Avoiding Common Pitfalls in Cooling Tower Pump Intake Design Related to Hydraulic Performance

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Abstract

Cooling towers are an attractive method to provide cooling water to power plants and other process cooling applications. The use of cooling towers versus once-through cooling significantly reduces the amount of water drawn from rivers and lakes, which is particularly important in many regions in the Western United States where water availability is a problem. Cooling towers also eliminate thermal pollution due to cooling water discharges into and greatly reduce the amount of water withdrawn from natural bodies of water.

Despite these advantages, cooling towers provide special challenges with regard to the design of cooling water pump intake structures. These challenges must be addressed to ensure a reliable flow of cooling water with a minimum expenditure of power in order to maximize the plant capacity and efficiency. Design factors such as design footprint, civil constraints, increases in plant capacity requiring increased cooling flow, and off-design operation can all affect the flow hydraulics and therefore negatively affect the performance of the intake pumps.

In this paper, general hydraulic design guidelines and performance acceptance criteria for pump intakes based on Hydraulic Institute Standards are outlined. Case studies from physical model studies of cooling water pump intakes are presented which may provide insight into likely problems and design flaws that engineers should be aware of while designing cooling tower pump intake structures. Examples of measures to avoid or remedy the commonly-encountered hydraulic problems derived from hydraulic model studies are discussed.

1.0 Introduction

Cooling towers are increasingly being used to provide cooling water to power plants. These structures are able to conserve the use of water, and minimize potential environmental impact caused by the use of once through cooling.

At the base of the cooling towers a pump intake structure is constructed to convey the flow from the tower to the power plant. These structures are designed to provide acceptable approach flow patterns to the pumps, free of adverse hydraulic problems such as unacceptable free surface and subsurface vortices, pre-swirl at the pump bell entrance and air entrainment. The Hydraulic Institute Standards (HIS) provides acceptance criteria as regards to the flow entering pumps, and gives general guidelines for the dimensions and layout of pump intakes. However, due to space constraints and limited submergences to pumps, it may not be possible to satisfy all HIS requirements. Hydraulic (physical) model studies are required in such cases to evaluate the hydraulic performance and to derive remedial modifications as needed.

Typically a hydraulic model study would include i) observation and documentation of flow patterns approaching the pump bays and within the pump bays, ii) observation and documentation of the location, strength and frequency of any free surface and subsurface vortices present, iii) measurement of swirl within the pump bell or in the suction pipe to evaluate any pre-rotation present in the flow approaching the impeller, and iv) measurement of velocity distribution within the pump bell or in the suction pipe to evaluate the axial velocity profile of the flow approaching the impeller. Acceptance criteria for vorti ces, swirl and velocity distribution are available in HIS. Further, for all pump intakes with larger pumps of capacities above 40,000 gpm per pump, HIS recommends hydraulic model studies to assure that the guidelines for satisfactory hydraulic performance are met. A hydraulic model study may also provide for solutions to flow patterns that may not directly impact the pumps but have a negative impact on the operation of the station such as flow separations and air entrainment due to reasons other than vortices.

Based on several hydraulic model studies, the issues that are of special concern in the design of cooling tower pump intakes are discussed. Some recommendations as to how to avoid these problems are also explored.

2.0 Common Problems at Cooling Tower Intakes

2.1 Conveyance of Flow from the Cooling Tower Basin to the Pump Intake Structure

When designing an intake structure from a cooling tower special consideration should be given to the area in which flow is transferred from the cooling tower to the pump intake fore-bay. Typically the cooling tower basin and the pump intake floors are at different elevations with the cooling basin higher. This presents a problem area in which the conveyance of flow must be given careful consideration. The flow entering the intake structure from a higher basin floor will generally result in higher velocities close to the water surface in the pump fore-bay, which could extend to the pump bays contributing to vortex severities. Thus, the transition from the basin floor to pump intake floor presents a critical design challenge where consideration needs to be given to the size of the fore-bay, the extent of the floor elevation drop, size of any gate openings, and the distance from the basin to the pumps.

The flow entering in the pump intake fore-bay from the cooling tower basin could be jetting from the cooling tower gates, or cascading into the intake structure from one or more sudden drops in floor elevations. The jetting flow can entrain air as well restricting flow into the fore-bay of the structure. If the jet is strong enough it may cause supercritical flow regions. In the case of a sudden drop in floor elevation or cascading flow with a number of drops, the resulting free over-fall into the intake may cause problems. If the water level in the basin is not high enough, the critical depth at the brink of the drop may be lower than that needed for sufficient inflow to pumps, thereby starving the pumps. Also, the turbulence entrains air into the system. The gate that divides the cooling tower and fore-bay should also be in the designers mind at this point, and has a big impact on the flow conditions entering the fore-bay. In general a smaller sized gate will have a greater chance of creating objectionable flow patterns, where as a large opening would reduce the velocities entering the fore-bay and result in fewer objectionable flow patterns. Due to space limitations sloping floors to accomplish the change in elevation may end be too steep resulting in supercritical flow and associated problems such as formation of a hydraulic jump.

