ENGINEERING IMPLICATIONS OF NEW FISH SCREENING CONCEPTS

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INTRODUCTION

As a result of present regulatory requirements for the protection of aquatic life at cooling water intake structures, numerous power plant intakes in the United States are being designed to incorporate fish protection facilities. Such facilities can be based in principle on three different concepts: fish collection and removal, fish diversion, or fish deterrence. The incorporation of fish protection systems can result in modifications to conventional intake designs and can influence screenwell layouts and the selection of screens and pumps.[1]

Biologists must be aware of the engineering implications that fish protection concepts can impose; likewise, engineers should be cognizant of the biological requirements for fish protection in order that potential engineering problems can be identified and resolved. The interaction of good hydraulic engineering and sound biological judgement is, therefore, required to develop fish protection facilities which are biologically effective without having an adverse effect on plant operation.

This paper discusses specific intake design considerations and engineering implications related to the three fish protection concepts mentioned above.

FISH COLLECTION AND REMOVAL CONCEPT

This concept involves modifications of conventional traveling water screens so that fish which are impinged on the screens can be removed with minimal stress and mortality. Recent biological investigations at

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power plant intakes have shown that modified screens can be utilized to reduce impingement losses of selected fish species provided that certain essential design and operating criteria are met.[2,3] The engineering implications of screen modifications can be significant, and must, therefore, be carefully considered prior to implementation.

One modification involves the addition of a shallow bucket to the trash lip of each individual screen basket which will hold approximately two inches of water once it has cleared the water surface during screen rotation. This arrangement prevents fish from falling or flipping off of the trash lips and allows impinged fish to be maintained in water while being lifted to a release point. Another modification is the addition of a low pressure (less than 30 psi) spray to wash fish gently from the screen prior to the high pressure (80-100 psi) debris removal spray.

At present, United States manufacturers of through-flow screens offer both front wash and back wash spray systems. With the back wash screen, sealing of the gap between the screen face and the fish collection trough has to be considered. Effective sealing in this area is required to prevent fish from being carried over the screens and into the cooling system. Neoprene deflectors have been tried but appear to be inadequate since this material fatigues rapidly. Therefore, other deflector materials, such as a composite urethane-clad berylium copper, are presently being tested for strength and durability.

With the front wash screen, all fish must be effectively removed from the lifting lips by a low pressure spray without the aid of gravitational forces. Therefore, the shape of the lip and the design and orientation of the fish removal spray are of particular importance. This screen design requires the use of both internal and external spray headers to ensure removal of fish and debris on the front side of the screen, thereby preventing carryover. A final investigation of the front wash screen, designed specifically for fish protection, has been completed and such screens are now commercially available.

Clogging of the low and high pressure spray nozzles can be a problem that affects debris and fish removal from the screens. Self-cleaning strainers or hydro-cyclone filters designed to remove suspended particles from the wash water can be utilized to ensure effective performance of the spray systems.

Depending on the number and species of fish of concern at a specific site, it may be desirable to operate modified screens on a frequent basis, or even continuously during certain times of the year, to minimize impingement time and resultant injury or stress. Frequent or continuous screen operation can result in substantial wear of the flex joints of the chain, the head shaft bearings and the foot shaft bushings. Wear of the chain flex joints occurs when the chain rollers support a differential head on the screens thus resulting in wear of the internal boring of the roller and the flex joint. This, in turn, causes misalignment of the chain and jamming of the baskets as they feed out of the boot area. To remedy this type of wear, the rollers, pins and bushings should be made of tool-quality alloy to resist continuous operation. Wear of the head

shaft bearing results mainly from the lack of adequate lubrication. A good solution to this type of wear is the utilization of anti-friction roller bearings.

Sand and silt in the water are abrasive to the footshaft bushings. As bushings wear out, slack in the chains develops and the lips of the baskets contact the boot plate, a process which results in wear and can even cause the baskets to be ripped from the chain assembly. Wear of the bushings can eventually result in "freezing" of the screen rotation. Proper slack tensioning and the utilization of tool-quality Stoody bushings and liners on the footshaft can reduce wear. Utilization of lighter screen baskets and narrower screen widths (a maximum width of 10 ft instead of the conventional 14 ft) can reduce the total deadweight to be carried by the screen assembly and thereby help reduce overall wear and maintenance resulting from continuous operation. For a given flow and velocity, the use of narrower screens results in the need for an increased number of screens and a wider screenwell than might be required for a more conventional layout.

A plenum located between the screens and the pumps, as shown in Figure 1, can be a desirable design feature relative to maintenance, particularly if frequent maintenance is anticipated. This arrangement allows maintenance of a screen in the dry without requiring shutting down the circulating water pump downstream, since the pump can continue to withdraw water via the plenum from the adjacent screens. Another advantage of a plenum is that it helps reduce overall approach velocities to the screens during partial pump operation.

Several other design modifications have been implemented for the protection of fish at shoreline intakes. First, many new screenwell structures are being situated such that conventional through-flow traveling screens can be installed flush with the shoreline. Second, lateral fish passageways are provided immediately upstream of screens to offer an escape route for fish entering the screenwell (Figure 1). The combination of these two features eliminate the physical boundaries, or fish entrapment areas, that commonly exist in older power plants. To allow maintenance of the screens in the dry, stop gates can be installed between the screen piers and the trash rack piers and a steel plate can be placed over the face of the trash rack in order to isolate a screen for dewatering. It should be pointed out that this arrangement may favor the use of backwash screens since any trash or fish trough on a front wash screen would pass directly over the dewatering stop gate slots thereby interfering with the installation and removal of the stop gates. Removable sections along the troughs over the stop gate slots may remedy this situation but will require additional operational and maintenance efforts and may cause interference to the normal operation of adjacent screens.

Very recently, attention has been focused on the feasibility of screening eggs, larvae, and juvenile forms of fish from cooling water systems. Protection of these forms may require low approach velocities and the utilization of fine-mesh with openings as small as 0.5 mm, depending on the size of the organisms to be protected.

