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INFLUENCE OF FISH PROTECTION CONSIDERATIONS ON THE DESIGN OF COOLING WATER INTAKES

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ABSTRACT

Stringent regulatory requirements in the United States often require the incorporation of fish protection facilities at power plant intakes. These facilities can be based on three different concepts: fish collection and removal, fish diversion, and fish deterrence. The incorporation of fish protection systems at specific sites can necessitate modifications to conventional intake designs. Such modifications can influence screenwell layouts and selection of screens and pumps, and in certain cases require model studies to develop design criteria which will ensure that proposed fish protection facilities will be biologically effective and will not adversely affect plant operation.

RESUMÉ

Les régulation sévères en vigueur aux U.S.A. imposent souvent l'incorporation des dispositifs de protection pour poissons aux prises d'eau de réfrigération des centrales thermiques. Ces dispositifs peuvent être divisés en trois groupes, selon leur principe de fonctionnement: ramassage et enlèvement, détournement ou effroyement. L'incorporation de l'un de ces systèmes peut nécéssiter des modifications á la prise d'eau. Ces modifications peuvent influencer l'arrangement et la sélection des grilles et des pompes. Dans certains cas, il est nécéssaire de faire appel á une étude sur modèle pour assurer le bon fonctionnement, biologique et opérationel, du dispositif.

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. In certain cases it has been necessary to use biological and hydraulic model

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studies in conjunction with field investigations to develop such intake designs.

This paper discusses specific intake design considerations related to the three fish protection concepts mentioned above, and gives criteria of model studies for such facilities.

FISH COLLECTION AND REMOVAL CONCEPT

This concept involves modification of traveling water screens so that fish which are impinged on the screens can be removed with minimal stress and mortality. The majority of the existing power plants in the United States utilize conventional through-flow vertical traveling screens to screen debris from the circulating water system. Recently, modifications to the through-flow screens have been developed for fish protection.

One modification includes the addition of shallow buckets along the trash lips of the screen baskets. The buckets are generally designed to hold approximately two inches of water while being lifted vertically upward. This arrangement prevents impinged fish from flipping off of the trash lips during screen rotation and allows impinged fish to be maintained in water while being lifted to a release point. In conjunction with lifting buckets for fish, the spray headers for screen cleaning can be modified to gently wash fish from the screen and minimize mortality associated with the conventional spray systems. Conventional screens typically utilize high pressure spray headers (80-100 psi) to wash debris to a collecting trough. The addition of a low pressure (less than 30 psi), high volume spray header to wash fish from the collecting buckets prior to the high pressure debris removal spray can provide better assurance that impinged fish are safely returned to the receiving water body. In some instances, it is also possible to isolate fish from debris by using separate troughs for each spray header. In this way, the fish in the fish trough can be routed back to the receiving waters while the trash is routed to a collection area for disposal. At present, United States manufacturers of through-flow screens offer both front wash and back wash spray systems, as shown in Figure 1.

Depending on the number and species of fish being impinged, it may also be desirable to operate the screens on a frequent basis, or even continuously during certain times of the year, to minimize the time that fish are impinged on the screen mesh. It is believed that the shorter the time a fish is impinged, the higher the probability for survival. However before electing to operate screens for continuous intervals, field tests should be conducted to verify that such action is, infact, necessary to reduce mortality. Continuous operation results in substantial screen wear and requires modification of the conventional screen construction to incorporate lighter baskets, anti-friction takeup roller bearings, Stoody bushings and liners on the footshaft, heavy duty chains, proper slack tensioning, and other improved design features. Some manufacturers recommend a maximum screen width of ten feet, instead of the 14 ft width commonly used in

