BIOLOGICAL ENGINEERING INVESTIGATION OF ANGLED FLUSH FISH DIVERSION SCREENS

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The design of cooling water intakes for the protection of aquatic organisms has become an important issue in the licensing of power plants. As a result, several utilities have undertaken research and development programs to investigate the potential biological effectiveness and engineering practicability of a wide variety of fish protective systems. Although numerous fish guidance, deterrent, and collection devices have been suggested for application at power plant intakes and appear to be potentially effective, they are largely untested and many have serious engineering design, operational and maintenance problems which limit their practicability. The state-of-the-art in fish protection is, therefore, presently limited to a relatively small number of systems which can be operated in a cost-effective manner.

This paper discusses the development of angled, flush-mounted, traveling screens which can be used to divert fish to bypasses within power plant intake screenwells. Although angled screens have not been utilized at power plants, they have been shown to be effective at hydroelectric facilities. To ensure that such a concept would function effectively, the development work was conducted in three phases.

First, an extensive literature review and engineering design evaluation was conducted to determine the effectiveness of previously evaluated facilities and to identify all engineering considerations which would influence the practicability of utilizing angled screens in a power plant intake. Second, 4 years of laboratory physical model studies with live fish were carried out to develop and optimize the design of the screen within the constraints imposed for power plant application. Finally, utilizing information obtained from the first two phases, design criteria for effective application were established and the angled screen fish diversion system was incorporated into two power plant screenwells. A further description of each phase of the study program is given below.

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BACKGROUND

Angled screens have been utilized at several hydroelectric facilities for guiding upstream and downstream migrants. At the North Fork Project on the Clackamas River in Oregon, angled traveling screens are installed at two locations along a 2-mile-long fish ladder (1). Downstream migrants, primarily chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon, and steelhead trout (Salmo gairdneri), approach the fish ladder via a downstream migrant channel and are diverted into the ladder by a set of screens angled 22 degrees to the flow. The two traveling screens (0.14-inch mesh, 16-gauge wire cloth) are each 11 feet wide and are set in tandem with a 2-foot center pier between them.

The second angled traveling screen installation is located within the fish ladder 2 miles downstream of the ladder entrance. This single screen is 7 feet wide and is set at a 45-degree angle to the flow. The structure is utilized to separate downstream migrants from the ladder flow for subsequent introduction to a 5-mile-long pipeline which carries them to a discharge point below the last dam in the complex. Both angled screen installations at the North Fork Project have been operating effectively for over 15 years.

At the Mayfield Dam on the Cowlitz River in Washington, extensive research has been conducted on guiding downstream migrants with louvers (4). Results showed that the louvers, spaced 2.25 inches apart and leading to an 8-inch-wide bypass, did not function satisfactorily. However, when the louvers were completely covered by 3/8-inch woven wire screens, fish were successfully bypassed without noticeable impingement.

The only evaluation of angled screens for possible power plant application was conducted for the Southern California Edison San Onofre Station (2, 3). Angled screens were not installed at this site since guidance efficiencies were low (0 to 70 percent) for the northern anchovy (Engraulis mordax), a primary test species. However, moderate-to-good guidance (60 to 90 percent) of other species was obtained with a screen set at 45 degrees to the flow, an approach velocity of 2 fps, and a bypass velocity of 1.5 to 4.0 fps. This was also the best setting for anchovies, which were guided with 30 to 70 percent efficiency.

The results of the above studies indicated that angled screens could be effective in diverting certain species given the proper design and hydraulic conditions. Therefore, Stone & Webster carried out an engineering evaluation in order to develop practical design criteria which could be evaluated in the laboratory. Engineering considerations relative to prototype application included the practicability of construction, the ability to achieve the desired hydraulic conditions in a cost-effective manner, the potential for clogging of the selected 6-inch-wide bypass, and the potential for developing a transportation system for returning bypassed fish to their natural environment.

On the basis of the engineering evaluation and past applications, a laboratory study program was initiated to develop the angled screen concept for application at selected sites. One study was conducted for Niagara Mohawk Power Corporation (NMPC) and Rochester Gas & Electric Corporation (RG&E) to determine the potential effectiveness of the angled screen in diverting alewives (Alosa pseudoharengus) and smelt (Osmerus mordax) within Lake Ontario power plant screenwells. A separate, but similar, study was conducted for Consolidated Edison Company of New York, Inc. (Con Edison) to develop the concept for diverting striped bass (Morone saxatilis), white perch (M. americana) and Atlantic tomcod (Microgadus tomcod) at intakes on the Hudson River. These studies are described below.