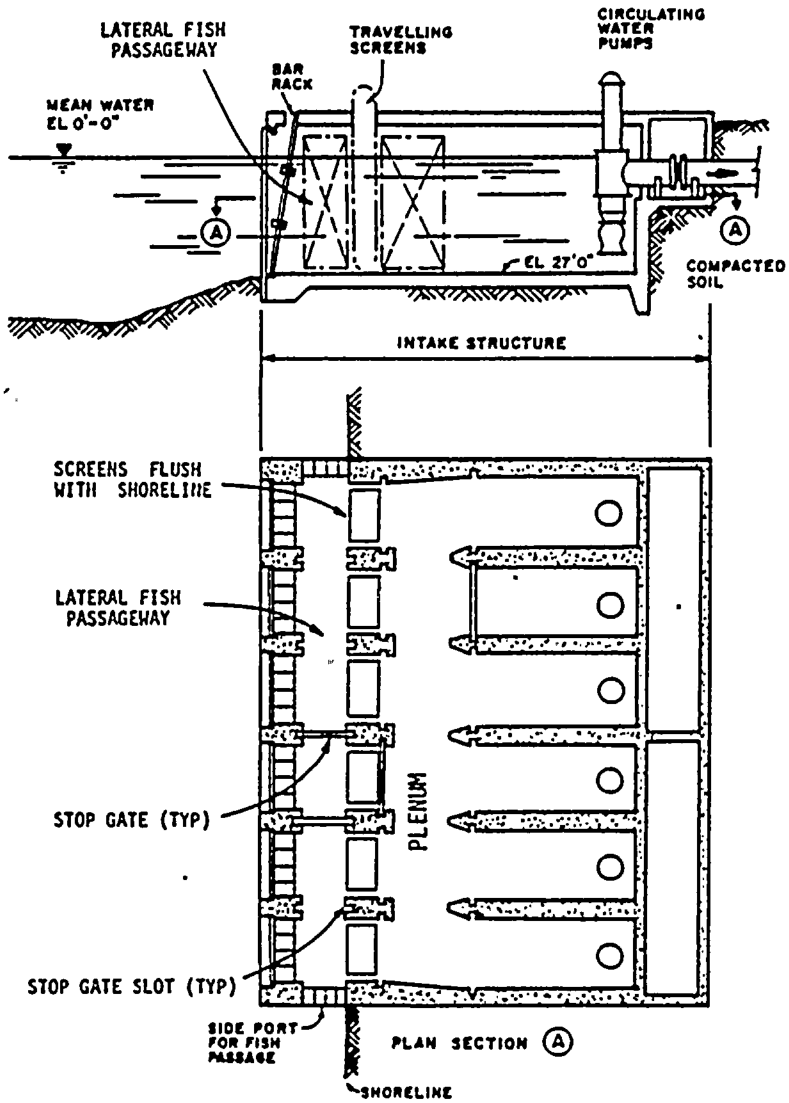


Figure 1. Screenwell with Plenum

The concept of fine screening of small organisms is presently receiving serious attention and is in an experimental stage of development. Numerous biological and engineering design and operational problems must be resolved through experimentation before fine screening devices can be considered to be an effective and available technology. Presently, three fine screening devices are being investigated: conventional traveling screens modified with fine-mesh screen panels, wedge-wire screens and center flow (single entry-dual exit) screens.

Biologically, all three devices share the same concerns in terms of impingement of passive organisms. Important parameters to be considered include species, life stage, size and body shape, and the ability of an organism to withstand impingement over time at given flow velocities.[4] For example, certain species may not be able to withstand impingement even for short periods of time at any velocity and may, therefore, stand a better chance for survival if allowed to pass through the circulating water system. Certain life stages may be more susceptible to mortality

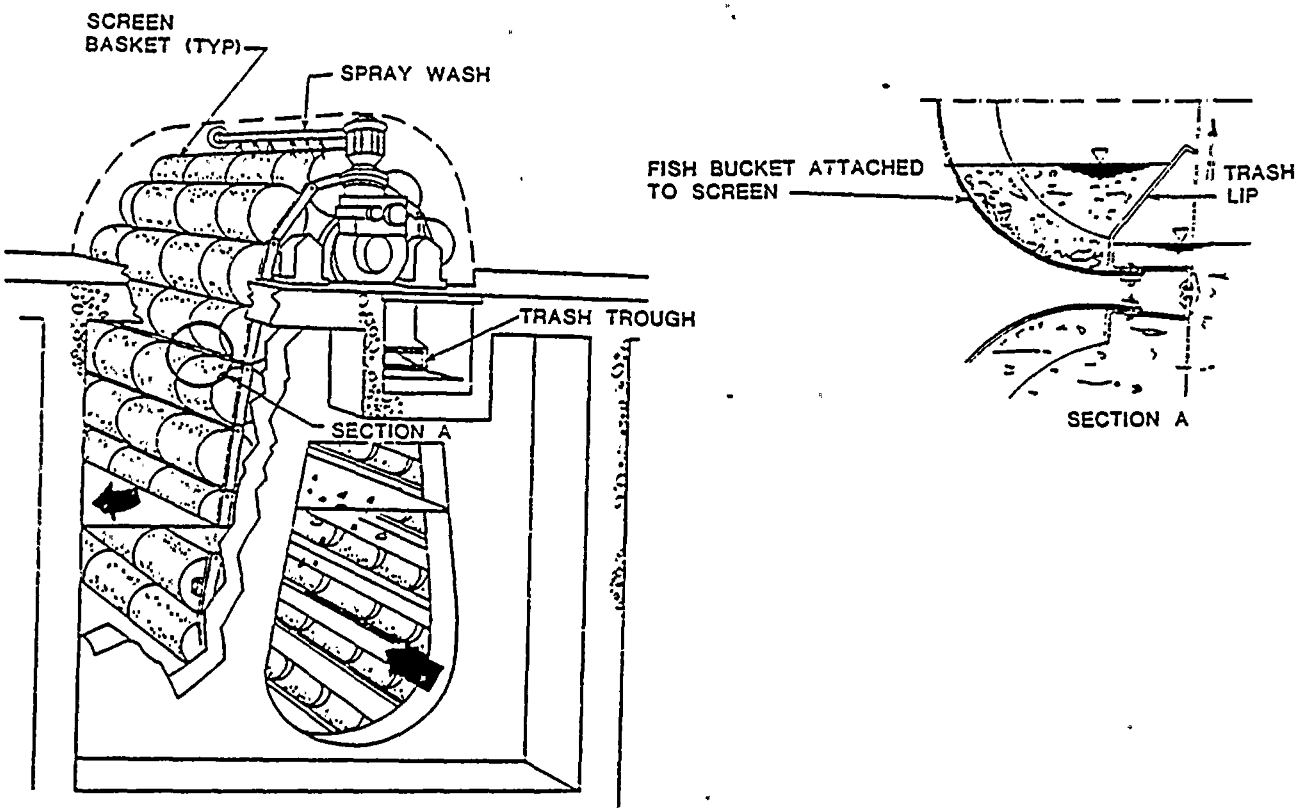
than others; therefore, the life stages to be protected will influence important engineering design parameters, such as screen mesh size and travel speed of the screen (i.e., impingement time). These parameters will, in turn, affect screen operational requirements relative to clogging and icing potential and routine maintenance to withstand frequent or continuous operation.