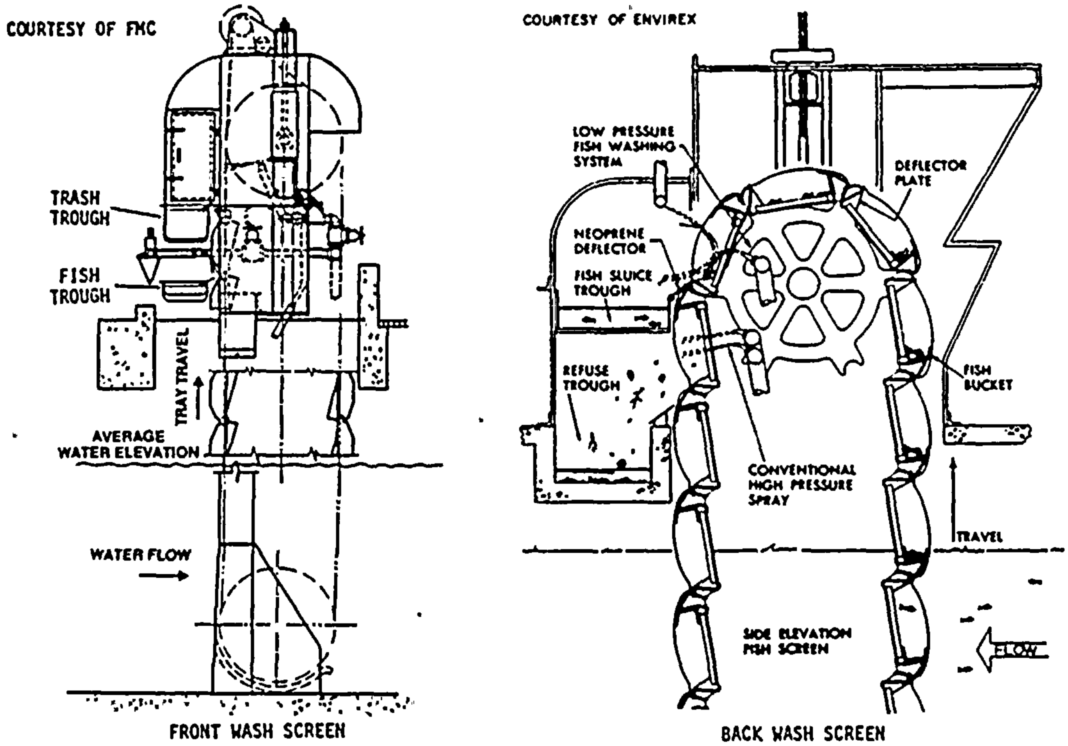


Figure 1 - Fish Screens

conventional designs, in order to reduce the total deadweight to be carried by the screen assembly. For a given flow and velocity, this results in the need for an increased number of screens and a wider screenwell than in a conventional layout. A plenum downstream of the screens, as shown in Figure 2, is sometimes desirable. This arrangement allows maintenance of a screen in the dry without requiring shutting down the circulating water pump dowstream, since the pump can 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.

Very recently, attention has been focused on the concept of screening eggs, larvae, and juvenile forms of fish from circulating 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. Again, this would result in wider screenwells than conventionally used.

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 2). 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.

