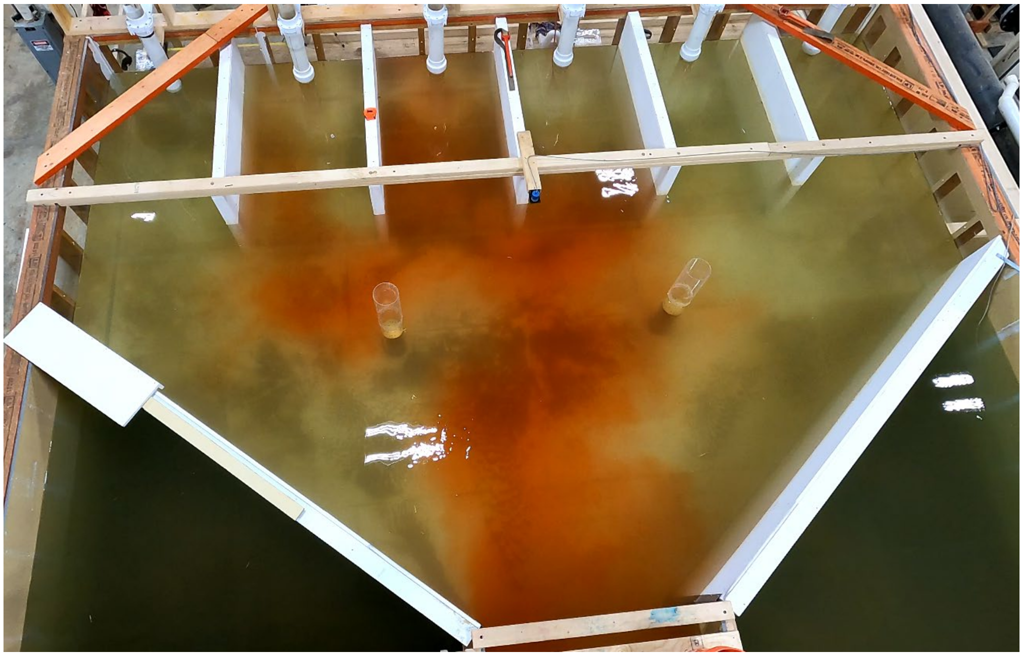
Hydraulic Laboratory Report HL-2023-02

East Low Canal 84.7 Pumping Plant Intake Physical Hydraulic Model Study



Columbia-Pacific Northwest Region
Odessa Groundwater Replacement Program

U.S. Department of the Interior

August 2023

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 14-08-2023	2. REPORT TYPE HL – Hydraulics Lab Report	3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE East Low Canal 84.7 Pumping Plant Intake Hydraulic Model Study	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Jacob Carter-Gibb	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Hydraulic Investigations and Laboratory Services Technical Service Center, Denver, CO	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Columbia Cascade Area Office, Columbia-Pacific Northwest Region	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Bureau of Reclamation's Hydraulics Laboratory at the Technical Service Center performed a physical hydraulic model study for the East Low 84.7 Canal pumping plant. The proposed pumping plant had an expanded footprint that was designed for ease of maintenance with five large pumps and one small pump. A computational fluid dynamics (CFD) model was completed in conjunction with the physical hydraulic model. The 1:4 Froude scale physical model included the full intake geometry, vertical pump inlets, and a partial canal section to match intake boundary conditions. Baseline tests of the original design found that the hydraulic conditions within the sump and entrance to the pump bells did not meet the recommended guidelines of the Hydraulic Institute Standard for Design of Pump Intakes 9.8. Several design modifications were tested to address the non-uniform intake flow conditions. A design configuration that included flow-straightening baskets was recommended for final design as it significantly improved the hydraulic conditions of the flow entering the pump bells to within HI 9.8 standards.

15. SUBJECT TERMS

pump intake, pumping plant, pump, Hydraulic Institute Standard

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Connie D. Svoboda
a. REPORT	b. ABSTRACT	a. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)* 303-445-2152

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Denver, Colorado

August 2023

Acknowledgments

Thank you to the Hydraulics Laboratory shop staff; Jason Black, Miles Van Zweden, Robert Borrego, and Jeff Falkenstine for their excellent craftsmanship of the physical model. Also thank you to Kit Shupe, Pesett Peau, and Aaron Hurst for their help with data collection and processing.