Another important parameter to be considered in fine screening is the type of screen mesh material utilized. These fall into three broad categories: woven metallic mesh with square or oblong openings, woven synthetic mesh (e.g., nylon, polyester, polypropylene), and wedge-wire screens. Each has biological, engineering, and cost advantages and disadvantages. For example, synthetic meshes may be smooth and have a low coefficient of friction, features which might help to minimize abrasion of small organisms. However, they may be more susceptible to flexing, fatigue, puncture and flammability than metallic meshes and could, therefore, create maintenance problems. Likewise, wedge-wire screens are smooth and durable but are several times more expensive than woven meshes.

In summary, the selection of screen design criteria for fine screening concepts must be made jointly by engineers and biologists working closely together to ensure optimal conditions for survival without jeopardizing plant reliability. At this time, it would appear that laboratory and/or field evaluations are required, first, to determine the survival potential of small organisms on fine-mesh screens and, second, to identify and resolve potential engineering problems which might influence plant operation, such as clogging potential and the design of equipment which can withstand almost continuous operation at relatively high speeds.

Several evaluations of this nature are presently ongoing, one of which is being conducted with a center-flow (single entry-dual exit) screen in Texas. This type of screen (Figure 2) has only recently been utilized in the United States, although it has been used extensively in Europe for many years. Water enters the screen through a single opening and exits through the entire internal, submerged area. Therefore, for a given width, the center-flow screen has a larger screening area than a through-flow screen, since water is cleaned by both the descending and ascending faces. The semicircular design of the screen baskets also adds to the screening area. These features offer the advantage of reducing the width and/or depth of a screenwell relative to the dimensions required for through-flow screens. However, the orientation of the screen is such that non-uniform flow patterns are established downstream of the screen which can affect the performance of pumps. This problem can be solved by increasing the distance from screen to pump or by incorporating baffles downstream of the screen to streamline the flow,[5] as shown in Figure 3. Horizontal or vertical dry pit pumps, which are less sensitive to flow disturbances than vertical wet pit pumps, can also be considered for these applications.

The center-flow screens being utilized in Texas are designed to operate continuously at a speed of 14 fpm and utilize 1.0 mm nylon mesh baskets. These screens were selected primarily to handle heavy seaweed loading at this site. However, preliminary observations of the condition of impinged



COURTESY OF PASSAVANT

Figure 2. Center-Flow Screen

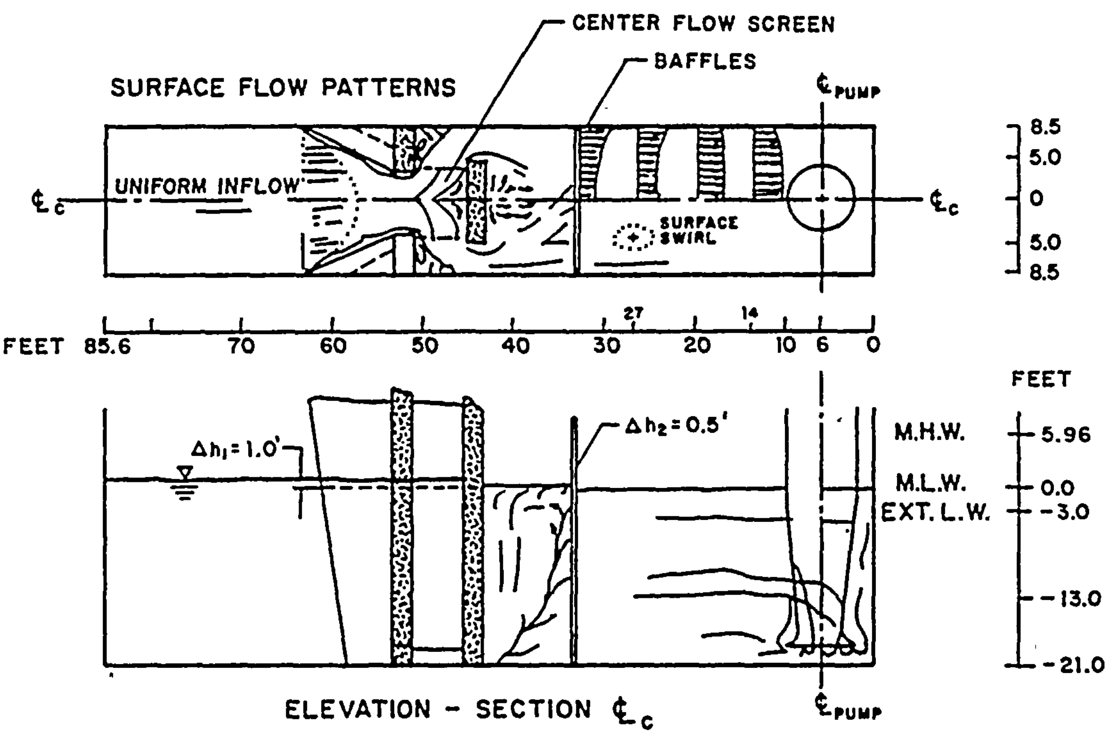


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Figure 3. Pumpwell Model with Center-Flow Screen

organisms indicate high initial survival of organisms washed into the trash trough. Further investigations are planned to quantify actual impingement survival.