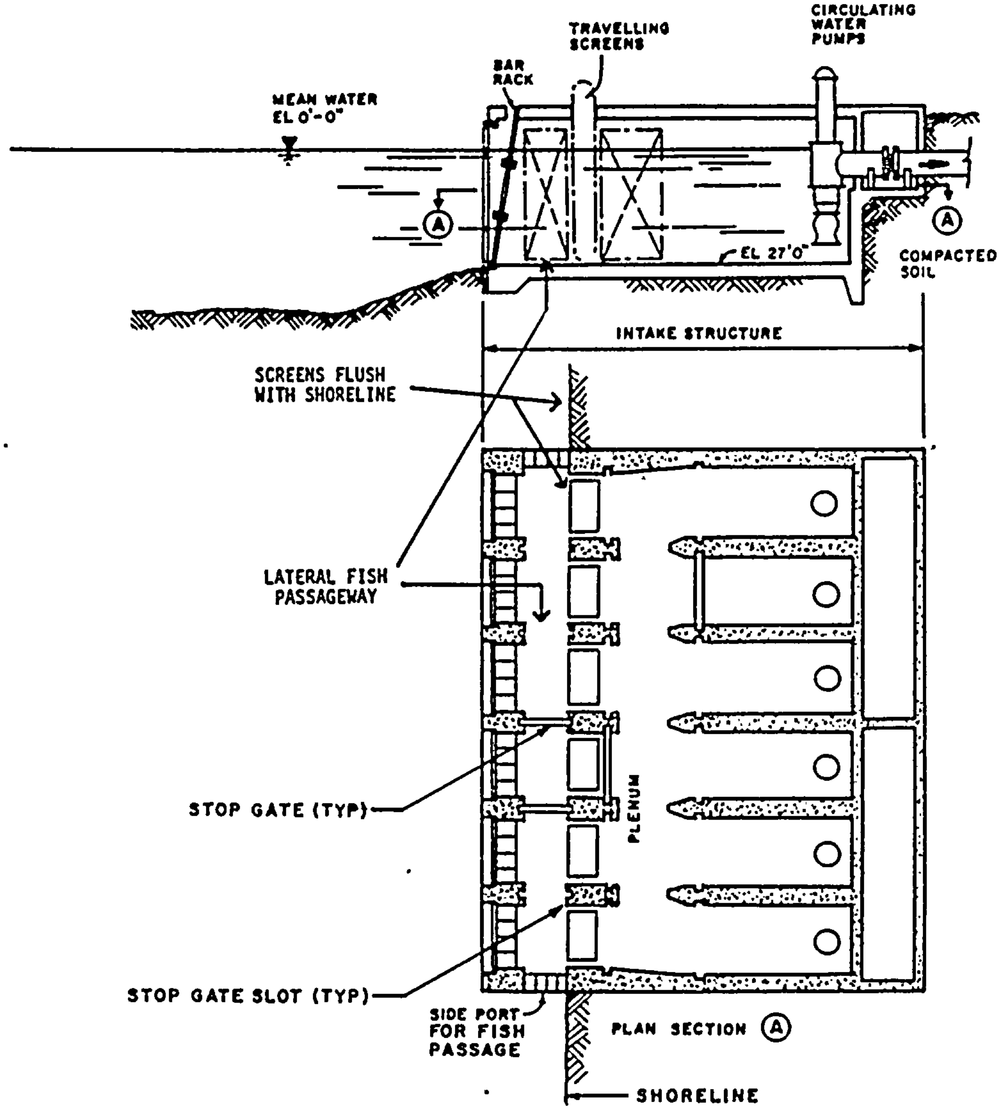
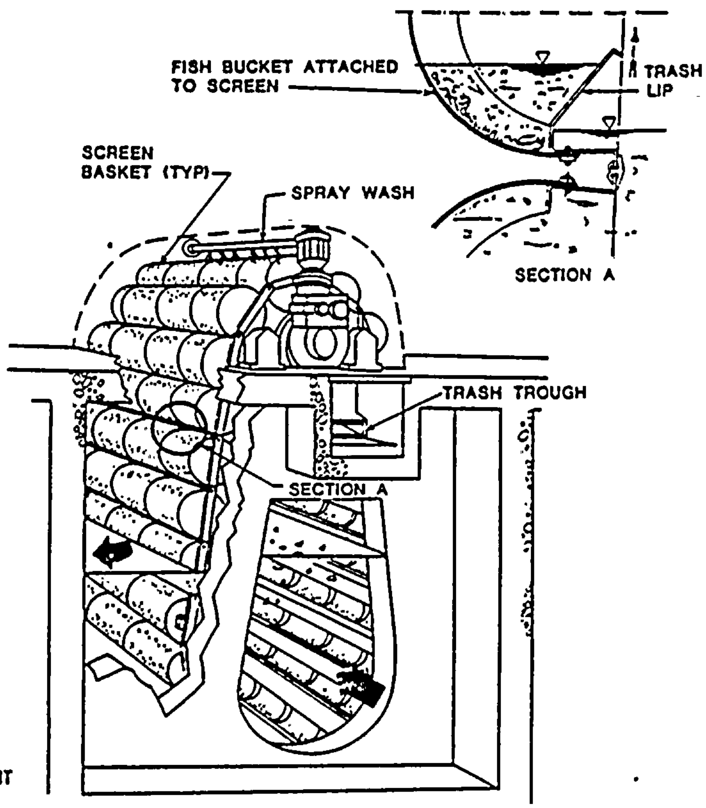


Figure 2 - Screenwell with Plenum

Another type of screen which may be used as a fish collection and removal system is a center-flow screen (Figure 3).

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,[1] as shown in Figure 4.

Horizontal or vertical dry pit pumps, which are less sensitive to flow distribution than vertical wet pit pumps, can also be considered for these applications.



