necessary to drive 45.6 cfs through the culvert.

Total energy at Sec 1. = Total energy at Sec 2. ~ Fig 6.

$H = h_B + \left(\frac{8}{h_B - 1}\right)^2 \frac{1}{2g} \times 1.3$; $\frac{h_c}{h_B} = 0.69$, $h_B = \frac{4.0'}{0.69} = 5.8'$,

$\therefore H = 5.8 + \left(\frac{45.6}{4.8}\right)^2 \frac{1}{64.4}(1.3) = \underline{\underline{7.6 \text{ ft}}}$

Thus, the headwater necessary to drive the flow through the culvert is about 27% greater.

Sample Computation.