Several modifications are possible to improve the survival potential of center-flow screens. One is to block off the lower portion of each screen basket to create a lip which will hold water (Figure 2). Another is to add a low pressure spray header to gently wash impinged organisms into the lip from which they can then be discharged by gravity into the collection trough. However, as previously discussed, modifications to improve the biological effectiveness of the screen will require careful consideration of their influence on engineering reliability.

With both through-flow and center-flow screens, fish which are discharged into the fish trough can generally be returned to their natural environment by gravity through a sluiceway and/or pipeline since they have been lifted above the water surface by the screen. Care must be taken in designing fish return systems to ensure that organisms are not stressed further during transportation.[6] Sluiceways should be smooth and U-shaped with sufficient depth and velocity to carry organisms without abrasion or excessive resistance to the flow. Where possible, bends should be of the long-radius type and couplings should be designed to prevent jagged obstructions. Where applicable, methods for controlling biofouling and icing should be incorporated. Finally, transitions from larger to smaller sluiceways and pipes, or vice versa, should be gradual to avoid rapid accelerations or decelerations in velocity.

FISH DIVERSION CONCEPT

The fish diversion concept employs design features to remove fish from intakes without requiring that they be physically impinged on mechanical screens. One type of diversion concept involves the use of angled screens or louvers which are designed to guide fish to a bypass where they can be returned back to the receiving waters. This concept takes advantage of natural behavioral responses which fish display when approaching an object in flowing water. An angled screen or louver creates a zone of localized turbulence which fish avoid as they move in the direction of flow. This avoidance response, in conjunction with an induced suction flow in the bypass, gradually directs fish into the bypass from which they can be returned to the receiving waters.

Studies with angled screens and louvers have shown these diversion devices to be highly effective in diverting a variety of fish species to bypasses over a wide range of environmental and hydraulic conditions.[7,8,9] As a result of these studies, angled screen and louver systems are presently being constructed at several new power plants on Lake Ontario and the West Coast.

There are several engineering considerations in designing this type of fish diversion system related to screen layout, flow patterns, and screen modifications. A design layout with a small-sized structure to accommodate the angled screens is economically desirable. For example, a V-arrangement (Figure 4) with bypasses at the vertex results in a shorter structure than an arrangement with a single array of screens leading to a single bypass.

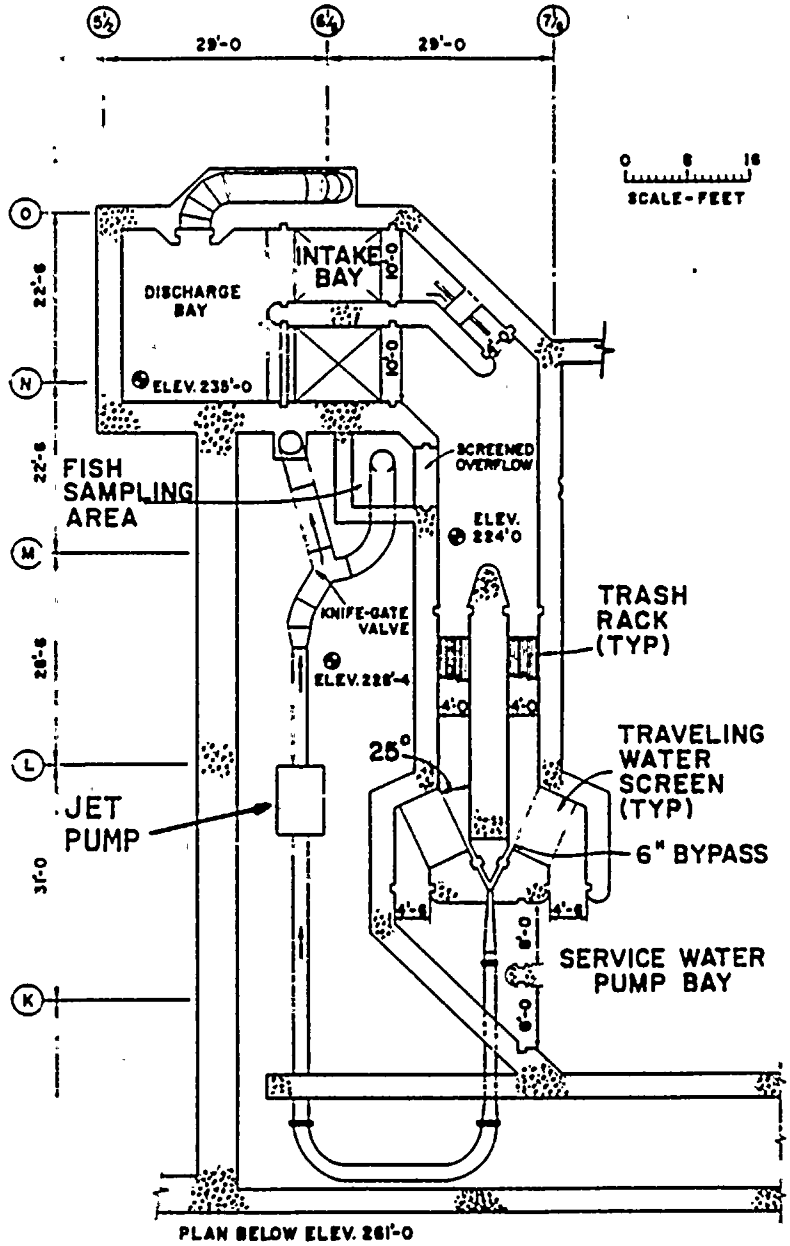

Figure 4. Full-Scale Design of Angled Fish Diversion Screen

In order to avoid obstructions in the flow which might disorient fish, the angled screen structures are mounted flush with the support piers between the screens. This is achieved by making several modifications to the conventional through-flow traveling screen.[7] These modifications involve setting the individual screen baskets flush in the vertical direction and eliminating the end seal plates on each side of the screen to form a flush surface with the concrete piers and the bypass (Figure 5). 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,