Hydraulic Laboratory Reports

The Hydraulic Laboratory Report series is produced by the Bureau of Reclamation's Hydraulic Investigations and Laboratory Services Group (Mail Code 86-68560), PO Box 25007, Denver, Colorado 80225-0007. This report was made available online at
https://www.usbr.gov/tsc/techreferences/hydraulics_lab

Disclaimer

Cover Photo: Overhead view of the EL 84.7 Physical Model (Reclamation).

Funding for this study was received from the Odessa Ground Water Replacement Program

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Glossary

CFD – Computational Fluid Dynamics
EL – East Low
ECBID – East Columbia Basin Irrigation District
gpm – gallons per minute
HI – Hydraulic Institute of Standards

Notation

The following symbols are used:

d = diameter of the pump casing, same as the throat of the pump bell (ft)
D = diameter of the pump bell (ft)
n = revolutions/second of the swirl meter used to measure θ
Q = volumetric flowrate (ft^3/s)
u = axial velocity within the pump casing (ft/s)
θ = angle of the swirl of the flow within the pump casing (degrees)

Executive Summary

Bureau of Reclamation's Hydraulics Laboratory at the Technical Service Center performed a physical hydraulic model study for the East Low (EL) 84.7 Canal pumping plant. The pumping plant had a proposed capacity of 48,000 gallons per minute (gpm) distributed among five large pumps and one small pump. The proposed pumping plant had an expanded footprint that was designed for ease of maintenance but as a result the proposed layout did not meet the design recommendations of the Hydraulic Institute of Standards (HI) (ANSI/HI 9.8 - 2018, 2018). A computational fluid dynamics (CFD) model was completed in conjunction with the physical hydraulic model to define the boundary conditions of the physical model and help guide potential hydraulic improvements. The 1:4 Froude scale physical model included the full intake geometry, vertical pump inlets, and a partial canal section to match intake boundary conditions. Baseline tests of the original design found that the hydraulic conditions within the sump and entrance to the pump bells did not meet the recommended guidelines of HI 9.8.

Several design modifications were tested to address the non-uniform intake flow conditions. Two of these design configurations significantly improved the hydraulic conditions of the flow entering the pump bells. One included a narrower pump bay width to allow the flow to accelerate and approach the pump bells with minimal circulation and turbulence. The second included a flow straightening basket mounted to the bottom of the pump bells and/or floor to evenly distribute the flow as it entered the pump. Both the narrower pump bay geometry and flow straightening baskets provided acceptable approach flow to the pumps based on the HI acceptance criteria. All final testing of the pumping plant was done with the flow straightening baskets installed.

The recommended configuration with flow straightening baskets will provide acceptable swirl and velocity distributions within the pumps to reduce operational issues such as vibration and uneven loading on the impeller that could lead to reduced performance and increased maintenance.

Introduction

Background

As part of the Odessa Groundwater Replacement Program pump stations EL 84.7 and EL 80.6 were designed by RH2 Engineering. These new facilities will help provide irrigation flows from the East Columbia Basin Irrigation District (ECBID) to farms from the surface water in the East Low Canal. The A/E design review of these facilities was performed by Bureau of Reclamation's (Reclamation) Technical Service Center (TSC) and the physical hydraulic model studies performed by TSC's Hydraulics Laboratory. While this report documents the study of EL 84.7, EL 80.6 will be tested using the same modeling facility, followed by a separate laboratory report.

Two other pumping stations on the EL Canal with a similar design have been modeled by other hydraulics laboratories (Hinton, 2017; Havice, 2021). These designs had very similar intake geometries with an entrance from a canal and expanding walls toward the pump bays. They found the baseline hydraulic conditions to be inadequate for the HI acceptance criteria with nonuniform velocities, dead zones and back eddies approaching the pump bays and high swirl levels near the pumps. ECBID has indicated that pumping stations designed to the HI hydraulic criteria increase difficulty of pump construction and maintenance due to the tight spacing for motors, piping, and equipment up above. They also indicated the extra cost of earthwork and modeling for a modified design to be a desirable tradeoff for ease of maintenance.

Model Study Objectives

- Ensure that the hydraulic conditions in the pump intake structure will allow for acceptable pump performance according to HI 9.8.
- Ensure acceptable uniformity of approach flow conditions through dye testing and measurement of swirl angle in the pump bell.
- Prevent vortex formation that may cause pump vibrations or other conditions detrimental to pump performance and service life.
- Ensure adequate velocity distribution and velocity fluctuation within the pump bell.