2.2 Fore-bay Design

When considering the design of cooling towers one critical design area is that of fore-bay. The fore-bay conveys flow to each individual pump bay from the cooling tower. The length, width and depth of the fore-bay and minimum operating water depth should be designed with consideration given to the flow patterns to prevent free over-falls and super critical flow regions that may result in starving the pumps of water. Any gate structures that separate the cooling tower basin and the intake structure should also be well thought out when designing the fore-bay. The gates should be designed such that they are wide enough at the lowest water surface elevation to allow the flow to enter the intake structure without reaching supercritical flow. By avoiding supercritical flow in this area jetting from the gates and the likelihood of air entrainment will be minimized.

The approach flow patterns into the individual pump bays should also be thought of at this point in time. In order to minimize the likelihood of flow separations and a recirculation pattern forming in the fore-bay, a gradual contraction in the fore-bay width (HIS recommends less than 10 degrees on either side) may be useful. But the contraction should end well upstream of the entrance to the pump bays to minimize the likelihood of flow separations in the pump bays. With flow separations in the fore-bay and pump bays, skewed and unstable flow leading to vortices may occur in the pump bays. It is most desirable to have a relatively uniform approach flow to the pump bays as this will help to limit pre-swirl in the pumps. If a sloping floor is desired in the fore-bay, the slope should be very gradual (HIS recommends that the slope should not exceed 10 degrees). The width of the fore-bay itself will depend upon the number of pump bays and the pump bay design as discussed below.

2.3 Pump Bay Design

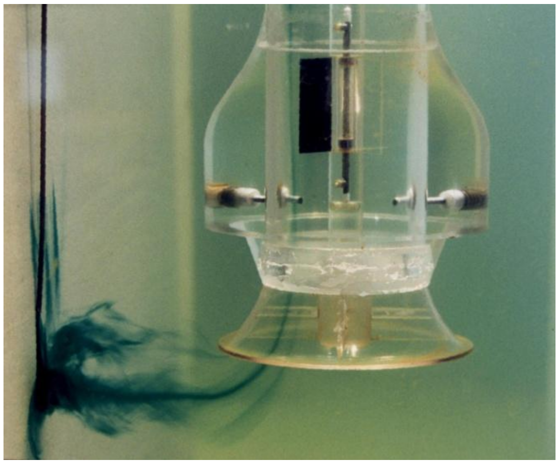


Figure 1 Detrimental Subsurface Vortex

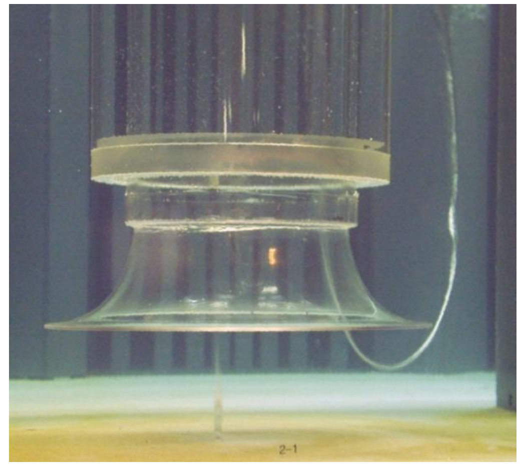


Figure 2 Air Drawing Surface Vortex

The pump intake should follow the Hydraulic Institute Standards (HIS) for pump bay dimensions, minimum submergence requirements and maximum approach velocity requirements to prevent unacceptable free-surface and subsurface vortices. Figure 1 shows an unacceptable subsurface vortex emanating from the pump bay back wall, while Figure 2 shows an air-drawing free surface vortex with an air-core. Both free-surface and subsurface vortices could induce unacceptable pre-swirl at the impeller entrance and vortices with air-cores could induce air entrainment degrading the pump performance and vibrations resulting in maintenance problems. The bay dimensions and minimum submergences recommended by HIS, are sometimes difficult to meet in the intake structure for a cooling tower because of space limitations and the fore-bay design limitations. The strong flow patterns that may set up in the fore-bay can be corrected by a variety of flow correcting devices and may be needed to provide uniform approach flow to the pumps. Such devices may include a series of columns placed near the entrance to the pump bay or a curtain wall to calm the surface flows. A quiescent flow pattern upstream of the pumps will be the least detrimental to the pumps.