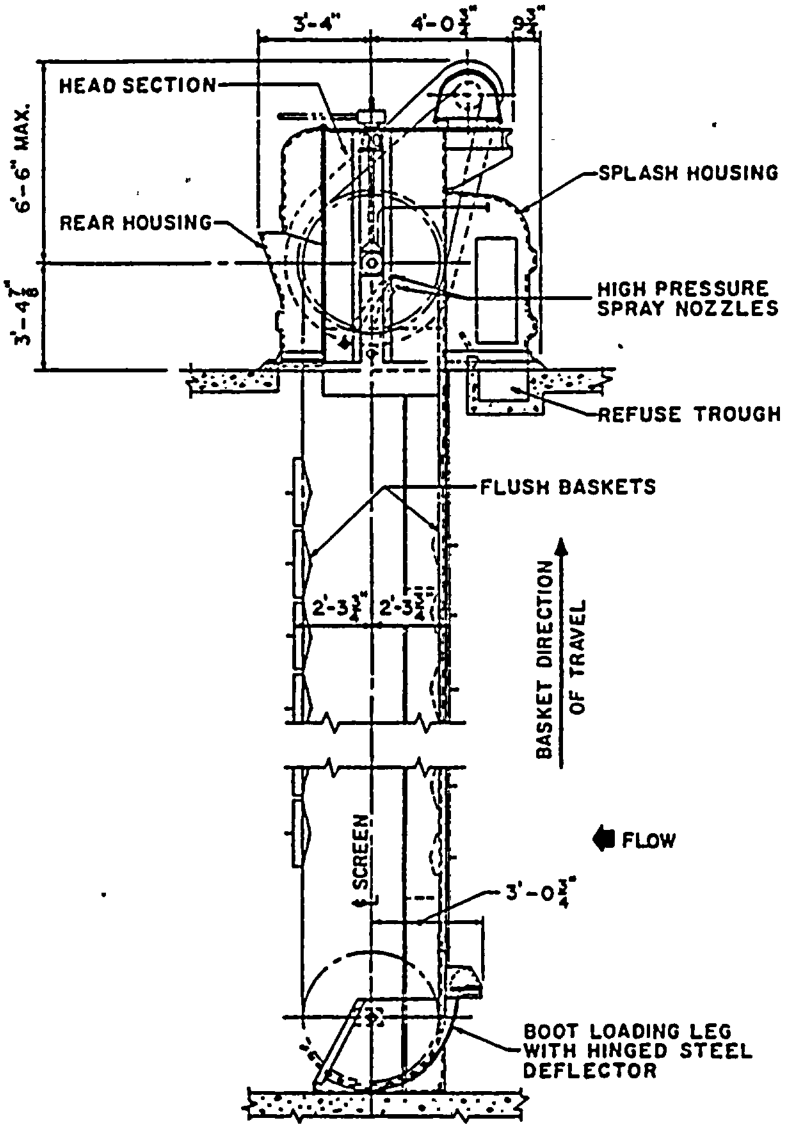

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Figure 5. Side Elevation of Flush-Mounted Traveling Screen

thus sealing the boot area. To reduce the clearance between the screen baskets and the main frame, an Ultrex wear bar strip is provided on the edge of the screen frame. The wear bar will also minimize the frictional forces that may result during momentary contact of the basket frame to the wear bar.

It should be noted that the angling of the screens can result in the formation of eddies and areas of flow separation downstream in the vicinity of the pump and can, therefore, affect pump performance, as shown in Figure 6. To minimize the distance from the screens to the pumps, vertical dry pit or horizontal pumps, which are less sensitive to flow disturbances, could be selected. With these pumps, where the screen-to-pump distance may be relatively short, care should be taken to avoid a non-uniform velocity distribution along the screen face which