EL 84.7 Proposed Intake Design

The proposed sump geometry and position relative to the canal are shown in Figure 1. The design includes a capacity of 48,000 gpm and six vertical turbine pumps installed in pump bays of 12.5 feet in width and 14.5 deep along a back wall 80 feet long. Since the exact bell size has not yet been selected, conservative assumptions were made of a bell diameter of 22.625 inches at a design flow rate of 9,600 gpm for the five large pumps and 16.125 inches at a design flow rate of 4,280 gpm for the small pump. The combinations, or stages, of these six pumps were tested per the original design and are shown in Table 1.

Table 1. Test matrix pump staging. Flow rates are in gpm. Pump 1 is the small pump and 2-6 are the large pumps.

	Pump					
Stage	1	2	3	4	5	6
6		9,600	9,600	9,600	9,600	9,600
5		9,600	9,600	9,600	9,600	
4		9,600	9,600	9,600		
3		9,600	9,600			
2		9,600				
1	5,250					
Total (gpm)	**5,250**	**48,000**	**38,400**	**28,800**	**19,200**	**9,600**

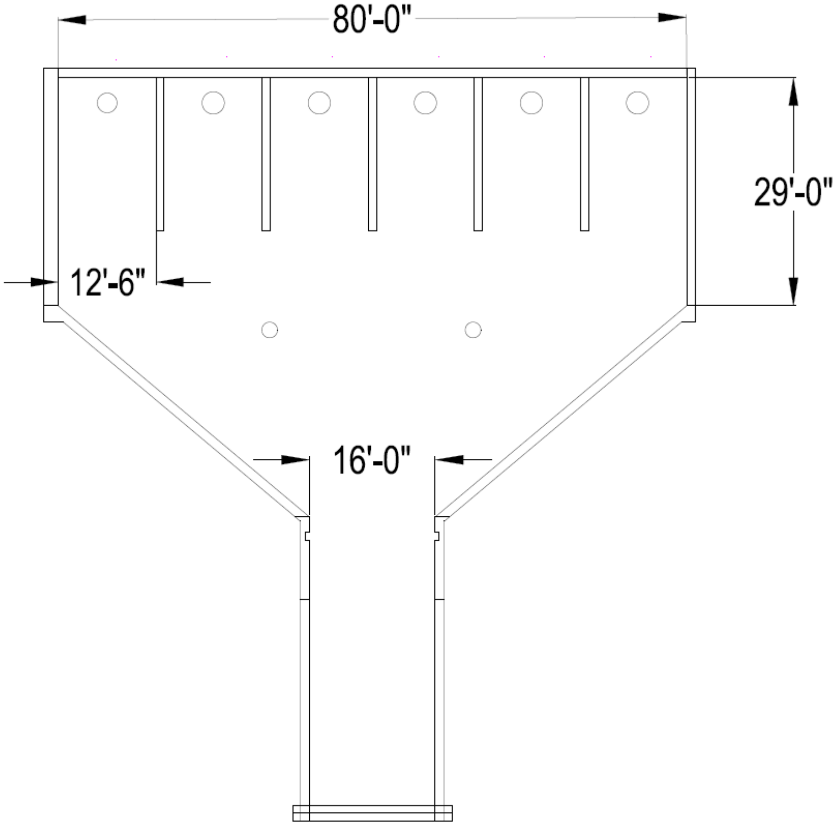

Figure 1. Proposed pump intake layout and prototype dimensions. The smaller pump (1) is on the left and the larger pumps (2-6) are on the right.

The EL canal had a discharge of 1,250 cfs, an average flow velocity of 2.4 ft/sec, a bottom width of 26 feet, a side slope of 1.5:1, a slope of 0.00009 ft/ft, a Manning's n of 0.0225, and a normal depth of 11.87 feet. Flow turns 90-degrees from the canal into the intake and passes through a set of traveling screens before entering a diverging forebay and the individual pump bays.

For all tests the water surface elevation was held at 1222.12 ft. Due to a control structure downstream of the proposed intake there was only one water surface elevation that the structure would be expected to see.

Experimental Approach

A hybrid approach with both numerical and physical modeling was used to study the intake's hydraulic conditions. The baseline design was modeled using CFD to determine the boundary conditions for the physical model. The physical model was used to study modifications to the original design and conduct all acceptance testing.