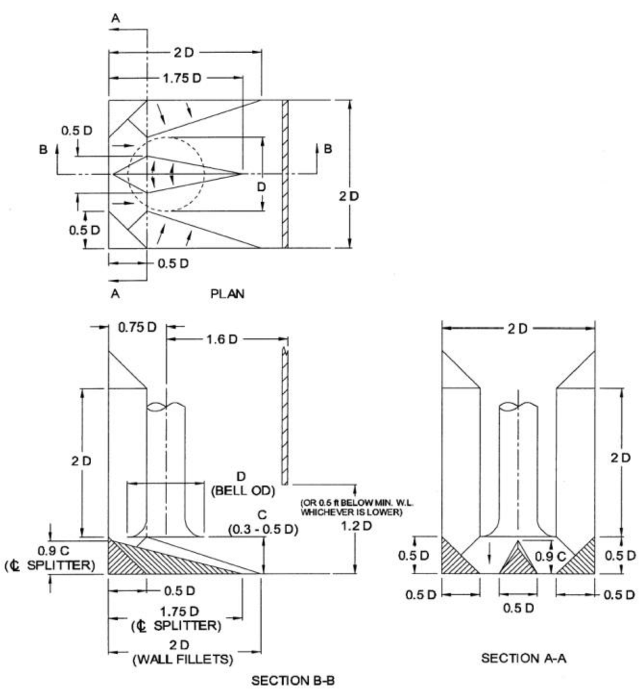


Figure 3 Common Fillet and Splitter Remedies
Note: D is the Pump Bell Entrance Diameter

In general pump intakes are designed prior to the selection of the pumps that will be used. This can cause some issues with the pump bay designs. The Hydraulic Institute Standards (HIS) recommend pump bay dimensions based on the entrance diameter of the pump bell, as indicated in Figure 3. The submergence is specified as a function of Froude number of the flow (defined with the flow velocity at the bell entrance and bell diameter at the entrance). Consideration should be given at the initial design phase to accommodate a change in the pump used. Some common remedial designs that can be used to correct this problem if a redesign is not possible would be to add benching to the sides of the pump bay, or the addition of fillets and splitters to direct the flow more uniformly into the pump bell as shown in Figure 3. It is recommended that the bay width fall within the HIS guidelines, and to only use these structures if detrimental flow patterns are found with a model study.

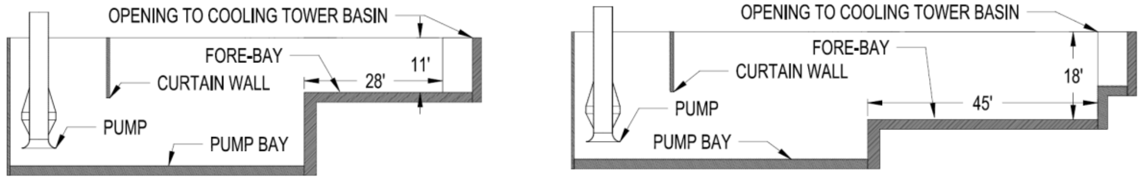
In cooling tower pump intakes, due to limited space availability for the fore-bay, the approach flow to the pump bays may be skewed, especially if all pumps are not operational. Flow distributors and/or curtain walls are often needed at the pump bay entrances (within the bays) to help improve the flow patterns approaching the pumps, or to limit the debris that may enter the pumps. A curtain wall spanning the entire pump bay is shown in Figure 3. Flow distributors may include a series of cylindrical or rectangular columns spanning the fore-bay before the pump bays. Both of these types of devices create a restriction in the flow and create a head loss (water level drop) in the system. These devices are intended to improve the approach flow conditions, but there remains the chance that the increase in head loss may not be acceptable in terms of minimum submergence to pumps.

When a trash rack or traveling screen is utilized in the pump bays consideration should be given to the area that is being used to screen debris in a manner to allow the majority of the flow to use the entire area of the screen. The use of the maximum area of the screen will minimize head loss due to blockage of these debris interceptors. An approach flow velocity to screens less than 1.5 ft/s is desired.