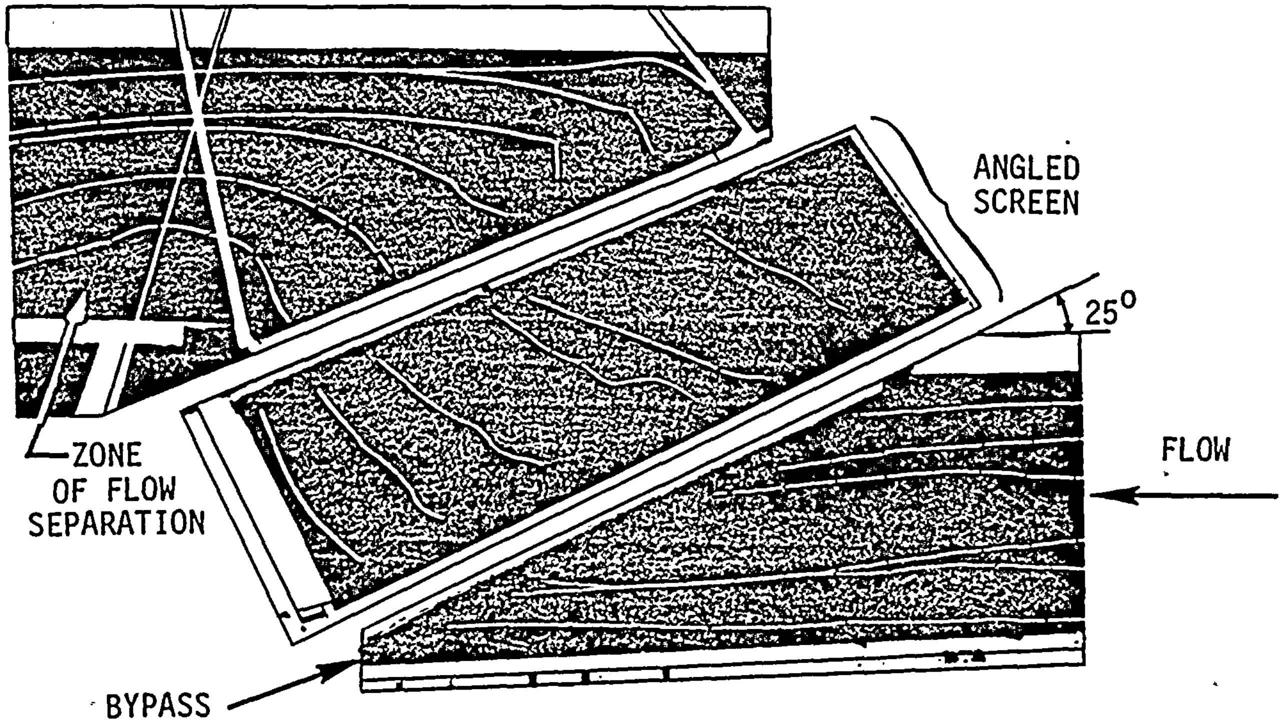


Figure 6. Streamlines Through an Angled Screen

might adversely affect fish guidance. Where vertical wet pit pumps are used, the screen-to-pump distance should be increased above that required by the Hydraulic Institute Standards, thereby increasing the overall screenwell length.

An advantage of this type of fish protection system, as compared to through-flow or center-flow screens which rely on fish being impinged on frequently or continously operating screens, is that the angled screens need only be operated intermittently as required for debris removal.

Proper flow streamlines, uniform velocity distributions along the diversion device and proper approach-to-bypass velocity ratios are all important factors in achieving satisfactory fish guidance. Figure 6 shows streamlines in a test flume with an approach velocity of 1.0 fps and a screen angle of 25 degrees.[8] The flow approaches the screen uniformly and does not turn into the screen prematurely, a condition which would adversely affect fish guidance. Therefore, optimal conditions for fish guidance were achieved.

An example where the velocity distribution along a louver array and into a bypass led to poor fish guidance is shown in Figure 7. The velocities gradually increased and then suddenly decreased in the vicinity of the bypass. A larger bypass-to-approach velocity ratio or the use of baffles on the back side of the louver array could possibly have acted to establish a more uniform velocity distribution along the louver array and into the bypass, thus resulting in improved guidance of fish.