Numerical Model

FLOW-3D, a commercially available computational fluid dynamics (CFD) software package by Flow Science Inc., was used. FLOW-3D utilizes the Reynolds-averaged Navier-Stokes (RANS) equations to solve for fluid flow. Modifications to the standard RANS equations include algorithms to track the water surface and flow around geometric object (Hirt & Nichols, Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries, 1981; Flow Science Inc., 2012; Hirt & Sicilian, A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes, 1985; Hirt, Volume-Fraction Techniques: Powerful Tools for Flow Modeling., 1992).

The CFD model was configured using prototype dimensions to avoid size-scale effects and to simplify comparison between the model, physical conditions, and design dimensions. The model was configured in three dimensions.

A 3D geometry file of the proposed design was brought in to FLOW-3D that included 1700-ft of the canal upstream of the intake as well as 225-ft downstream of the canal. The geometry was overlaid with a computational grid of three separate mesh sizes that included rectangular shaped cells. Grid 1 included the canal geometry with a cell size of 2 ft, grid 2 covered the sump intake with a mesh size of 1 ft, and grid 3 nested inside grid 2 that included the pump bells and bowl geometry with a mesh size of 0.5 ft. The volumetric flow boundary (-x) was set to 1,250 cfs at the upstream end of the canal and a pressure boundary was set to a water surface elevation of 1,221 ft at the downstream boundary of the canal. Water that entered the sump exited the simulation through mass source objects located within the pump bells to provide design flows through each pump.

Turbulence was modeled using the Renormalized Group theory (RNG) because it more accurately describes low intensity turbulent flows and flows with strong shear regions using fewer computations than other methods (Flow Science Inc., 2012).

Physical Model

Model Design and Construction

The physical model was designed and scaled using Froude scale modeling techniques since gravity is the dominant force acting on the open channel flow within the structure. A model scale of 1:4 ($L_r = 4$) was selected to allow for the largest flow rate and model structures in the laboratory. The resulting Froude scale relationships are as follows:

Geometry – 1: L_r - *1:4*

Discharge – 1: $L_r^{\frac{5}{2}}$ - 1:32

Velocity – 1: $L_r^{\frac{1}{2}}$ - 1:2

Time – 1: $L_r^{\frac{1}{2}}$ - 1:2

Using the pump bell diameter of the large and small pumps as the critical length dimension results in a minimum Reynolds number of 8.34×10^4 and a minimum Weber number of 558. Both parameters are greater than the minimum required by H.I. standard of 6×10^4 and 240 respectively for physical modeling (ANSI/HI 9.8 - 2018, 2018) and are high enough to neglect viscous and surface tension effects at the model scale.

The exterior and floor of the model intake structure were constructed out of structural lumber and marine-coated plywood sheeting (Figure 2). Both sides and downstream exterior walls of the pump bell section of the sump were sheeted with clear acrylic for flow visualization. Interior features such as the dividing walls were made from expanded PVC sheets that resist swelling from long term water exposure. The pump bells were 3D printed using a Form Labs Form 3L resin printer. This allowed the assumed geometry to be refined at model scale while still being able to see through the pump bells to observe hydraulic phenomena. Each bell was connected to a separate PVC pipe for individual operation and flow control.

Figure 2. Left, construction methods utilized marine-coated plywood sheeting, clear acrylic paneling and expanded PVC sheeting. Right, clear 3D printed pump bells.

Testing and Instrumentation

Flow was delivered to the model via the hydraulic laboratory closed loop pumping system which pulls from a 240,000-gallon sump using four 100 hp pumps and is measured using venturi flowmeters accurate to ±0.25%. Each of the six model pumps were operated individually as siphons with the individual discharges controlled with downstream PVC gate valves. Each pump flow rate was measured individually with an acoustic flow meter (accurate to ±2%). Water surface elevations in the intake structure immediately upstream of the pump bay walls and in the canal upstream of the intake were measured using MassaSonic ultrasonic water level sensors.

The intensity of flow rotation entering the pump was quantified by the swirl angle (ANSI/HI 9.8 - 2018, 2018). A 3D printed rotometer (swirl meter) was installed in each pump (Figure 3) and used to determine the swirl angle of the flow entering the pump according to Eq. (1).

$$\theta = tan^{-1}(\frac{\pi d n}{u}) \qquad \text{Eq. (1)}$$

Where:
θ = swirl angle (degrees)
u = average axial velocity at the swirl meter (ft/s, estimated from pump discharge and d).
d = diameter of the pipe at the swirl meter (ft)
n = revolutions/second of the swirl meter