LABORATORY STUDIES

The laboratory studies were conducted by Stone & Webster in conjunction with the Alden Research Laboratories in Holden, Massachusetts. Essentially the same approach was taken in developing the angled screen for the three utilities. During the 4 years of development, three experimental flumes were utilized to evaluate the screen over a wide range of environmental and engineering conditions. Variables investigated included test species, temperature, approach and bypass velocity, light conditions, and the mortality associated with diversion. A summary of the physical and biological parameters investigated in each test flume is given in Table 1.

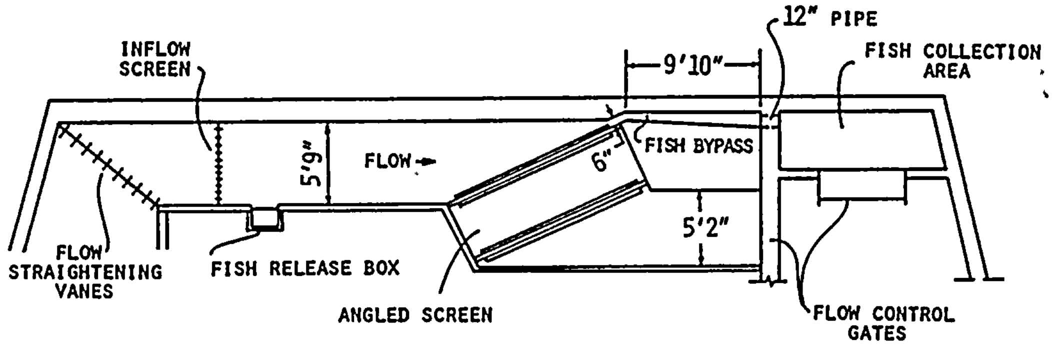
Table 1.
Physical and Biological Parameters
Investigated in Each Test Flume

Test Parameters	NMPC 3-Foot Flume	NMPC/RG&E 6-Foot Flume	Con Edison 6-Foot Flume
Test Species and Temperature (°F) Range	Alewife; 78-49 Smelt; 37-36	Alewife; 82-39	Striped bass; 77-35 White perch; 77-52 Tomcod; 36-35
Approach Velocities, fps	1.0	0.5,0.8,1.0,1.5,2.0,3.0	0.5,1.0,1.5,2.0,2.5,3.0
Bypass Velocities, fps	1.4	0.5,0.8,1.0,1.5,2.0,3.0	0.5,1.0,1.5,2.0,2.5,3.0
One week mortality studies	No	Yes	Yes
Number of tests	7	36	32
Screen mesh	1/4 in., 14 gauge	3/8 in., 11 gauge	3/8 in., 11 gauge
Flume dimensions (WxDxL), ft	3 x 3 x 70	6 x 6 x 40	6 x 7 x 80
Flume flow capacity, cfs	12	130	110

Each test consisted of placing from 100 to 2,000 fish in a test flume under the desired conditions and allowing them to react naturally. After being diverted, the fish were removed from a bypass collection area and held for up to one week for observations of latent mortality. A separate control group was held for comparison. In this way, differential (test minus control) mortalities were determined.

Initial studies for NMPC were conducted in a flume, 3 feet deep by 3 feet wide by 70 feet long and were designed to obtain a preliminary indication of the effectiveness of a 25-degree, angled screen in diverting alewives and smelt to a 6-inch-wide bypass. In 7 tests with over 2,000 fish, diversion efficiencies for both species was nearly 100 percent. Therefore, it was decided to conduct a further evaluation of the concept with alewives in a large-scale flume in which all of the details of a prototype screen could be closely simulated.

The large-scale flume was approximately 6 feet wide, 6 feet deep, and 40 feet long and incorporated a 12-foot-long angled screen (Fig 1) leading to a 6-inch-wide bypass. Simultaneously, a third flume with similar dimensions (Table 1) was constructed for Con Edison to determine the potential of the angled screen concept for effectively diverting Hudson River species.