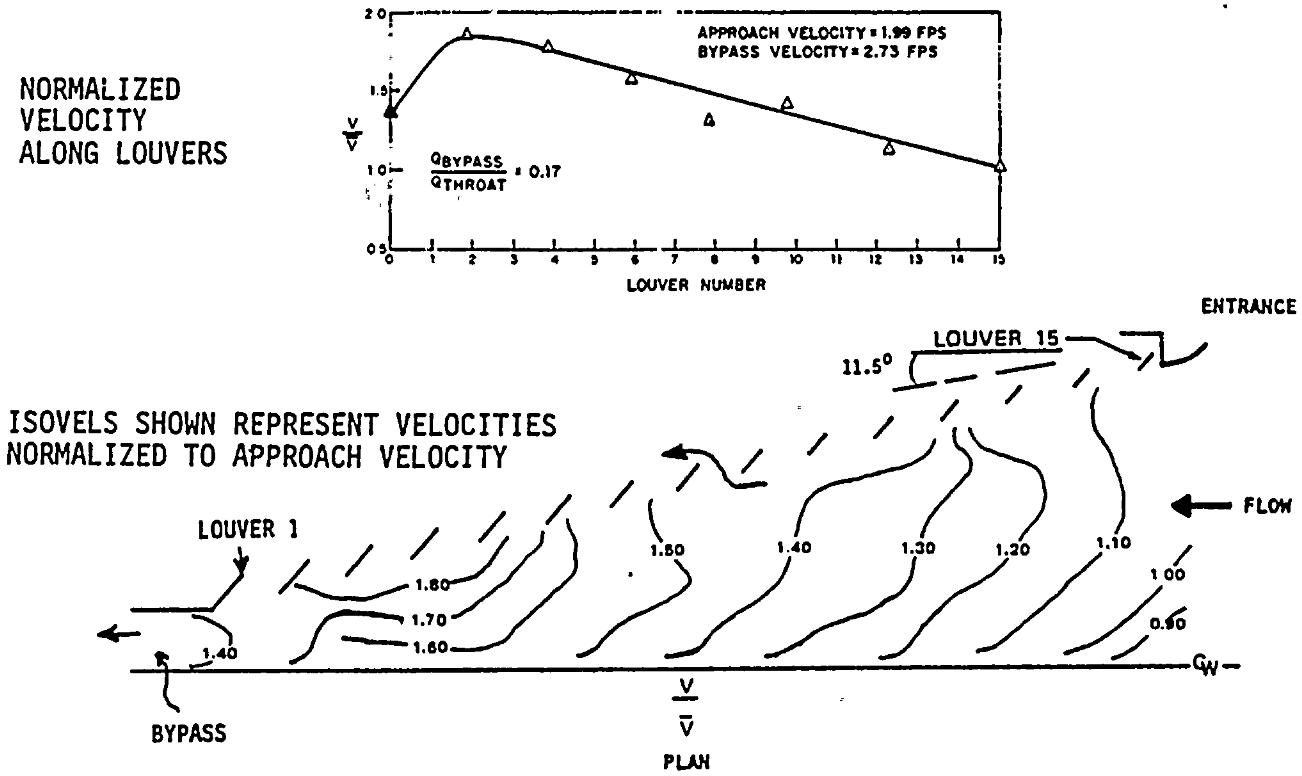
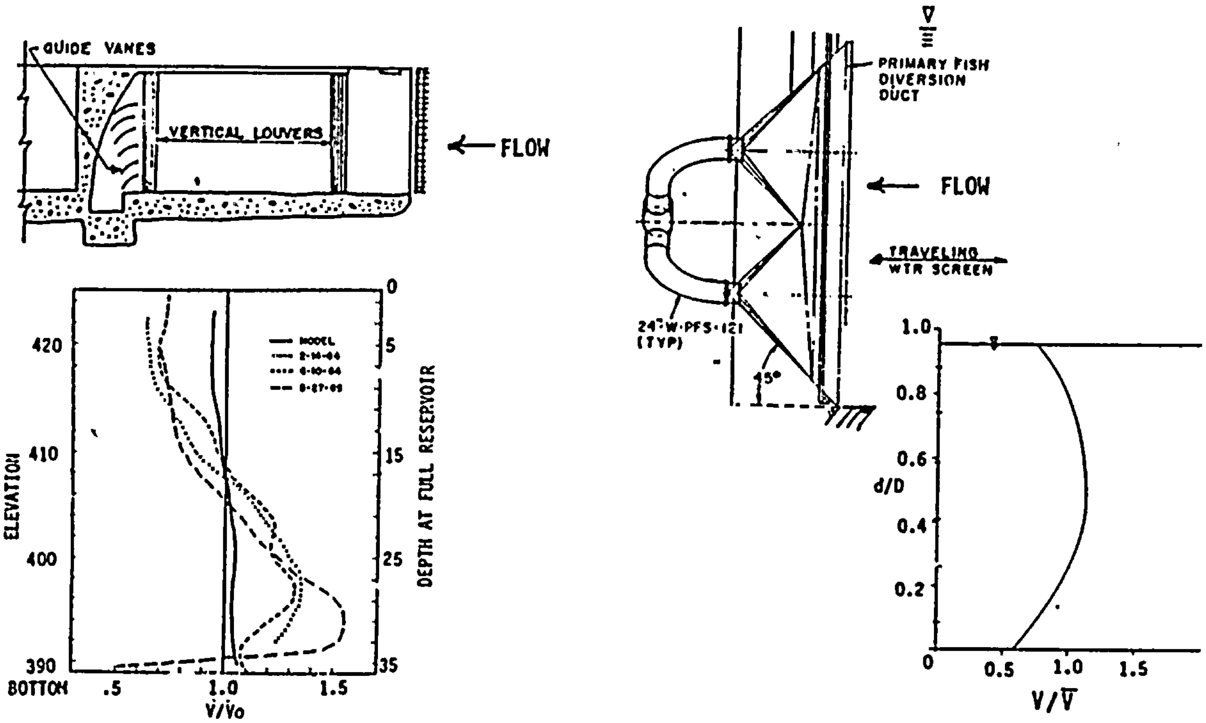


Figure 7. Velocity Distribution Along Louver Array

Fish diversion systems which guide fish to a bypass require some method for returning the bypassed fish to the receiving waters. Since the fish are bypassed within the water column rather than being impinged and mechanically elevated by traveling screens as with the collection and removal concept, other lifting devices are required. These include lift baskets and several types of pumps.[6,10] At a West Coast power plant presently under construction, a lift basket will be used to lift fish bypassed by a louver system to a discharge point for gravity return to the ocean.[9] At two power plants on Lake Ontario, jet pumps will be utilized to transport fish diverted by angled screens. The jet pump was selected as the best system for these sites on the basis of extensive laboratory testing. As shown on Figure 4, the fish return system consists of the bypass, a transition section into a pipeline, and an adequate pumping unit to induce flow into the bypass and to return the fish back to their natural water body. Bypasses should be designed such that uniform velocity distributions are established to minimize rapid accelerations or decelerations in flow which can elicit an avoidance response by fish. Figure 8a shows a bypass configuration with a bottom withdrawal and guide vanes. Although model studies were conducted with this design, in full-scale application the velocity distribution at the bypass was not uniform, as intended, resulting in poor fish diversion efficiency due to avoidance.[11] An alternative bypass configuration is shown in Figure 8b. In this case, the lateral bypass gradually transitions into two funnels which manifold into a pipe. Full-scale laboratory studies showed that a relatively uniform velocity distribution at the bypass was achieved with this design.



a. BYPASS VELOCITY DISTRIBUTION

b. BYPASS VELOCITY DISTRIBUTION

Figure 8. Bypass Configurations

In general, angled screens have two advantages over angled louvers which consist of an array of evenly spaced, vertical slats generally spaced at least one inch apart. First, since the screen acts as both a diversion device and a screening medium, back-up screens, required behind louver systems for removal of fine debris and non-diverted fish, are not necessary. Second, it has been shown that louvers require an approach-to-bypass velocity ratio of approximately 1.0:1.5 to function effectively, while screens operate efficiently at a 1:1 ratio. Therefore, bypass flows, and pumping costs, are lower in an angled screen system. These facts do not preclude the use of louvers in all cases. For example, at an existing intake, stationary louvers could be installed as a backfit, in which case the existing traveling screens would be maintained as backup screens. Further, at pumped-storage projects or other water diversions where fine screening is not required, louvers may offer an acceptable alternative to angled, traveling screens.