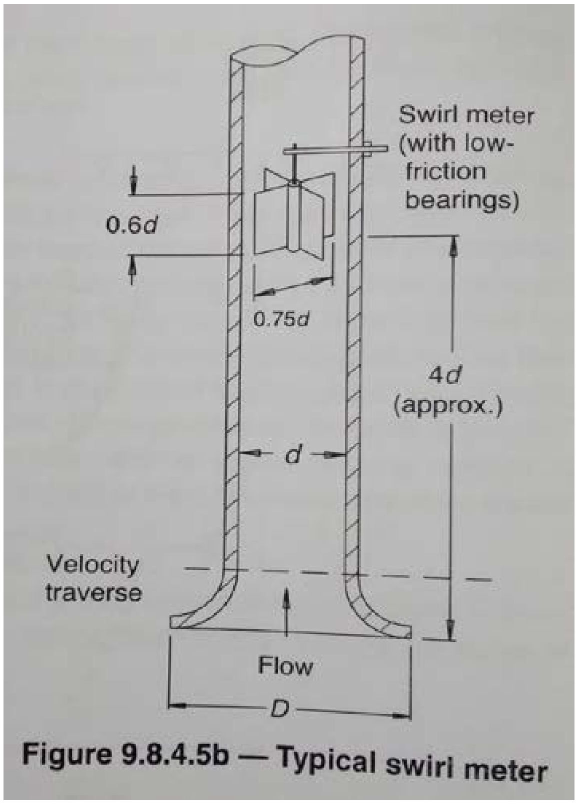

Figure 9.8.4.5b — Typical swirl meter

Figure 3. Schematic of swirl meter used to measure the swirl angle of the flow entering the pump. (ANSI/HI 9.8 - 2018, 2018)

To measure velocity uniformity in the throat of the pump bell, eight different locations were measured using a dynamic pitot tube at ¼ of the throat diameter (Figure 4). This was incorporated in the 3D print of one pump bell (Figure 5) to reduce the amount of flow interference as much as possible. This specialized pump bell was rotated for each location for velocity testing. Velocity testing within the pump was performed for verification of only the worst-case operating conditions of the final modified design to ensure compliance.

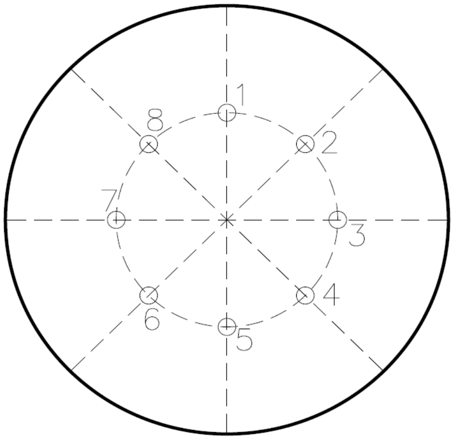

Figure 4. Axial velocity measurement locations within the cross-section of the throat of the pump bell.

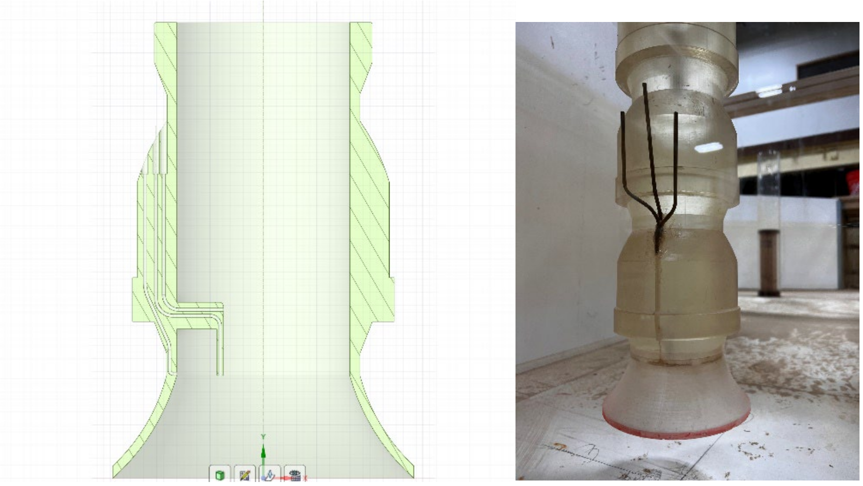

Figure 5. Left, cross section of the pitot tube pump bell. Right, 3D printed pump bell with piping installed.

