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by

Yusuf G. Mussalli

and

Edward P. Taft, III

Stone & Webster

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By Yusuf G. Mussalli,[1] M. ASCE, and Edward P. Taft III[2]

As a result of present regulatory requirements for the protection of fish at cooling water intakes, several power plant intakes are being designed to incorporate fish protection facilities and transportation systems to return live fish to their natural environment. Fish protection can be based in principle on three different concepts: fish collection and removal, fish diversion, and fish deterrence. The first two concepts require systems to return collected or diverted fish from circulating water systems to their natural environment. The third concept involves exclusion of fish prior to entering an intake.

FISH COLLECTION AND REMOVAL CONCEPT

This concept involves modifying traveling water screens such that fish that are impinged against them can be removed quickly with minimal stress and mortality. Screen modifications involve bolting buckets on the trash lips of the screen baskets. The buckets should be capable of maintaining a minimum water depth of 2 inches during screen rotation. This arrangement prevents fish from flipping off the screen and becoming reimpinged and also ensures that the fish are maintained in water as they are lifted to the point of release. Fish are washed off with a low pressure spray (20-30 psi) into a fish trough. Debris is washed off with a high pressure (80-100 psi) jet into a separate trash trough. U.S. manufacturers of through-flow screens presently offer both a front-wash and a back-wash system, as shown in Figure 1. For through-flow screens with buckets and center-flow and dual-flow screens, which can also be fitted with buckets, the fish discharge into the trough and are returned to their natural environment by gravity via a sluiceway and/or a pipeline.

Sluiceway and pipeline designs will vary according to the size and type of fish being transported. In general, however, they should be designed to maintain a water depth which will allow free movement of fish without abrasion on the sides or bottom. At the Surry Power Station, a 20 inch wide, 34 inch deep, U-shaped fiberglass trough is used to transport fish collected from the modified traveling screens in a water depth of approximately 1-foot. This arrangement has been functioning effectively for over 2 years (10). Velocities should be high enough to transport the fish without potential for resistance to the flow, but not so high as to cause complete dis-

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[1]Consultant, Environmental Engineering Division, Stone & Webster Engineering Corporation, Boston, Massachusetts

[2]Ecologist, Environmental Engineering Division, Stone & Webster Engineering Corporation, Boston, Massachusetts