COURTESY OF PASSAVANT

Figure 3 - Center Flow Screen

COURTESY OF ARL

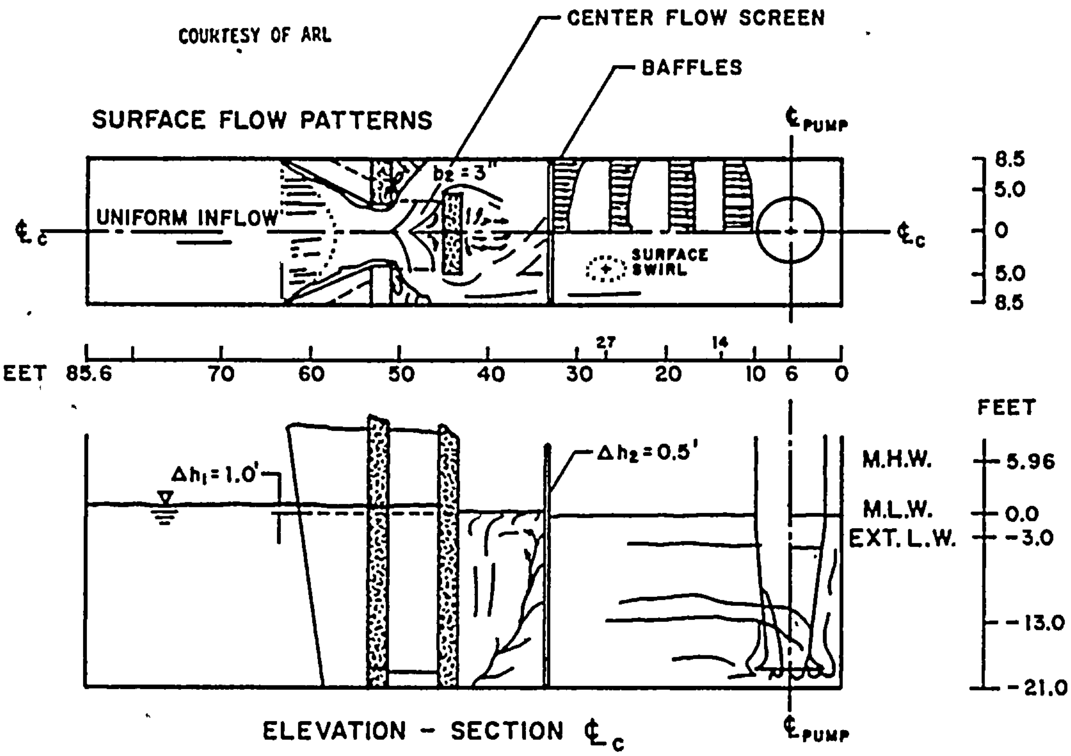


Figure 4 - Pumpwell with Center Flow Screens

With both through-flow and center-flow screens, fish 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.

FISH DIVERSION CONCEPT

Fish diversion concepts employ 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 direct fish into the bypass from which they can be returned to the receiving waters.

There are several important engineering concerns which must be considered when designing this type of fish diversion system. These can best be illustrated by referring to the design of a specific fish diversion system for a power plant having an offshore intake and an onshore screenwell with angled screens, as shown in Figure 5.

