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A SYNOPSIS OF COOLING TOWER PUMP SUMP MODELING EXPERIENCE

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ABSTRACT

Cooling tower pump sumps are often designed according to the Hydraulic Institute (HI) Standards [1]. However, when geometric or economic limitations lead to deviations from these standards, a physical hydraulic model study is often conducted. This paper summarizes a number of recent physical model studies and brings to attention some of the recurring problems observed during the physical model studies. Performance comparisons are made between stations strictly adhering to the established design standards and those with minor or significant variations.

INTRODUCTION

The recent deregulation of many markets within the power industry has led to a surge in new power plant construction. To maximize control and operational flexibility, as well as minimizing impacts from drought and changing water needs, many of these plants utilize re-circulating cooling water systems as opposed to once through supplies from a lake or river. After passing through the cooling tower system, the water is re-circulated back into the system through pumps located in a sump on the end or side of the cooling tower basin.

A widely accepted set of guidelines developed by the Hydraulic Institute are often used to assist engineers in the design of these cooling water pump sumps. Adhering to these standards helps to avoid adverse hydraulic conditions which may decrease performance, accelerate pump wear, vibration, noise, and possibly damage. However, following the guidelines often requires a sump layout, or size, which may not fit within the existing or available space allotted for the sump. Understanding that no single set of guidelines can address all the possible scenarios a designer may encounter, the Hydraulic Institute requires that a physical hydraulic model study be conducted to ensure acceptable flow conditions if the design deviates from the established standard or exceeds a maximum flow rate.

During the past two years, the Clemson University Hydraulic Labs has conducted over twenty physical hydraulic model studies of cooling water pump stations with capacities ranging from 15,000 gallons per minute to over 600,000 gallons per minute. Many of these pump stations had limited space or other restrictions which resulted in sump layouts and designs which varied significantly from the established standards.

This paper provides a synopsis of this modeling experience and attempts to highlight some of the unique challenges posed to engineers when faced with geometric site restrictions, as well as some of the solutions used to overcome these problems. The paper focuses on the standard cooling tower configuration with the pumps located either on the side or end of the cooling tower basin. The intention of this paper is not to develop concrete guidelines for the development of sumps, nor is it intended to disagree with existing standards. The large number of variables between sumps makes it unlikely a single catch-all design can be developed for all situations. The intention of the paper is to provide the designer with the experiences learned from many sump studies so that cost saving measures may be identified early in the design process. This paper is not intended as a substitute for a physical model study but to provide insight which may be used to develop a cost effective initial design which can be verified and if necessary, modified through physical modeling.

NOMENCLATURE

W = pump bay width
L = pump bay Length
D = pump bell diameter
S = submergence distance from water surface to bottom of the pump bell
V = pump bell velocity
g = gravitational constant
Re = Reynolds number (VD/υ)
υ = kinematic viscosity

EXISTING KNOWLEDGE

There has been extensive research conducted in the past on the optimum pump station design, layout and modeling by Prosser [2], Hecker [3], Padmanabhan and Hecker G.E [4], Sweeney et.al. [5] and others. These researchers have investigated the optimum pump bay lengths and widths, optimum intake geometry and approach flow configurations, required submergence to minimize vortex formation, and optimum pump placement. This research, in conjunction with many industry professionals has led to the development of a standard published by the Hydraulic Institute in 1998 [1], which is widely used by engineers to aid in the design of pump intake structures.

These guidelines provide engineers with recommended intake configurations, dimensions, maximum velocities, and minimum water levels. The guidelines are furnished with the intent of providing uniform flow at the pump bell or in certain cases, the pump impellor. Failure to provide uniform approach flow can result in pump performance that differs significantly from that predicted from the performance curves. The pump may not operate at the best efficiency point, flow or head may be less than expected, power requirements may vary, and if the approach flow conditions vary enough, significant damage could occur to the pump itself. Research by Tullis [6] has shown that these conditions can lead to fluctuating loading on pump impellers, vibration, cavitation, as well as decreased flow and efficiency.

While the HI Standards are a compilation of the works and experiences of many different researchers, it is the author's experience that currently it is probably the most widely used document to guide engineers in the design and development of pump intake structures. In fact, many pump manufactures will not warranty certain pumps if the intake structure does not conform to these standards.