3.0 **Case Studies**

3.1 Problem conveying flow from Cooling Tower to Intake Structure

A hydraulic model study of a recently designed intake structure showed that the conveyance of flow from the cooling tower basin to the intake structure fore-bay had a detrimental impact on the flow patterns to the pump bays. The gate structure that was used was selected by the designer of the cooling tower basin, and sufficient thought was not given to the design of the gates. The gates were narrow and the flow exiting the gates entered the fore-bay as strong jets close to the water surface. The jet generated supercritical flow regions within the fore-bay. The result was a turbulent water surface and a series of hydraulic jumps resulting in unstable flow to the pumps. The water surface profile in the fore-bay did not allow enough depth within the pump bays and the pumps were starved of water and the system would not function properly. The turbulence also entrained air bubbles into the system that reached the pumps. The solution to this problem was a redesign of the fore-bay geometry. Figure 4a shows the original design and 4b the modified design. The fore-bay was lengthened and the floor elevation change was made in steps because of the issue, and the flow became much more quiescent. The impact of the jetting from the gate geometry was greatly reduced and the problem was solved without changing the gate design. Had the intake structure designer selected the gates this issue may have been avoided. The use of the Hydraulic model study to evaluate this problem saved the designer from constructing a prototype design that couldn't pass the flow to the pumps, and allowed them to evaluate and modify the design for a relatively small cost.

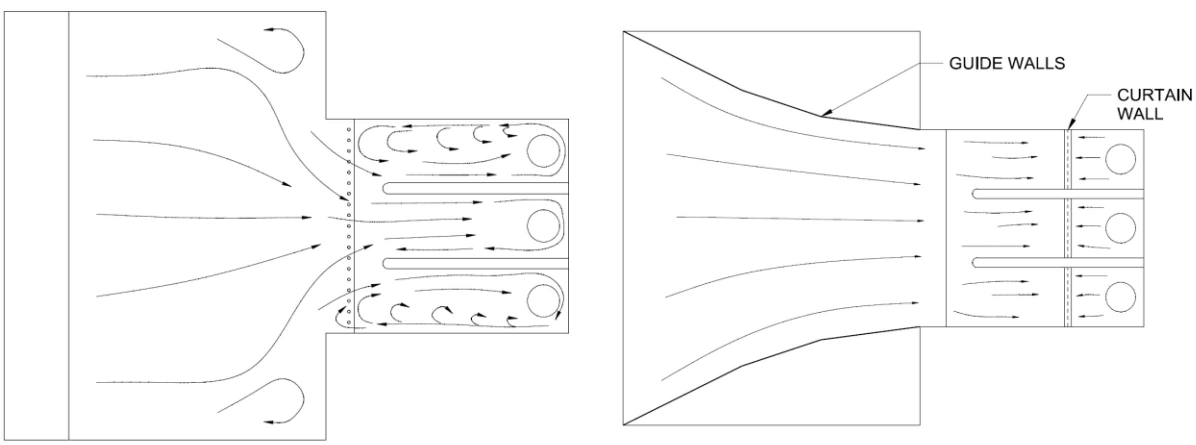


a) **Original Design** b) **Modified Design**

Figure 4 Modified Design with Expanded Fore-bay

3.2 Issues with poor approach flow patterns to the pump bays

In another cooling tower intake structure the fore-bay design had problems in effectively moving the flow to the pumps. The pump bays were drawing flow from a fore-bay geometry that was much larger than the total width of the pump bays combined. This design created a strong flow separation and eddy (pre-swirl condition) within the pump bays as shown in Figure 5a. The addition of guide walls to direct the flow into the pump, as shown in Figure 5b, made the flow much more uniform. The column type flow distributor was found to be detrimental due to high losses lowering the submergence at pumps, as discussed in the next section and was removed. Instead, a curtain wall was added within the pump bays (see Figure 5b) to correct the surface vortex activity that was observed.



a) **Original Fore-bay Design** b) **Modified Fore-bay Design**

Figure 5 Modifications Involving Flow Guidance within Fore-bay

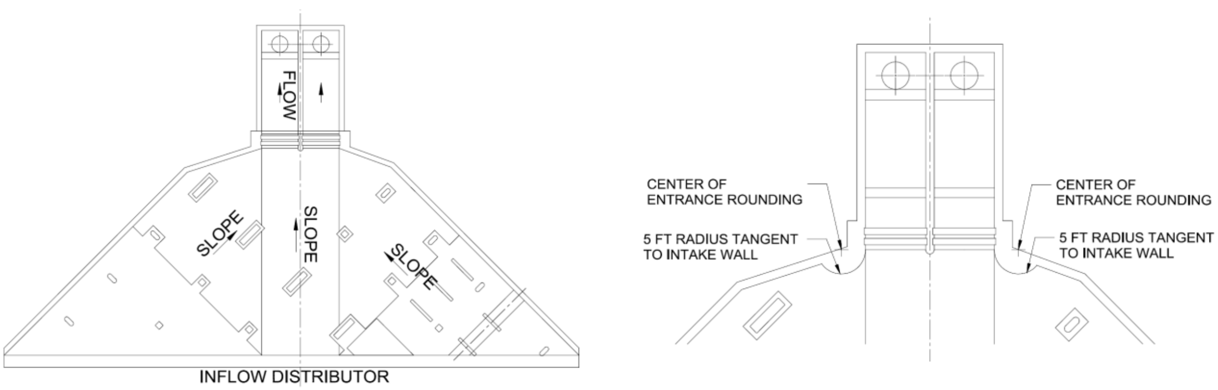
Note: Fillets and Splitters Removed for Clarity