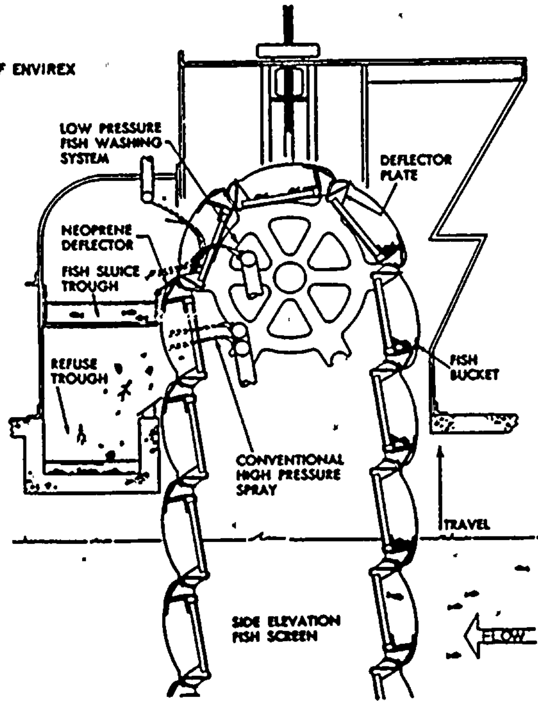


Figure 1. Fish Screen With Buckets

orientation. At many existing stations, impinged fish are on the order of 1 to 6 inches long, and transport velocities of from 2 to 4 fps should be adequate. Sluiceways and pipelines should be constructed of smooth material to prevent injury due to abrasion. In brackish and salt water installations, consideration should be given to preventing the establishment of fouling organisms, such as barnacles and mussels, which could restrict flows and damage fish. Where practical, all bends should be of the long-radius type ($r/d \geq 2.5$) such that fish are not forced to abrade on the sides in these areas. Pipe joints should be constructed carefully so that they are even and do not create jagged obstructions. Valves, flowmeters, etc., if required, should also be designed to create as little obstruction to the flow as possible. Transitions from smaller to larger pipes, or vice versa, should be gradual so that rapid velocity changes do not occur. Where it is necessary to combine flows from several pipes, the pipes should be carefully manifolded to minimize abrupt transitions. Finally, in northern latitudes, above-ground sluiceways or pipes should be protected from freezing and buried pipes should be located below the frost depth.

FISH DIVERSION CONCEPT

This concept consists of louvers or flush-mounted traveling screens set in an array which is angled to the approach flow and leads to a bypass. Such an arrangement creates an area of turbulence along the louver or screen face which fish avoid. This avoidance response, in conjunction with a downstream flow component, eventually directs fish to the bypass.

The fish return system consists of the bypass, a transition section, a pipeline, and an adequate pumping unit to induce flow into the bypass and to discharge the fish back to their natural water body. Each element of the system is discussed individually below.

BYPASS

Bypasses should be designed such that uniform velocity distributions are established. Obstructions and rapid accelerations or decelerations in flow are undesirable since they may elicit an avoidance response by fish. The width of the bypass should be determined on the basis of the size of the fish to be handled, the amount of debris present, and the amount of flow which is available at a given design velocity. At various installations, bypasses have been designed to range from 6 inches to 3.0 feet. The 6 inch bypass will be used in conjunction with a jet pump at two power plants where fish range from 2 to 6 inches in length, debris loading is light, and all the bypass flow must be returned to the source water body with the fish (8). The 3.0 foot bypass will be used in conjunction with a lift basket in an area of heavy debris loading where water conservation is not a problem since the bypass flow is screened and returned to the circulating water system for cooling purposes (3).

At certain sites, bypasses must connect to a pipe to allow for the transport of fish back to their natural environment. Therefore, a transition section is required to channel the flow from the full-depth bypass into the pipe. Any such transition should be gradual so that the acceleration of flow is gradual and the suction flow does not create a skewed velocity distribution at the bypass opening. Past studies have shown that a transition angle of 45 degrees is acceptable (9).

PUMPING UNIT

Peripheral-type jet pumps, non-clog centrifugal pumps, and lift baskets have been used or have been incorporated into the design of fish return systems at power plants. Air lift pumps and screw pumps have been used to pump fish for special applications. Each is described separately below.

1) Jet Pumps

A jet pump operates by the transfer of energy from a high velocity jet to one of lower velocity. As shown in Figure 2, there are two basic types of jet pumps; the core type, in which the driving jet or jets are discharged centrally into the suction flow, and the peripheral type, in which the driving jet surrounds the suction flow. Major elements of these types of pumps are the driving flow nozzle, the suction flow nozzle, and the mixing tube.

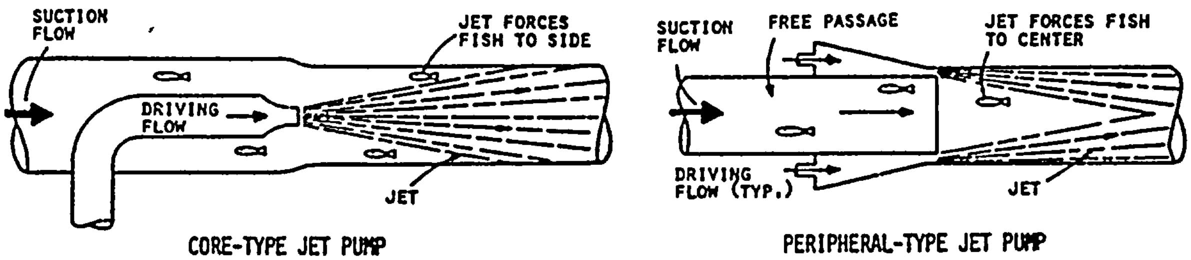


Figure 2. Types of Jet Pumps

The peripheral type pump appears to have a lower potential for damaging fish because of its non-obstructed suction flow path and its tendency to force fish to the center of the mixing tube, thereby minimizing the possibility of abrasion on the sides (8).

