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PROJECT COMPLETION REPORT ON FLUID MECHANICS OF DOWNSTREAM FISH PASSAGE STRUCTURES

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ABSTRACT

The hydraulic characteristics of flow over an inclined, porous plane of a type used as a fish passage facility, and the hydraulic indices of guidance stimuli associated with a converging channel were studied as two phases of the downstream fish passage problem.

In the first phase, an analytical method, augmented by experimental data, was developed for predicting the key hydraulic features, discharge, length, velocity, etc., of the flow over the plate, given an initial flow rate and plate inclination and porosity. Experimental data covered a range in porosity from 0.2 to 0.33, two types of openings, and positive plate angles up to 15°. Results were obtained for the supercritical case only, since the subcritical one is unimportant.

In the second phase, a set of experiments concerning the behavior of fish to flow conditions caused by a channel convergence were reproduced as hydraulic experiments. Open-channel methods were applied with experimental results to define some limiting indices of guidance stimuli. Wedges of about 7° placed with a relative spacing of 0.5 had shown positive guidance effects; those of about 3° showed none. A hydraulic index (acceleration, pressure or velocity change) for the large angle was about seven times that for the smaller angle. For the 7° wedges, it is predicted that an increase in the relative spacing from 0.5 to 0.8 would eliminate any guidance effect.

Key words: *open-channel flow, *fish guidance, spatially varied flow

INTRODUCTION

The integrated development of the rivers harboring anadromous fish often requires the resolution of methods to bypass the migrants around the hydraulic structures needed for river control. A system usually has to be designed as an individual problem to meet the conditions at each site. The designers, specialists in fisheries and in hydraulic engineering, must draw heavily from the records of both successful and unsuccessful installations, yet the reasons often are not clear why one installation has worked well while another has been less successful. Therefore, the objective was formulated to evaluate, in numerical terms, hydraulic parameters which might be reliable indices of stimuli in the flow of water to which fish respond. If this evaluation could be accomplished, then the hydraulioian would have a firmer set of principles to apply to new designs and to use in explaining some of the guidance patterns observed under field conditions.

A two-part program was proposed to (1) reduce some field structures known to present special fish passage situations down to laboratory scale for measurement and analysis and (2) to carry out with the cooperation of one of the fisheries agencies tests with fish under conditions which would simulate those under purely hydraulic study.

At the time (1965) the first part of the program was to be implemented, possible methods of handling migrant fish at a new, major hydroelectric plant were being studied. One of the methods under consideration would have involved the use of an inclined, porous plate of unusual dimensions, so the basic hydraulics of the application were examined with the idea of optimizing the extension to the very large application that would have been needed. Other schemes were to have been studied similarly, but the interest and urgency for such studies waned when the plans emerged for eliminating the fish passing facilities at the site, so the program effort was shifted to the second part, that dealing with the hydraulic indices of guidance stimuli.

FLOW OVER A POROUS, INCLINED PLATE

The inclined plane screen has been used in small installations quite successfully and frequently for concentrating migrant fish into a reduced water volume. For the small installations, very little design information is needed to develop a workable plan, since field adjustments can be made to develop good performance characteristics.

For a large installation, a prediction of the hydraulic characteristics is required to develop an economical design and to insure satisfactory field performance with a minimum of adjustment. To meet this requirement, an analysis was developed and augmented with data from an experimental program, reported in full in the thesis by Murphy (1965).

The analysis based on either an energy or a momentum method leads to a non-linear differential equation descriptive of the water surface slope, but no general solutions for it can be obtained. Solutions of the equation by iterative procedures were not successful, because of difficulties in prescribing initial conditions with suitable certainty. Perhaps, also, the streamline curvature, not accounted for in the analysis, is relatively important at the very beginning of the plate.

A suitable step-wise solution was obtained, however, by returning to a constant-energy assumption and using some experimental data to evaluate discharge coefficients and brink-depth relationships. The experiments were conducted in a channel designed as an extension to a flume one foot wide. Provisions were incorporated into the design so that the channel slope and length, the porosity of the bottom, and type of bottom openings could be changed to cover the range of variables which might be encountered in field conditions. The channel bottom was made of flat bars with their long axes normal to the flow direction; porosity was adjusted by changing the bar spacing. The geometric condition of varying plate porosity with distance along the channel was not included. The discharge through the porous bottom was measured incrementally along its length by isolating the flow from each slit-like opening. Measurements for gross flow rate, velocities, and water surface profiles were quite conventional. Experiments were conducted for a combination of variables of Froude Number between 1 and 3, plate porosities of 0.20, 0.26, and 0.33, square and rounded openings, and plate angles of 0°, 5°, 10° and 15°.

In conclusion, it was found that the simplified analysis should provide a satisfactory basis for the design of large-scale installations within the range of the experimental variables covered. After selecting a slope, porosity and the geometry of the openings, the solution method allows the prediction for each flow rate first of the plate length and flow profile and then the mean velocity distributions and withdrawal rates.

Certain practical considerations enter the design steps. For a given geometry, there is a different profile for each flow rate, so that, to meet cases of time-varying flow rates, adjustments may have to be made in plate slope or effective porosity. A plate angle of about 5° appears to be the angle optimizing hydraulic features and length of section. Steeper angles allow a reduction in plate length for a given degree of flow concentration, but since the initial flow is likely to be supercritical, the flow tends to become unstable and therefore difficult to either predict or to control.

Allusions can be made regarding regions or conditions which might create hazards to the migrants. For example, if the rate of withdrawal is too great in any section, the pressure difference across the openings may lead to the trapping of fish. Field observations have shown the first few feet of screen to be critical in this respect. The actual limiting hydraulic conditions will have to be determined through tests with live fish.