STANDARD DESIGNS

While there are countless possible intake structure layouts, this paper will focus on the common arrangement of housing the pump intake structure either on the end or on one side of the cooling tower basin. Photo 1 shows a model photograph of a pump intake located on the end of a long cooling tower basin, Photo 2 shows the intake structure located on the side.

The HI Standards provide detailed guidelines for the dimensioning of these intake structures. For rectangular sumps, such as those typically encountered on cooling tower basins, the length (L) and width (W) of the pump bays are well established and based on the pump bell diameter (D). HI recommends a minimum pump bay length (L) equal to 5D, and a bay width (W) equal to 2D. It is the author's experiences that these dimension guidelines are typically followed and have been used in many successful installations.

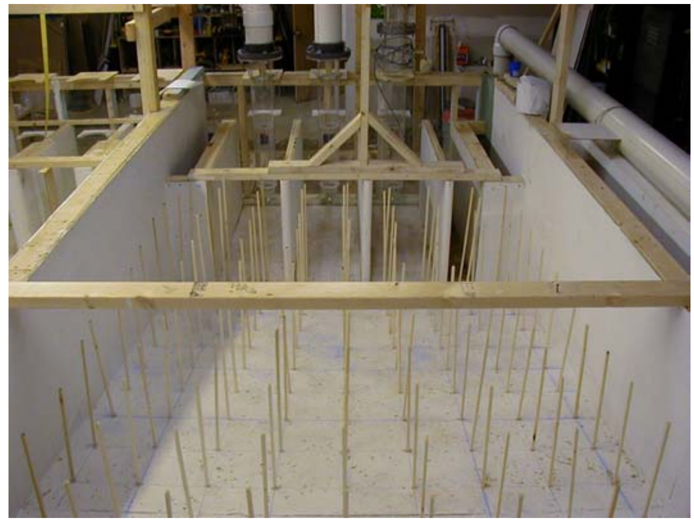

Photo 1 End Inlet Configuration

The greatest variations between pump stations typically occur at the transition between the actual cooling tower basin and the intake structure. The type of transition chosen can significantly affect the overall length, cost, and degree of difficulty to construct. The following sections discuss the experiences and lessons learned from numerous model studies of both end and side inlet configurations.

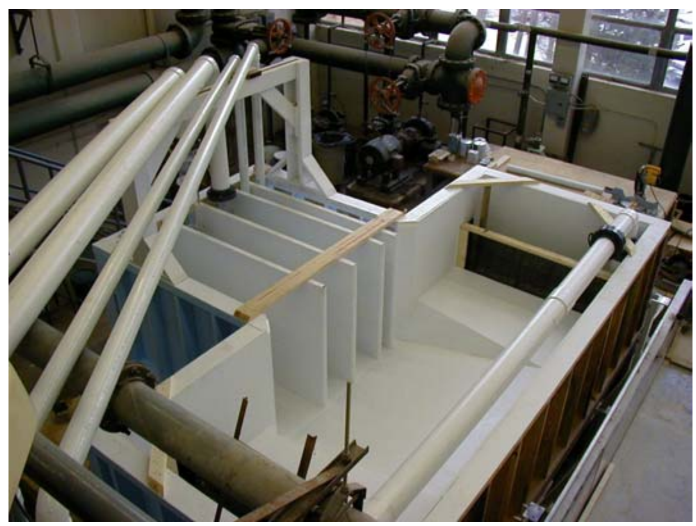

Photo 2 Side Inlet Configuration

INTAKE CONFIGURATION

Locating the sump on the end of a long cooling tower basin has a number of advantages in terms of hydraulic approach flow conditions. The biggest advantage is that the flow does not have to make a right angle turn into the sump. Another is that regardless of which cooling towers are in operation, flow will always approach the sump from the same direction. A significant disadvantage is that the overall length of the cooling structure must be longer, which can pose a problem on sites with limited space. A second disadvantage, depending on the location of the structure relative to the condensers is that it may require significantly more discharge piping to move the water from the pumps to the condenser units. However, modeling experience has shown that the overall hydraulic conditions tend to be better in intake structures located on the end of the basin.

Locating the intake on the side of a cooling tower also offers a number of advantages. First, it is possible to isolate one side of the cooling tower to conduct repairs or maintenance without taking the entire basin off-line. A second advantage is that locating the intake structure on the side of the basin results in a shorter overall basin. This is often desirable on sites with limited available space. A third advantage is, depending on the cooling tower basin location relative to the condensers, it may require less overall piping. A significant disadvantage is that the flow must turn 90-degrees to reach the pumps. This can result in significant flow separation at the entrance to the pump bays, resulting in higher pre-swirl and turbulence at the pumps.