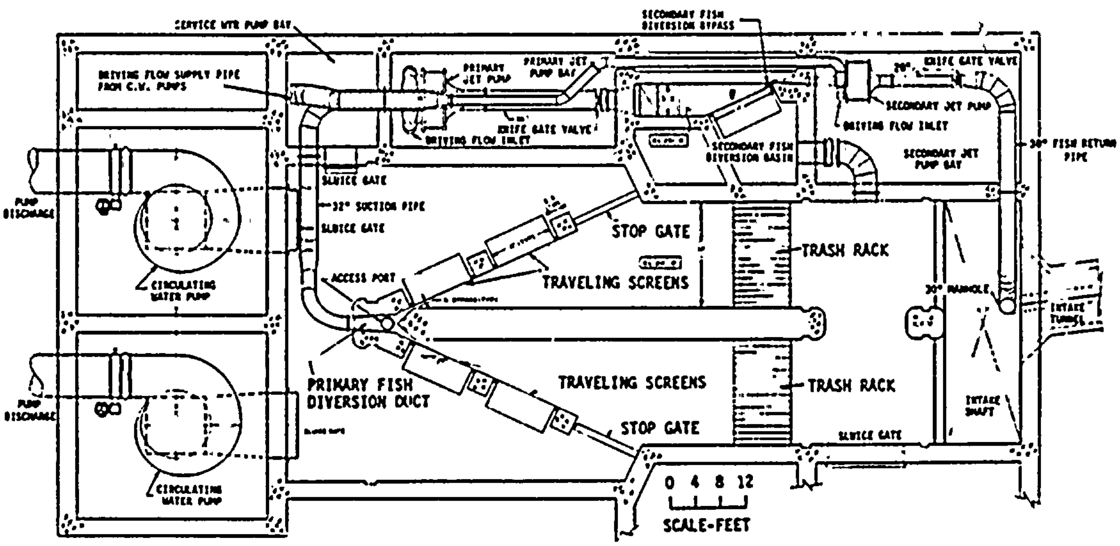


Figure 5 - Prototype Application of Angled Fish Screen

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.[2] 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.

In this instance, the screens were arranged in a V-arrangement with a bypass at the vertex in order to minimize the length of the screenwell and the length of screen that a fish would have to traverse before entering the bypass. An alternative arrangement would be to angle the screens in a continuous array to a bypass. This design, however, would necessitate a more costly screenwell design.

It should be noted that the angling of 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. In the example shown in Figure 5, the distance from the screens to the pumps was minimized through the selection of vertical, dry pit pumps which are less sensitive to flow disturbances of this type. The use of other pumps could necessitate increasing the screen-to-pump distance and, therefore, 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 continuous operating screens, is that the angled screens need only be operated intermittently for debris removal.

Fish entering a screenwell bypass must be returned to their natural water body. The fish return system shown in Figure 5 consists of the bypass, a transition section into a pipeline, and an adequate pumping unit to induce flow into the bypass and to discharge the fish back to their natural water body. The bypasses were designed such that uniform velocity distributions were established to minimize rapid accelerations or decelerations in flow which can elicit an avoidance response by fish. The width of the bypass was determined on the basis of the size of the fish at the site and the amount of debris expected to be present.

Once fish move into the bypass, a system is required to return them to the receiving waters. Since bypassed fish are not impinged and mechanically elevated by the traveling screens with this design, other lifting devices were evaluated. These included lift baskets and several types of pumps.[3,4] On the basis of results from laboratory testing, a jet pump was selected as the best system for transporting fish at this site. A series of two jet pumps were required, as shown in Figure 5.

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 back-up 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 DETERRRENT 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. Several of these 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.[5]

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, an air bubble curtain surrounding an offshore intake should be placed far enough away from the face of the intake (Figure 6) that the bubble stream will clear the top of the intake during normal storms, since air entering an intake tunnel system may result in undesirable flow conditions. In designing behavioral barriers, consideration should also be given to potential problems associated with icing, siltation, clogging of nozzles (in air and water jet curtain diffuser pipes), and wave action.[6]

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 self-cleaning. 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 fine mesh wedge-wire screens 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.[7] Preliminary results indicate that wedge-wire screens may function effectively at certain sites. If used, this