Peripheral jet pumps have been used to transport live fish in hatcheries. Harris Thermal Products, Tualatin, Oregon, manufactured 4-inch diameter single-stage and three-stage peripheral jet pumps for use in hatchery truck loading and handling of stock. The maximum lift was 5 ft per stage. These pumps were used to transport salmonids with no initial or delayed mortality (4).

Recently a large-scale peripheral jet pump (36 inch diameter), which is capable of inducing bypass flows of up to 30 cfs, has been incorporated into the design of fish return systems in two power plants on Lake Ontario (8,9).

The pump was developed for these sites by Stone & Webster Engineering Corporation during a four year laboratory study program. The program was conducted in conjunction with the Alden Research Laboratories for Niagara Mohawk Power Corporation (8). Three different peripheral jet pump models (3.5, 4, and 12-inch diameter) were utilized to evaluate the pump hydraulically and biologically. Jet nozzle velocities of up to 60 fps were tested. The most meaningful data were obtained when the 12-inch diameter pump was tested in conjunction with an angled fish diversion screen and transport pipeline with alewives (Alosa pseudoharengus). Results showed that the combined effects of the screen, pipe, and jet pump resulted in a mean differential latent mortality (test mortality minus control mortality) of only 4 percent with jet nozzle velocities as high as 50 fps (8). These data indicate that the peripheral jet pump provides a safe and effective means for transporting fish.

The hydraulic performance characteristics of the peripheral jet pump can be expressed by the following non-dimensional parameters:

Pressure ratio, $N = \frac{P_d - P_s}{P_n - P_d}$, flow ratio, $M = \frac{Q_s}{Q_n}$, and efficiency, $\eta = NM$

where P is a total head and Q is a flow rate. Subscripts d, s, and n denote discharge, suction, and driving, respectively.

The performance characteristics have been developed analytically and verified experimentally utilizing small (4-inch diameter) and large (12-inch diameter) peripheral jet pumps (8).

Peripheral jet pumps have low hydraulic performance efficiencies (a maximum of 30%). Selection of a jet pump for fish transportation requires matching of the pertinent biological and hydraulic parameters. The driving nozzle and mixing tube velocities should be limited to velocities that would not result in fish mortality. Pumping against a total head loss of 7.0 ft is feasible with a flow ratio of about 1.0. Higher head losses would result in lower flow ratios or would require higher driving nozzle velocities.

Model E Torque-flo pump are examples. In a recessed impeller pump, a mass of water rotates with the impeller such that the impeller does not, theoretically, touch any of the solids being pumped. Recessed impeller pumps have not been used successfully as fish pumps (1).

In selecting a non-clog centrifugal pump for pumping fish, the following criteria are recommended:

a) The sphere size of the pump should be 50% greater than the body depth (back to belly) of the largest fish to be pumped,

b) the pump should operate at the point of maximum efficiency, and

c) the single-port "bladeless" pump should run at a speed not to exceed 600 rpm, and the double-port pump not to exceed 300 rpm.

At these low speeds, pumping capacities of about 3 to 6 cfs can be achieved. For power plant applications, the bypass flow can be as large as 20 to 30 cfs, thus requiring several pumps installed in parallel.