The biggest variable observed in both configurations is the transition from the cooling tower basin to the sump. This transition is necessary because of the significant variation in depth between the cooling tower basin and the actual pump sump as well as differences between the basin and sump width. This results in some type of vertical and horizontal transition. The 1998 HI Standards suggests transitioning vertically from the shallow basin to the deeper sump with a sloped ramping floor. The standards suggest that this vertical transition occur over a sufficient distance to ensure that the horizontal angle of the transition results in a slope of less than 10-degrees. Photo 3 shows a typical sloped ramp transition. Another approach which has been seen with increasing frequency to transition vertically from the basin to the sump is a single or multiple vertical drops. This configuration is shown in Photo 4.

In addition to the vertical transition, it may also be necessary to provide a horizontal transition in the typical case of a sump which is not as wide as the cooling tower basin. One alternative is to make the sump as wide as the basin, and then transition the bay width down to the suggested width of 2D before reaching the pumps. This option requires more excavation and concrete, thus increasing the overall cost. It is more common to see a smaller sump with a width required to provide a constant bay width of 2D.

The recent model studies conducted of end oriented intake structures has shown a wide variety of horizontal transitions to take the narrow sump out to the width of the basin. One approach is to simply provide a 90-degree corner at the junction of the basin and sump. This is the most common approach for side oriented intake structures. This approach is shown in Photo 5.

Photo 3 Sloping Ramp Transition

Photo 4 Multiple Vertical Step transition

An alternative approach, and one suggested by the HI Standards is to provide an angled wing wall to transition out to the full width of the cooling tower basin. The standards suggest that the angle of these wing walls be less than 10-degrees. Photo 6 shows a photo of a wing wall transition. A disadvantage to this configuration is that again, it requires a longer overall structure. A variation of the 90-degree transition is to round the entrance as shown in photo 7.

The optimum cooling tower layout is one that provides uniform approach flow conditions at the pumps, minimizes cost, and stays with geometric site restrictions. The actual layout of the sump varies not only with the intake configurations mentioned above, but with the number of pumps and the actual flow rates. Seldom are the requirements of two different intake structures identical. This variability was recognized in the development of the HI Standards and the intended purpose of the guidelines is to provide guidance for those stations which fall within a set of parameters. Most notably is that the 1998 HI guidelines are intended to serve as a basis for design for rectangular pump sumps which have individual pump flows of less than 40,000 gpm or total station flows less than 100,000 gpm. If the intake flows exceed these limits, or if the intake structure varies from the recommended layouts, then the guidelines are intended to serve as a starting point and a physical hydraulic model study should be conducted to verify, and if necessary, modify the design to ensure acceptable approach flows. The following sections discuss several model studies which were conducted for large cooling water intake structures.

Photo 5 90-Degree Transition

Photo 6 Flared Wing Wall Transition

Photo 7 Rounded Entrance Transition

MODEL STUDIES

Model studies were conducted for twenty-one individually unique cooling tower intake structures. These studies were conducted according to the 1998 Hydraulic Institute Standards. The models were used to verify the design and to develop modifications to ensure acceptable approach flow to the pumps. The HI Standards indicates several criteria which are to be used when evaluating this type of structure. In particular, pre-swirl, velocity distributions, turbulence levels, and vortex activity are evaluated. Each model was constructed as an undistorted Froude scaled model with a large enough length scale to ensure that the Reynolds number at the model pump bell exceeds $1x10^5$ as defined by Equation 1.

$$Re = \frac{VD}{\nu} \quad [1]$$

Pre-swirl was determined with a rotometer, velocity and turbulence levels were measured with a miniature propeller meter, and vortex activity was evaluated visually with the aid of dye. The reader is encouraged to refer to the HI Standards for a more inclusive explanation of modeling theory and testing procedures.