PLAN VIEW

Figure 1. Angled Screen Model

Results of testing in both large-scale flumes were similar. In most cases, the 25-degree angled screen was found to be 100-percent effective in diverting all test species (alewife, white perch, striped bass, and tomcod) to a 6-inch-wide bypass under all test conditions (Table 1). The results of latent mortality studies showed a mean differential mortality and 95-percent confidence limits of 35.7 ± 13.5 percent for alewives (25 tests) and 3.3 ± 2.5 percent for Hudson River species (32 tests).

The relatively high mortality observed among alewives was assumed to be largely attributable to the difficulty in handling this fragile species in the model facility. This assumption was verified in later studies in which the angled screen bypass was connected to a fish transportation system. The system consisted of a 180-foot-long, 10-inch-diameter pipe and 12-inch-diameter jet pump which discharged into a large stilling basin where mortality could be observed without handling. Since the pipe and jet pump

were tested at velocities up to 9 and 50 fps, respectively, it would be assumed that mortalities in the system would be higher than those observed in studies with the angled screen alone, due to the additional stresses imposed.

However, the results of 11 tests in the combined angled screen and fish transportation system model showed mean test and control mortalities of 11.8 and 7.8 percent, respectively, resulting in a mean differential mortality of only 4 percent. Therefore, this value is considered to be a better estimate of the most probable mortality which might be expected to occur in a prototype angled screen application.

In conjunction with the biological testing, hydraulic and trash testing were also conducted. The hydraulic testing consisted of velocity distribution measurements to ensure uniform flow distributions at the approach section, along the screen face, and at the bypass; and streamline visualization studies to document the flow patterns at various depths as they approach and exit the screen.

Fig 2 shows the streamlines with approach velocities of 1 fps and the screen angled at 25 degrees. The flow approaches the screen uniformly and does not turn into the screen prematurely. Therefore, optimal conditions for fish guidance were achieved. The flow streamlines within the screen are almost perpendicular to the screen, which will result in a normal thrust force on the prototype

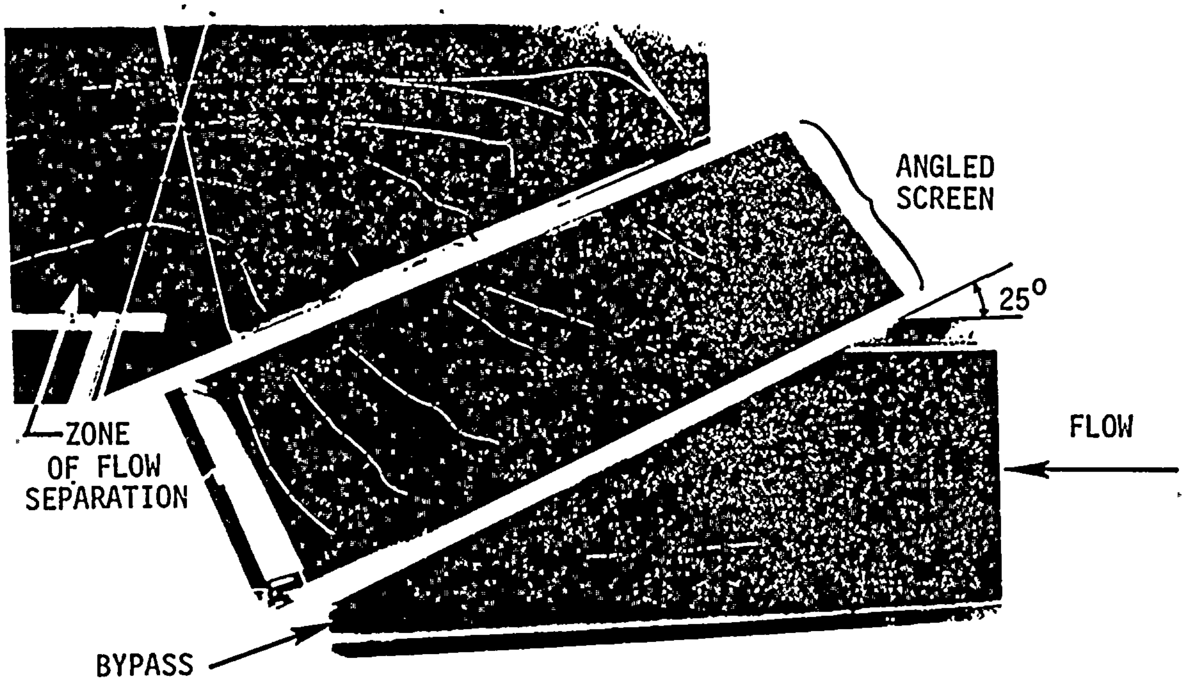


Figure 2. Streamlines Through an Angled Screen

screen. A zone of separation is created downstream of the screen. The effect of this eddy on pump performance should be considered in a prototype installation. Adverse effects of flow disturbances can be minimized by locating a vertical wet pit pump further downstream from an angled screen than for a conventional through-flow screen, incorporating baffles to streamline the flow, or selecting dry pit or horizontal pumps which are less sensitive to flow disturbances than wet pit pumps.