FISH DETERRENCE CONCEPT

A number of devices have been developed that are designed to alter, or take advantage of, the natural behavioral patterns of fish in such a way that they will avoid entering an intake flow. These are commonly referred to as behavioral barriers and include visual keys, hanging chains, air bubble curtains, water jet curtains, electrical screens, sound, and light. All have been evaluated in the past with limited success. Hanging chains, air bubble curtains, and water jet curtains have shown moderate success in deterring fish over a range of hydraulic and biological parameters.[12]

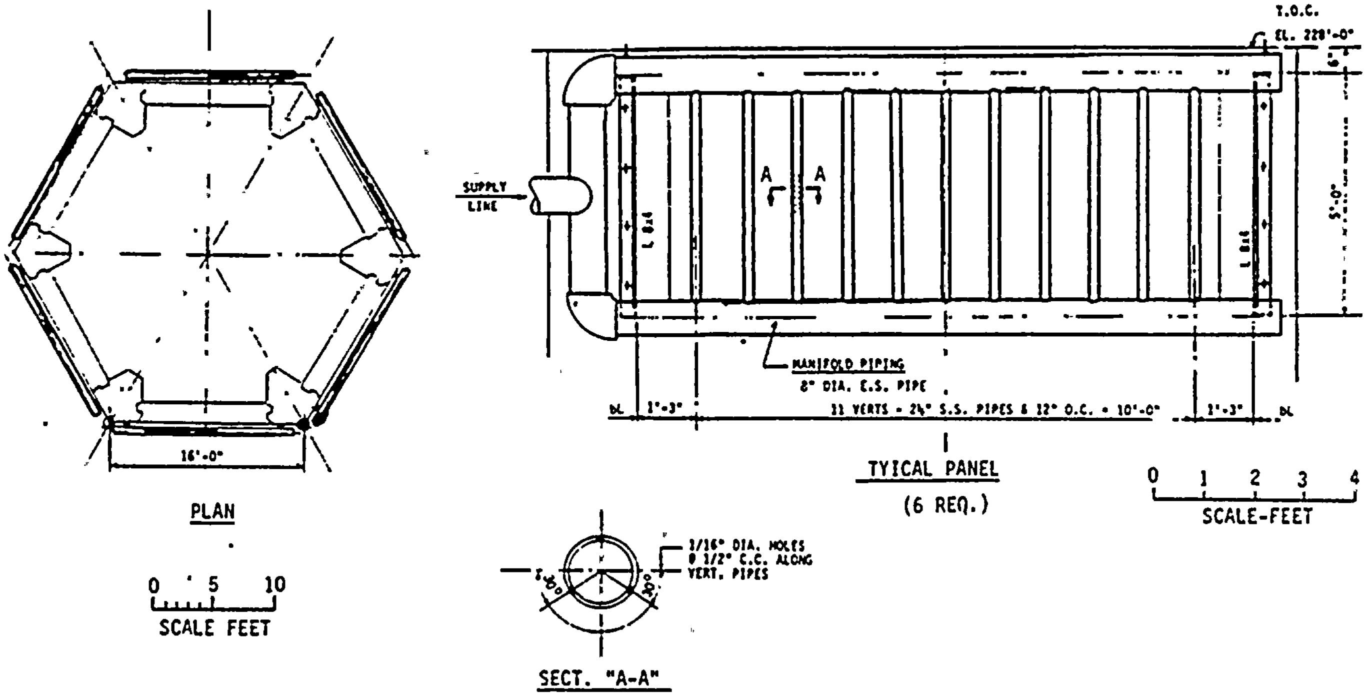


Figure 9. Water Jet Fish Behavioral Barrier at an Offshore Intake

When considering the use of behavioral barriers at an intake structure, the effect of such devices on intake operation should be carefully evaluated. For example, an air bubble curtain at a shoreline intake, supplied with a high air flow rate, may cause violent water churning and air entrainment problems in the pumps. Similarly, in designing a water jet curtain, as shown in Figure 9, for an offshore submerged intake, the vertical bars should be placed about 1 ft apart in order to prevent potential blocking of the intake due to debris accumulation. As a result of laboratory studies, water jets with 60 psi pressure ejecting from 1/32 or 1/16 in. diameter nozzles in a diffuser pipe oriented at a 30 degree angle to the face of the intake have been found to be moderately successful in deterring fish.[12,13] Since the strength of a submerged water jet dissipates within a short distance, two rows of closely spaced nozzles jetting toward each other are recommended to ensure a dense and effective curtain. Filtration of the supply water is required to prevent clogging of the small nozzle openings.

In designing behavioral barriers, consideration should also be given to potential problems associated with icing, siltation, and wave action.

Considerations With Closed-Loop Cooling

In selected instances, fish protection facilities may be required for makeup water intakes of closed-loop circulating water systems. In addition to utilizing modified through-flow or center-flow screens, as previously discussed, perforated pipe or stationary wedge-wire screens may be well-suited for offering adequate fish protection, provided that the through-slot velocities are sufficiently low to prevent fish impingement. These screens should be located in currents with sufficient velocities to promote selfcleaning. Since these types of screens are

usually entirely submerged and are not mechanically cleaned, particular attention should be focused on potential siltation, biofouling, and icing problems. In general, screen backwash systems should be incorporated into the design. In addition, navigational restrictions must be considered.

Recently, studies have been initiated to determine the feasibility of utilizing small slot wedge-wire screens of a cylindrical design for the protection of smaller organisms, particularly fish eggs and larvae. Such screens would be designed with small slot openings (as small as 0.5 mm) and low through-slot velocities. Conceptually, such a screen, when placed in a natural current of sufficient velocity, could establish hydraulic conditions which would minimize the impingement of eggs and larvae, as well as debris. At present, this fine-screening concept is being evaluated on an experimental basis.[14] Preliminary results indicate that wedge-wire screens may function effectively at certain sites. If used, this type of screen may favor the selection of a dry pit pumpwell with horizontal pumps.

CONCLUSION

The incorporation of fish protection facilities into cooling water intakes have greatly affected intake designs. As discussed, there are several engineering considerations that have to be evaluated to assure that fish protection facilities will be biologically effective while not adversely affecting plant operation.

The choice of a fish protection concept depends on the effectiveness of a particular design for the fish species of concern and on engineering and cost considerations.

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