Table 1 shows a summary of each of the sumps modeled. The table indicates whether the sump was located on the side or end of the cooling tower basin, the number of pump bays (including auxiliary pump bays), the pump bell diameter, and the minimum submergence from the water surface to the bottom of the pump bell (S/D). In addition the vertical transition angle from the basin to the sump invert is given in degrees from horizontal. The horizontal transition angle is also given in degrees. For example, a 90-degree transition indicates that the narrow pump bay meets the wider cooling tower basin at a right angle corner as shown in Photo 5, while a 10-degree horizontal transition flares outward at 10-degrees to the full width of the basin with wing walls as shown in Photo 6. The pump bay width to bell diameter ratio is also given.

Table 1 Intake Layout Summary

Sump	Intake Location	# of Pump Bays	Vertical Transition Angle (deg)	Horizontal Transition Angle (deg)	Pump Bell Diameter (in) [cm]	Min. Sub. Ratio (S/D)	Width Ratio (W/D)
1	End	2	14.25	90	61 (155)	3.56	2.0
2	End	2	9.5	90	74 (188)	1.55	1.84
3	End	2	9.5	90	59 (150)	1.95	2.31
4	End	2	8.7	90	66 (168)	1.85	2.06
5	End	3	10	90	55 (140)	1.91	1.84
6	End	3	10	90	74 (188)	1.88	2.27
7	End	3	10	90	74 (188)	2.09	2.03
8	End	3	14.2	15.2	54 (137)	2.02	2.06
9	End	3	90	90	100 (254)	1.61	2.0
10	End	4	10.7	5	78 (198)	1.75	2.0
11	End	4	90	90	74 (188)	2.81	2.0
12	End	4	10	90	66 (168)	1.73	2.0
13	End	4	12	7.5	49.5 (126)	2.18	2.14
14	End	4	10	10	70 (178)	1.61	2.29
15	Side	2	90	90	85 (216)	2.03	2.01
16	Side	2	90	90	88 (224)	1.47	2.39
17	Side	2	16	45	82 (208)	2.49	2.0
18	Side	3	90	90	97 (246)	1.83	2.0
19	Side	4	90	90	64 (163)	2.27	2.23
20	Side	4	15	Rounded	73 (185)	1.97	2.0
21	Side	5	13.4	90	64 (163)	2.31	2.0

Each model was used to verify acceptable hydraulic performance at the intake to each of the pumps. If the hydraulic conditions did not meet the established criteria, then modifications were developed to alleviate any adverse hydraulic phenomena. Typical modifications included fillets & splitters under the pumps, a curtain wall to deflect flow downward from the surface, flow straightening piers, and grating platforms to dissipate vortex activity.

RESULTS

To compare the wide variety of intakes modeled, and to gain insight into the effectiveness of the different types of structures, a list of the modifications developed for each intake structure was compiled. While it is difficult to compare the different types of structures with one another, it is possible to get a sense of recurring problems and modifications required to alleviate them. This list is shown as Table 2.

Sub-Surface Vortex Activity

As expected with pumps of this size, sub-surface vortex activity in the vicinity of the pumps was observed in all twenty-one intake configurations. To eliminate this vortex activity, fillets and splitters were installed in every intake regardless of the intake orientation.

Surface Vortex Activity

Vortex activity originating from the water surface was present in every intake. These vortices are a function of submergence, bell velocity and diameter, and fluid rotation. The degree of surface vortex activity varied between structures, but was outside of the established acceptance criteria. The 1998 Hydraulic Institute Standards provides guidelines for determining the submergence required to prevent air entraining vortex activity. It is interesting to note that while 18 of the 21 intakes had more submergence than suggested by the HI Standard, all 21 stations required curtain walls to dissipate the surface vortex activity.

Table 2 Required Modifications

Sump	Intake Location	Fillets & Splitters	Curtain Wall	Piers	Curtain Wall Grating	Pump Bell Grating	Entrance Half Pipe
1	End	Yes	Yes				
2	End	Yes	Yes		Yes		Yes
3	End	Yes	Yes		Yes		Yes
4	End	Yes	Yes		Yes		Yes
5	End	Yes	Yes				
6	End	Yes	Yes				
7	End	Yes	Yes				
8	End	Yes	Yes	Yes	Yes		
9	End	Yes	Yes			Yes	
10	End	Yes	Yes				
11	End	Yes	Yes	Yes			
12	End	Yes	Yes	Yes		Yes	
13	End	Yes	Yes	Yes	Yes		
14	End	Yes	Yes	Yes	Yes		
15	Side	Yes	Yes	Yes			Yes
16	Side	Yes	Yes	Yes		Yes	
17	Side	Yes	Yes		Yes		
18	Side	Yes	Yes	Yes			
19	Side	Yes	Yes	Yes	Yes		
20	Side	Yes	Yes	Yes			Yes
21	Side	Yes	Yes	Yes			