Tests were also conducted to study the distribution of trash on the screen and to determine the percentage of trash entering the bypass. Three tests with approach and bypass velocities of about 1.0 and 0.5 fps were performed. Test results indicated that the distribution of trash between the screen and the bypass follows the distribution of flow. The majority of the trash became lodged on the screen face at the point of initial contact.

Considering the high diversion efficiencies and low resultant mortalities obtained with the angled screen in the laboratory, NMPC requested Stone & Webster to design full-scale angled screen and fish transportation systems for two new power plant intakes on Lake Ontario, as discussed below.

PROTOTYPE ANGLED SCREEN APPLICATION

Fig 3 shows an actual screenwell arrangement incorporating angled flush-mounted traveling screens which will be utilized for a once-through cooling system screenwell on Lake Ontario. Fish entering the screenwell will pass through trash racks and be guided by angled screens into a 6-inch-wide bypass. The screens will be angled at 25 degrees to the direction of flow. The approach velocity will be approximately 1.0 fps, resulting in a 0.5 fps velocity at the screen face. The screen mesh openings are 3/8-inch with No. 12 gauge wire cloth. The angled flush screens are essentially a modification of conventional through-flow screens. The modification involves setting the individual screen baskets flush in the vertical plane and eliminating the end seal plates on each side of the screen (Fig 4) to form a flush surface with the concrete piers and the bypass. In order to prevent debris from passing under and around the foot shaft of the screen, a condition which might result in jamming due to the absence of the seal plates, the boot section is further modified by the addition of a hinged metal deflector at the top of the boot loading leg to seal the boot area. The screen will be operated intermittently for debris removal.

The bypass flow is designed such that the ratio of the screenwell approach velocity to the bypass entrance velocity is 1:1, a condition which yielded high diversion efficiencies in the laboratory. A jet pump provides the energy to induce the required bypass flow and to return the fish back to the lake.