3) Lift Baskets

Lift baskets have been used frequently at hydroelectric facilities for lifting fish to trucks for transport. Only one system has been designed for removing fish from a bypass collection area within a power plant screenwell. This system is part of the louver diversion scheme presently under construction at a west coast nuclear station (3), as shown in Figure 4. The lift basket system consists of a bypass approach channel, a baffle wall, a collection area, an elevator basket, and a vertical traveling screen. Fish enter the collection area around the baffle wall which creates a quiescent

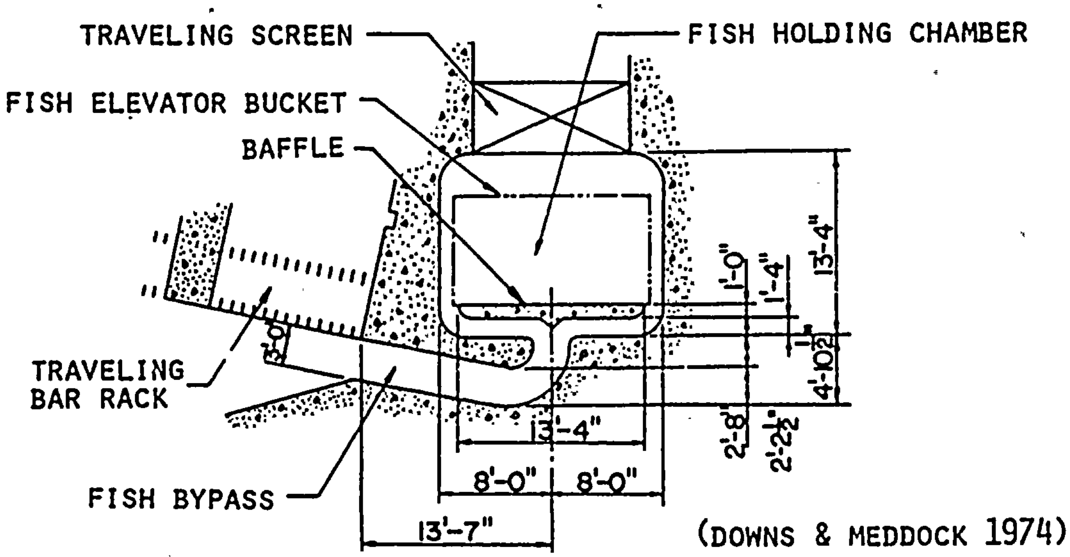
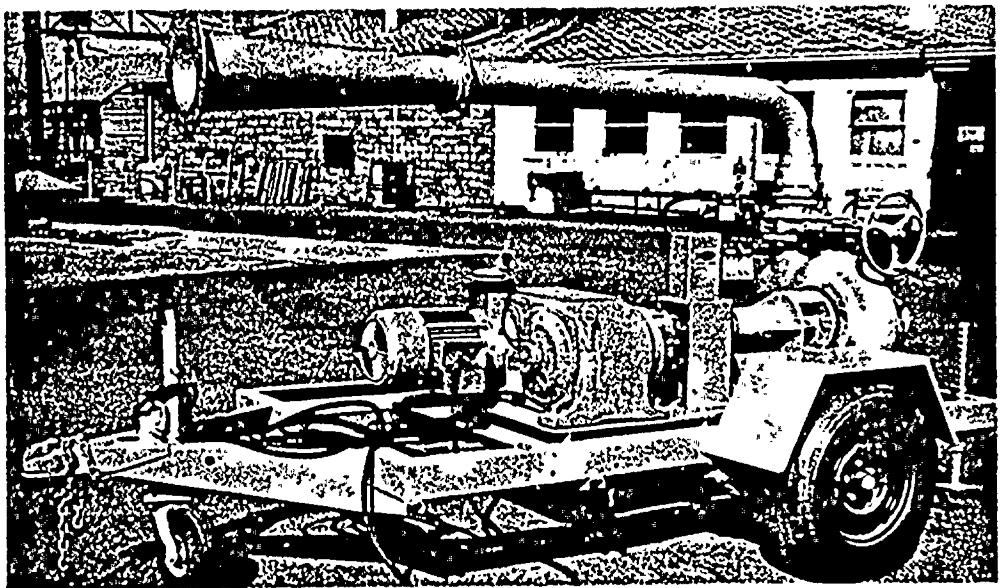


Figure 4. Lift Basket

2) Non-Clog Centrifugal Pumps

Non-clog centrifugal pumps contain impellers with large passages and a large clearance between the impeller and the cutwater. These pumps can handle relatively large entrained solids but at the cost of reduced hydraulic efficiency. Two designs are currently used for pumping of fish. One uses a single-port "bladeless" impeller. Examples of this pump are the 8 inch Fairbanks Morse Food Handling Pump and the 5 inch, 6 inch, and 10-inch fish transfer pumps manufactured by Neilsen Metal Industries, Inc. (Figure 3).