Flow Separation

Flow separation at the entrance to the intake can lead to skewed velocity distributions and pre-swirl of flow into the pumps. Intake structures located on the side of a cooling tower are expected to have more flow separation due to the fact that the flow must turn 90-degrees to enter the sump. However, intakes located on the end of a basin are also susceptible to this flow separation. End oriented intakes often have non-symmetrical pump layouts. This is often the case when an auxiliary pump is located adjacent to one of the circulating water pumps, if one or more pumps are not operating, or if some type of smooth transition between the wider cooling tower basin and the sump is not provided. The typical remedy for this flow separation is to install some type of flow straightening device at the entrance to the pump bays.

Of the side oriented sumps investigated in this study, 86% of the intakes required flow straightening piers at the entrance to the sump. The only one that did not was Sump 17, which had a 45-degree flared transition out to the sump.

Grating Platforms

Occasionally, the installation of a curtain wall simply moves the surface vortex activity upstream. These surface vortices may pass under the curtain wall and into the pump. The location of the curtain wall affects the flow conditions in the vicinity of the pump, so it may not be possible to move it far enough upstream to prevent these vortices from traveling under the wall and to the pump. It is sometimes necessary to install a grating platform or a series of pipes upstream of the curtain wall to dissipate this vortex activity. This was necessary in 43% of the end oriented intakes and 29% of the side oriented intakes.

In addition to the region in front of the curtain wall, severe approach flow conditions may cause vortex activity behind the pump even with fillets and splitters installed. If this activity is strong enough, it is sometimes necessary to install a grating platform around the back of the pump as well. This was necessary in 14% of the end oriented intakes and 14% of the side oriented intakes.

To provide the reader with a better understanding of the types of modifications typically installed in these types of pump intake, Photo 8 shows the typical modifications necessary to achieve acceptable hydraulic conditions.

COMPARISONS

Several components of the HI recommended sump design seem to surface more frequently in conversation as being problematic or undesirable by designers. It is the author's experience that the transition from the main basin to the sump is the design component that suffers most when cost cutting measures are being implemented or space is at a premium. Review of the twenty-one intakes models discussed in this paper may provide some insight into this component of sump design. Although countless variations may exist, this paper will focuses on the horizontal and vertical transitions discussed in earlier sections.

Photo 8 Curtain Walls, Piers and Fillets & Splitters

Effective Vertical Transitions

What is probably the single biggest expense, and probably has the most significant impact on transitioning flow from the basin to the sump is the vertical transition. It is well known that shallow, uniform, and gradual vertical transitions provide the best hydraulic conditions for proper pump operation. The Hydraulic Institute recommends that this sloping transition be at an angle of 10-degrees or less from horizontal. For intakes in which a model study will not be conducted, and other dimensioning guidelines have been followed, this is wise advice. However, if a model study will be conducted, as is often the case with larger pumps, it may be possible to increase this transition angle.

Constructing a sloped transition on the end of a cooling tower is typically accomplished by extending the sloped floor up in to the basin. While this does not increase the need for any additional space, it does require modification to standard cooling tower designs. The legs of the cooling towers must be made longer, flat mounting surfaces must be constructed in to the slope, and additional excavation is required beyond that of a vertical transition.

The average sump depth for the twenty one intakes investigated was 3.8 m (12.5 ft). To transition down 3.8 meters over a 10-degree slope requires a horizontal length of 21.6 m (70.6 ft). This same sump would require a length of only 14.2 m (46.5 ft) with a 15-degree slope. Reviewing the data shown in Table 2 indicates that in most cases, vertical transition slopes greater than 10-degrees did not require any additional modifications beyond those less than 10-degrees for intakes located on the end of the basin. Nearly all basin located on the side required piers. Care must be taken in interpreting the data. The authors experience has been that vertical 90-degree drop off transitions generally do not yield as uniform conditions at the pump as those with sloped transitions. Experience over many studies has shown that a 15-degree sloping transition will yield as good of flow conditions as those with 10-degrees of less, while significantly reducing the transition length.

Effective Horizontal Transitions

The author has seen many cooling tower intakes which have attempted to transition slowly out to the wider cooling tower basin. This can be achieved successfully for basin located on the end of a tower, but is generally not possible for those located on the side.