HYDRAULIC INDICES OF FISH GUIDANCE STIMULI

A structure engineered as a component of a water resource development to control some hydraulic feature of a stream, river or lake often imposes extra hazards to a population of anadromous fish supported by the waterway. The complete development of the water resource requires that these hazards be reduced to a level which will permit the fishery to be maintained and even increased.

A few basic methods, with many variations, have been used in the designs for fish passage facilities. Each site usually requires special tailoring to suit special conditions, but unfortunately, the special conditions are not always definable. There are cases where the performance of a new facility has been disappointing even though its design was based upon a very successful unit. It is natural that the successful systems may not get the scrutiny that unsuccessful ones receive, so that just why they have worked well may not be completely understood.

An objective of the project covered by this report was to add to the meager list of hydraulic conditions known to be either attractive or repulsive to the small (downstream) migrants. The project aimed to bring the views and field experiences of the fisheries biologist into confluence with analytical methods and experimental techniques of the hydraulician to see if some of the "special site conditions" could be understood, anticipated, or created to improve the systems of guiding downstream migrants.

What senses the fish uses for guidance is still something of an uncertainty. In addition to those for sight and sound there seems to be the facility of detecting a velocity difference, or small pressure difference, or a turbulence or noise level, for fish may enter some accelerating flow regions only under a stress like fright or fatigue. Such regions of acceleration seem to provide a guidance effect, but rather than try to assist the biologist in ascertaining what senses, or combination of senses, the fish may use as a detector of favorable and unfavorable flows, the approach is to try to define some hydraulic parameters which may be indices of conditions to which the fish respond, even though the reasons for the response remains unknown.

Fish can be expected to "hang-up" in the relatively low-velocity regions upstream of abrupt changes in flow sections as encountered ahead of weirs and orifices; often they will hug the sides or bottoms of a channel. One guidance structure, the louver, provides a gradual increase in average velocity and a reduction in area in the flow direction. The most critical region of the louver is that near its terminus where its guidance effect tends to break down if the hydraulic conditions are not right. These few field cases serve as typical examples of guidance problems, but studying them in detail under field dimensions and complexities is difficult.

Fortunately, some experiments had been performed in a fisheries behavorial laboratory to check the reaction of fish to a flow pattern developed by wedges in a channel. Fish introduced into the channel upstream of the wedges tended to stay upstream of those wedges with subtended angles of about 7°, but paid little heed to those with angles of about 3°. Guidance effects tended to disappear with increased transverse spacing of the wedges. Even fish blinded to eliminate any guidance on visual references responded to the wedges in about the same way as the unblinded fish.

These environmental experiments seemed to localize a clean-cut hydraulic condition that (1) provided some guidance effect and (2) could be duplicated in a hydraulic laboratory where better measurements could be obtained than were possible in the environmental setting.

Abiodun (1966) proceeded to study the hydraulics of the wedges by analysis and through an experimental program to bracket those configurations which had shown the most pronounced stimulus, or absence thereof, in the behavioral experiments. Wedge angle and relative spacing were the main geometric variables covered. Measurements of water surface, pressure and velocity profiles were taken for the range of wedge angles (2.6° to 7.1°) covered in the behavioral studies. The analysis of the problem came into good agreement, except near the end of the wedges, with the experimental values. At this stage consideration was given to trying to measure turbulence or noise levels, but the expected problems in instrumentation and coordination of behavioral tests put the pursuit of this facet beyond the scope of the current study.

The study results point out the obvious conclusion that it should not matter from a hydraulic viewpoint whether one considers that the fish sense pressure change, velocity change, or acceleration. It would be contradictory on physical grounds to attempt to set up an experiment with flowing water to test fish response to these variables one at a time. For the relative spacing of wedges corresponding to that used in the behavioral experiments (b/B=0.5), a hydraulic index (acceleration, for example) averaged about seven times larger for the wedge angle of 7.1° than for the one with an angle of 2.6°. The former had provided a strong guidance effect in the behavioral experiment, the latter none. For the wedge angle of 7.1°, the guidance effect would be lost by increasing the relative spacing to b/B=0.8. The behavioral studies had shown a reduction in guidance effects at the wider spacings, but the data were not sufficiently extensive to allow more than a qualitative conclusion.

For the work following that by Abiodun, it was planned initially that (1) there would be a refinement made in the guidance limits by more extensive behavorial studies and (2) some additional field cases identified in terms of the proposed guidance indices. As the final project year actually unfolded, the effort was dedicated to a more thorough investigation (Chang, 1967) of the hydraulic behavior of the converging flow wedge guidance configurations. Data collected during the preceding experiments had cast a shadow on the validity of using the assumption of constant specific energy throughout the entire length of such a structure. Since it had been indicated by fisheries biologists that this configuration was one of primary concern, the assumption of constant specific energy was investigated in detail. Tests were made of various flows at various wedge aspect ratios, and it was determined that this assumption is valid under those conditions where the converging wedge structure provides the control of the channel flow.

A second problem was studied in conjunction with this type of structure, namely, the geometry of the wedges which would produce a control in the structure. The dimensionless parameters of upstream width to downstream width ratio, the wedge angle and the Froude number of the approach flow were varied and the combination of these variables which will furnish wedge-control have been correlated and tabulated. The practical result of this latter investigation will be to provide a means for designers to determine the rate at which sidewalls may be permitted to converge and the minimum width to which the channel may be contracted before the channel control shifts to the convergent section from some other location. Conversely, it will permit a determination of those conditions whereby the control is deliberately placed within the wedge structure.

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