Courtesy of Neilsen Metal Industries, Inc.

Figure 3. Centrifugal Fish Pump

Kerr (5) reported fish survival rates of 77 percent and Robinson (6) reported a 2.7 percent mortality resulting from passing juvenile king salmon through the single-port pump at speeds of 550 to 900 rpm. Non-clog pumps are also available with double-port impellers up to 10 inch nominal size. Robinson (7) reported an 8.3 percent mortality rate among juvenile steelhead and rainbow trout using a double-port pump set at a speed of 600 rpm. A large power plant on Lake Michigan (2) reported 80 percent survival of fish passing through an 8 inch pump operating at speeds of 400-700 rpm. Data of Robinson's report can be extrapolated to predict zero mortality rate using the double-port pump below 300 rpm (1).

Maximum pumping performance for the single-port and the double-port non-clog pumps are as follows:

Pump	Capacity, gpm	Head, ft	Speed, rpm	Maximum Efficiency, %
10 inch single-port	2,800	33	600	71
10 inch double-port	1,500	33	300	81

A second design of centrifugal pumps uses a recessed impeller. Ingersoll Rand's type-M Cyclo-flo pump and Wemco's

area over the elevator basket. The traveling screen confines collected fish in this area and collects bypassed debris. At specified intervals, the basket is lifted mechanically and the water and fish contained therein are spilled into a sluiceway for return to their natural environment by gravity. In laboratory testing, the bypass and collection area configuration proved very effective in congregating fish over the lift basket. However, the actual lifting and sluicing procedure was not evaluated. Therefore, although it seems likely that the lift basket collection system will function effectively, it has not yet been tested in a power plant intake.

4) Air Lift Pumps

An air lift pump consists simply of a partly submerged pipe with an air bubbler at its lower end. As air is diffused into the pipe, the air/water mixture created is displaced upward due to its lower specific gravity, thereby causing water to be drawn into the pipe. Air lift pumps have proven to be relatively maintenance-free and dependable. The two most important factors in air lift pumping are the percent submergence of the air diffuser and the relative size of the air and water pipes. Generally, the hydraulic efficiency of an air lift pump (which ranges from 10 to 70 percent) is greatest when the submergence is 60 percent or more, submergence being the proportion of the length of the air line that extends below the pumping level.

Air lift pumps have not been used for transporting fish at power plants, but have been successfully utilized at hydroelectric facilities and in special applications. It would appear that an air lift pump could be designed to transport fish from collection areas in power plant screenwells or directly from a bypass pipe. In such an application, fish would be lifted to an elevation where they could be returned to their natural environment by gravity. Due to the high air content of the water at the point of discharge, deaeration would be required to prevent slug flow in the return pipeline and to avoid the possible adverse effects of supersaturation on fish.

5) Screw Pumps

Screw pumps are presently used for handling of sewage, sludge, storm and waste water and irrigation water. The pump consists of a screw operating at constant speed within an inclined trough which conveys liquid up the spiral and discharges it in a surge-free stream at a rate equal to the feed. Although screw pumps have not been used for transporting fish, their design is such that they should be capable of moving fish without injury and might, therefore, have certain applications at power plant intakes. The maximum efficiency of the pump is 75 percent and the largest model can lift 28,000 gpm to a height of 25 feet.

CONCLUSION

With the present concern for the protection of fish at cooling water intakes, a number of systems have been developed to collect or divert fish within power plants. These systems require a means of transporting collected or diverted fish back to their natural environment. In designing transport systems, careful consideration of engineering detail is required to ensure that hydraulic conditions are established which will act to effectively move fish without injury. This paper describes, in general, important parameters which should be considered in designing each element of various fish transport system.

APPENDIX I - REFERENCES

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