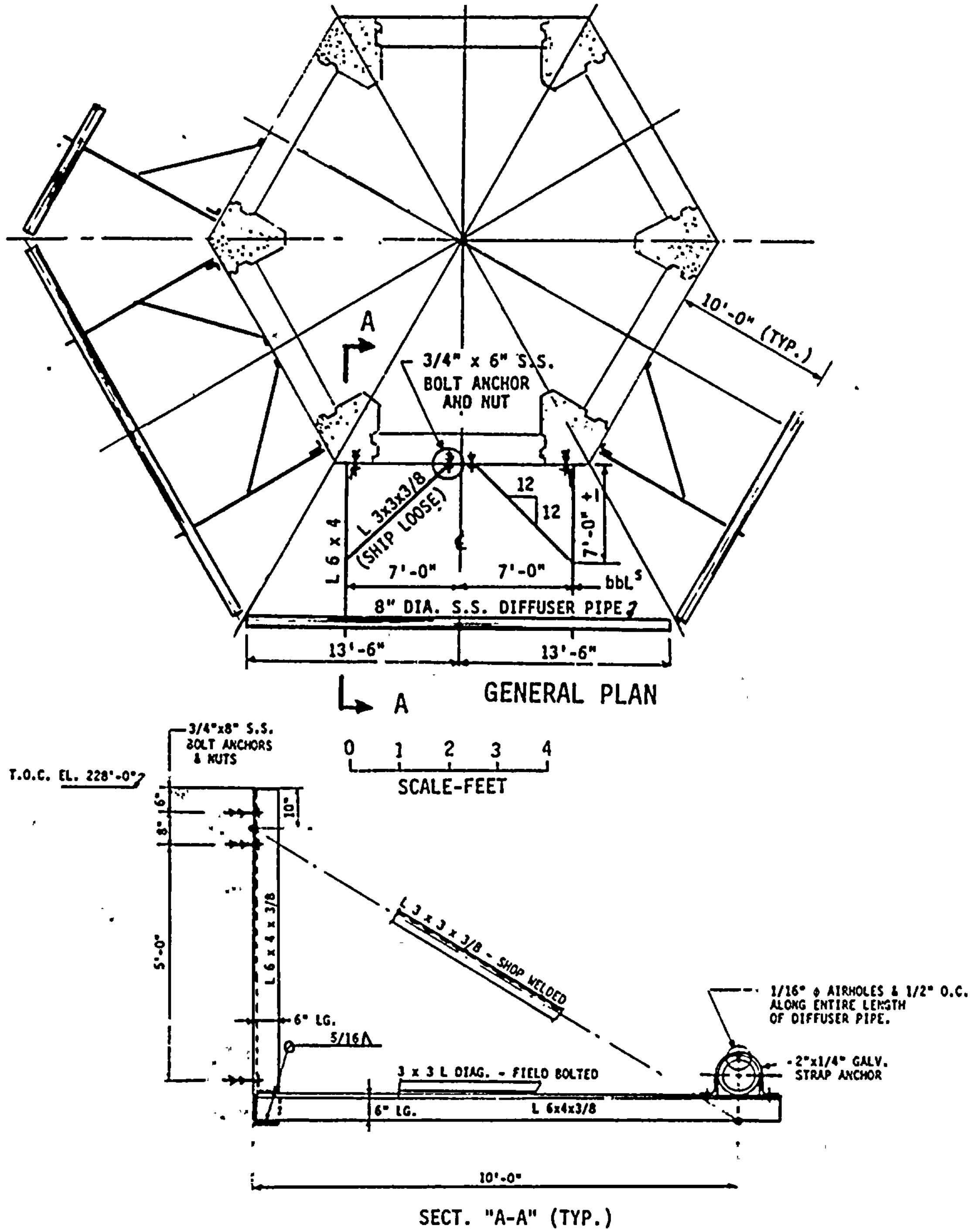


Figure 6 - Air Bubble Curtain at an Offshore Intake

type of screen may favor the selection of a dry pit pumpwell with horizontal pumps, as shown in Figure 7.

Another possible design utilizing small slot wedge-wire screens is a submerged, revolving vertical or horizontal drum screen with an internal water jet spray. This design also requires a moving current, of lesser magnitude, to carry away organisms and debris that are washed off. Vertical pumps can be provided in such a screen, if velocities can be equalized, or a pipeline can feed the water from the screen to a pump in a dry pit arrangement.