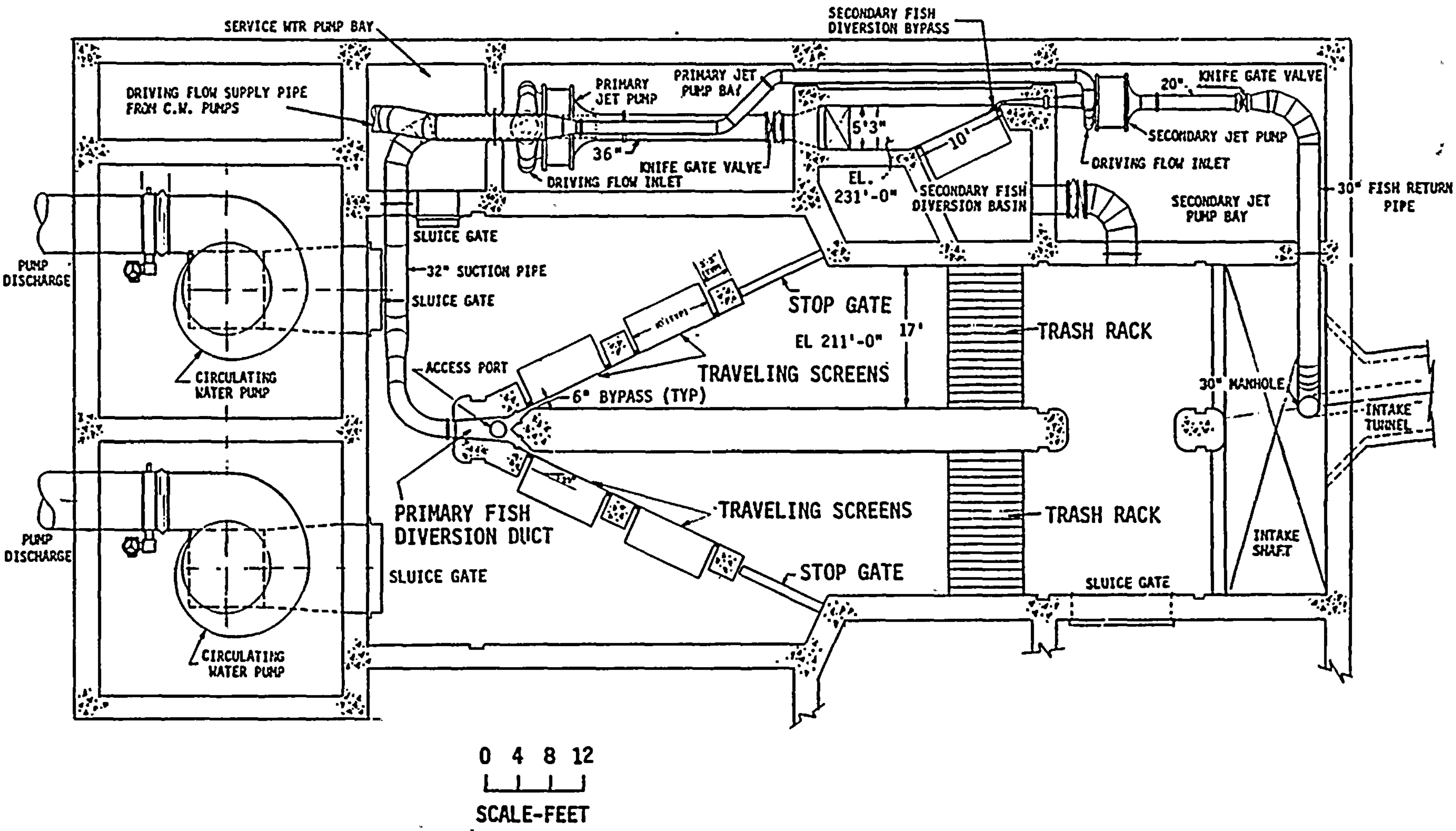


FIGURE 6. PROTOTYPE APPLICATION OF ANGLED FLUSH SCREEN

A single jet pump is adequate for transporting fish where total head losses do not exceed 7 feet. For the installation shown in Fig 3, greater lift will be required. Therefore, a secondary angled screen and jet pump will be incorporated, both to achieve the additional lift and to concentrate the fish into a smaller flow for return to the lake.

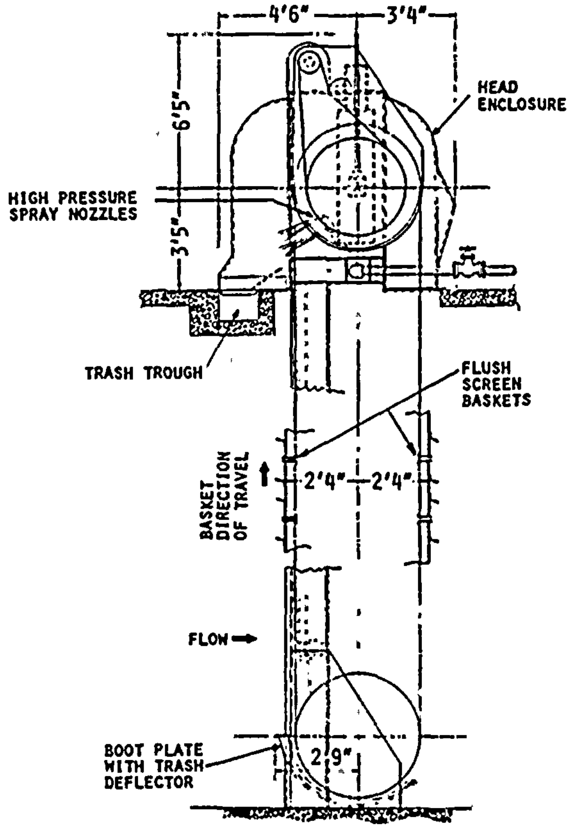


Figure 4. Side Elevation of Flush-Mounted Traveling Screen

On the basis of the development efforts conducted by Stone & Webster, it appears that the angled, flush-mounted traveling screen concept may have the potential for diverting fish at other selected power plant intakes.

ACKNOWLEDGEMENTS

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APPENDIX I. - REFERENCES

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