Reviewing Table 2, the reader can see that for intakes located on the end of a cooling tower basin several intakes that attempted to flare out at some angle actually resulted in additional modifications. Again, caution should be taken when attempting to generalize this data. A two cell pump bay will inherently have fewer problems than a three or four cell sump which has been proportioned geometrically similar. However, when looking for trends, it can be seen that in general, a simple 90-degree transition at the entrance to the sump does not increase the required modifications.

The ideal horizontal transition is a smooth rounded corner. However, this is difficult and costly to construct in the field when compared to a 90-degree corner. Having seen numerous 90-degree horizontal transitions work as well as elaborate transitions, the author recommends a 90-degree transition for sumps on located on the end or the side of the cooling tower basin for sumps which will be physically modeled. If necessary, a simple modification is to simply bolt a piece of half-pipe, in the basin, at the 90-degree corner to simulate a smooth rounded entrance, which typically provides the best results. This type of modification is inexpensive, and has worked as well as those formed into the transition. The diameter of this half-pipe is a function of the velocity and is beyond the scope of this paper to determine exactly. However, to provide the reader with a sense of scale, a 6-ft diameter pipe, cut in half and bolted to each side of the entrance is a typical size for cooling tower applications, but again, this type of modification should be verified in the model.

NUMBER OF PUMP BAYS

The number of individual pump bays is a function of the required flow, operating scenarios, and requirements for stand-by pumps. However, two 50-percent capacity circulating water pumps are common in cooling tower applications, and generally have the best approach flow conditions. These stations often have auxiliary pumps for a variety of reasons. These pumps often run for short periods of time, and often when one of the circulating pump do not, and are often housed in their own pump bays. This can create non-symmetrical approach flow conditions when only one auxiliary pump bay is present, or increase the degree of cross flow when one or more are included.

Many of the intakes investigated in this study had auxiliary pumps which were housed upstream, but in the same bay as a circulating water pump. This design has proven effective in most cases, and has often resulted in improved flow conditions. There are many variables involved with doing this, and the reader is cautioned that persons with experience with this layout should be consulted prior to eliminating the separate auxiliary bays, or a proven design should be followed. This is included in this text to indicate that this is possible so that this option could be investigated in the conceptual design, with the intention that the overall size may be reduced and possibly improve the conditions for the larger circulating water pumps by reducing the number of bays. Again, it must be stressed that unless a proven design is followed, or a hydraulic model study is conducted, the recommendations provided in the Hydraulic Institute Standards should be followed.

CONCLUSIONS

In reviewing the results of twenty one individual model studies, several conclusions may be drawn. It should be noted however, that if a model study will not be conducted, the guidelines presented in the Hydraulic Institute Standards should be followed carefully.

For larger pump stations, which are often modeled, then the comparisons presented in this paper may provide opportunities for cost saving measures. The typical cooling tower design process occurs rapidly, and by the time the hydraulic model study is completed, the design is typically completed and construction is often underway. At this point only non-structural modifications are possible, preventing major structural cost savings from being implemented. Therefore, it is desirable to maximize structural cost savings early in the design process.

The results appear to indicate that a sloped vertical transition of 15-degrees is just as effective as 10-degrees, and should not require additional modifications. This will reduce the required transition length, excavation, and modification to the standard cooling tower supports in the sloped region. Fillets and splitters and curtain walls were required in all stations, regardless if the transition slope.

A simple 90-degree horizontal transition between the basin and the sump is the least expensive and easiest to construct. This type of transition appears to be just as effective as transitioning to the sump with shallow angle wing walls. In the cases where the 90-degree transition created problems, then a simple proven solution was to simulate a rounded entrance by bolting a half pipe to the basin wall at the entrance to the sump. This simulates a formed radius and is must less expensive to construct.

While vertical 90-degree drop inlets into the sump appear to require similar modifications as those with sloped transitions, the overall approach flow conditions were rarely as uniform as those with sloped approaches. The designer is cautioned to move carefully with this approach unless past experience in this design has proven effective and validation will be conducted.

It is not possible to list all the scenarios one may encounter when designing an intake structure, however, by utilizing the findings generalized in this study, significant cost saving measures such as reducing slope lengths and squaring corners may be implemented early in the design process for those intakes which will be verified with a model study.

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