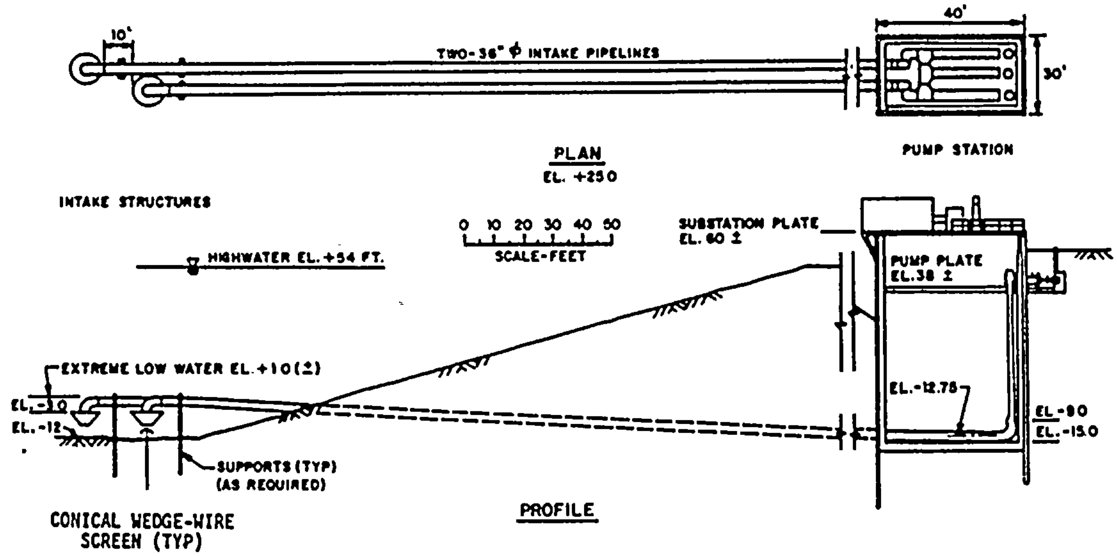


Figure 7 - Wedge-Wire Screens with Dry Pit Pumpwell

Another method of fish protection, which extends to smaller biological forms as well, is the radial well infiltration intake, which is a horizontal version of a vertical water well drawing water from a surrounding aquifer. When an adequate aquifer exists, experience indicates that the maximum capacity of a single well may be as high as 20,000 gpm. Several wells may be placed in a group. A vertical pump is usually used with this design. Although infiltration intakes offer significant potential for minimizing loss of aquatic organisms, their use is restricted to very few sites.

MODEL STUDIES

Recently, experimental approaches utilizing large-scale hydraulic models and live fish,[8,9] were used to develop intake designs. Laboratory evaluations enable testing of an intake concept over a wide variety of hydraulic and environmental parameters at a relatively low cost. In laboratory testing, every attempt should be made to establish test parameters which closely simulate those that would exist in a prototype system. For example, when evaluating a screenwell fish diversion concept, hydraulic parameters such as water velocity, screen orientation, and bypass width can be easily modeled. Modeling of full-scale screenwell depths, lengths of screens and pipelines, pipe diameters, and pressure changes may not be feasible. However, on the basis of past studies, water depth is not considered important. Modeling of smaller diameter pipes than in a prototype is considered conservative. In fish guidance studies, model diversion devices should be as long as possible to ensure that fish can be effectively guided to a bypass despite conditions which might result in fatigue. Although pressure change along tunnels and shafts may not be easily modeled, pressure chambers can be used to simulate pressure effects on fish. Environmental parameters, such as fish species, temperature, and selected water quality should be modeled. The layout of an experimental flume that was used to develop a screenwell fish diversion concept is shown on Figure 8.

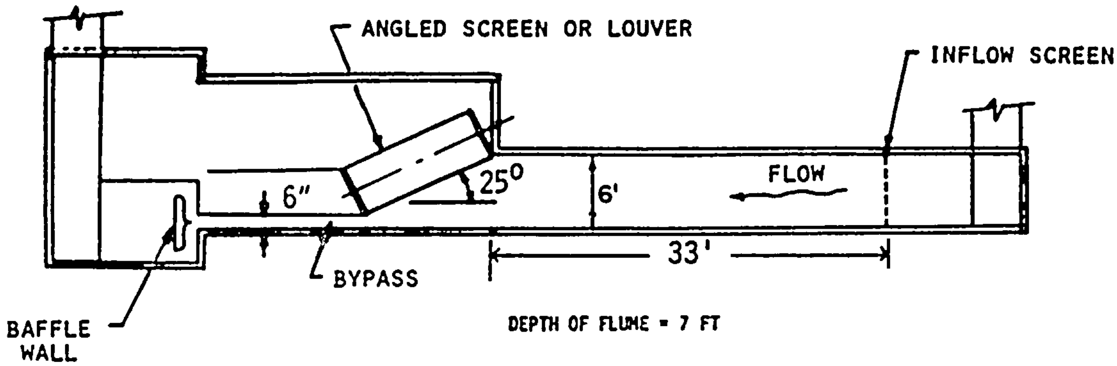


Figure 8 - Experiemental Fish Flume

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. In certain cases, model studies and field investigations are desirable to evaluate specific design parameters.

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

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