3.3 Problem with starving pumps of flow

The cooling tower intake structure that was evaluated with a physical model and discussed in Section 3.2 and shown in Figures 5a and 5b, also encountered problems with water levels that are too low, starving the pumps of water. In this design a series of columns were placed at the entrance to the pump bays. The designer also wished to utilize a rather low water surface elevation in the intake structure. The combination of these two factors led to too low water levels due to flow distributor losses, and starving of the pumps. The flow distributor with columns generally require a low percent open area to be effective in redistributing flow and making it more uniform; but the losses induced by them may be too much as indicated in this case. The solution that was implemented in this case was the removal of the columns at the pump bay entrance, and to increase the minimum operating water surface elevation. However, with the cylindrical columns removed the flow was less uniform approaching the pumps and resulted in a large pre-swirl angle, as well as strong surface and sub-surface vortices. To correct for these problems a curtain wall was added to calm the water surface by generating an under flow and reducing surface velocities. The calmer water surface removed the surface vortex activity, and the increased velocity near the floor weakened the subsurface vortices. Since the subsurface vortices were still objectionable based on the HI guidelines fillets and splitters were added to the pump bays to resolve the issue.

3.4 Issues with poor approach flow patterns in the pump bays

One of the cooling tower intake structure that was investigated had issues with poor flow patterns in the pump bays that was created by the fore-bay geometry. In this design, shown in Figure 6a, a rather abrupt contraction with sharp corners was used to guide the flow to the pump bays. This design led to a large flow separation and eddy (recirculation) forming just upstream of the pump bay entrances, near the walls that were designed to guide the flow. The result was that this eddy caused poor approach flow



a) Original Fore-bay Design **b) Modified Fore-bay Design**

Figure 6 Modifications to Remedy Flow Separations in the Fore-bay

patterns in the pump bays. To correct for this problem a half cylindrical structure, as shown in Figure 6b, was placed in the area of flow separation to help guide the flow into the pump bays more uniformly. This device helped to improve the flow patterns but was not sufficient in itself to fully correct the flow patterns. A flow distributor was added that reduced the open area in the bay by 47%. This device redistributed the flow and made it much more uniform. As discussed earlier, the flow distributor should be used with caution as in the previous case where it was detrimental to the pumps and caused them to be starved by the increase in head loss.

Conclusions

In designing cooling tower pump intakes, the designer should be aware of a number of problems that can affect the hydraulic performance of the pump intake. The problems that are encountered may not initially be obvious, but can have some serious ramifications on the performance of the intake structure.

In general the designer should make every effort to avoid large floor drops from basin to intake fore-bay floor that may result in free over falls and/or supercritical flow, gates at the basin outlet that are too small and result in high velocity jets and sudden area contractions at the fore-bay to pump bay junction. Also, steep floor slopes greater than 10 degrees should be avoided. Sufficient submergence at the pumps (HIS criteria can be used) should be available to reduce detrimental vortex severities and pre-swirl. The implementation of common remedies should also be considered when designing the intake. The use of curtain walls, fillets and splitters, as well as flow redistributors will help to improve approach flow patterns. Rounding of corners and providing guide walls will have an enormous benefit in reducing flow separations and eddies.

The best way to ensure that adverse hydraulic problems will not be encountered at the facility is to use a hydraulic model study to evaluate flow patterns, vortex severities and pre-swirl. The use of a hydraulic model study to evaluate these problems and derive remedial modifications will help in the long run to reduce cost and maintenance of the facility. Potential major problems can be rectified at a much lower cost before construction rather than modifying a prototype design already constructed. The physical hydraulic model will also be useful in optimizing the location and size of flow correction devices that may be required in the prototype.

References

1. Hydraulic Institute Standards, ANSI/HI 9.8, 1998
2. Various Hydraulic Model Studies Conducted at Alden Research Laboratory