Acceptance Criteria

The measurements and observations taken in the physical hydraulic model were used to evaluate the intake design. This evaluation closely followed the acceptance criteria in HI 9.8.7.7 and are as follows:

- Free surface and subsurface vortices entering the pump must be less severe than vortices with coherent (dye) cores. Dye core vortices may be acceptable only if they occur for less than 10% of the time or only for infrequent pump operating conditions. The visual vortex classification can be seen below in Figure 6.

- Swirl angles, both the short-term (30-second model) maximum and the long-term (10-minute model) average indicated by the swirl meter rotation, must be less than 5 degrees. Maximum short-term (30-second model) swirl angles up to 7 degrees may be acceptable, only if they occur no more than 10% of the time or for infrequent pump operating conditions. The swirl meter rotation should be reasonably steady, with no abrupt changes in direction when rotating near the maximum allowable rate (angle).

- Time-averaged velocities at points in the throat of the bell or at the pump suction in a piping system shall be within 10% of the cross-sectional area average velocity.

- Time-varying fluctuations at a point shall produce a standard deviation of less than 10% of the time averaged signal.

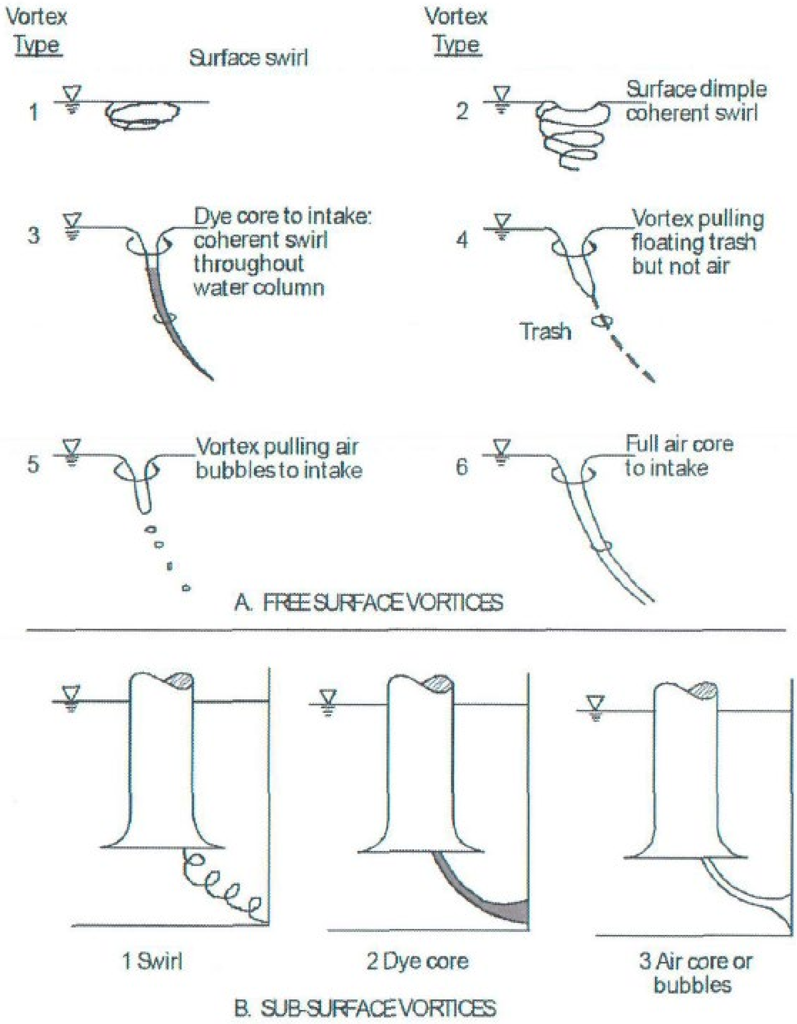

Figure 6. Classification of free surface and subsurface vortices. (ANSI/HI 9.8 - 2018, 2018)

Results

Numerical Modeling

The CFD model showed that the velocity distribution near the pump intake was fairly uniform due to the long straight section upstream which allowed streamlines to be mostly oriented downstream (Figure 7). This required minimal flow conditioning in the physical model to provide representative flow conditions at the pump intake. As flow entered the pump intake the numerical model showed a significant flow separation with greater velocities along the right side of the entrance (Figure 8). This produced a significant amount of turbulence and poorly distributed flow in the forebay section of the intake. Velocities in the entire intake were non-uniform approaching the pumps leading to inactive flow areas and back eddies which will likely set up vortices and high levels of swirl (Figure 9).

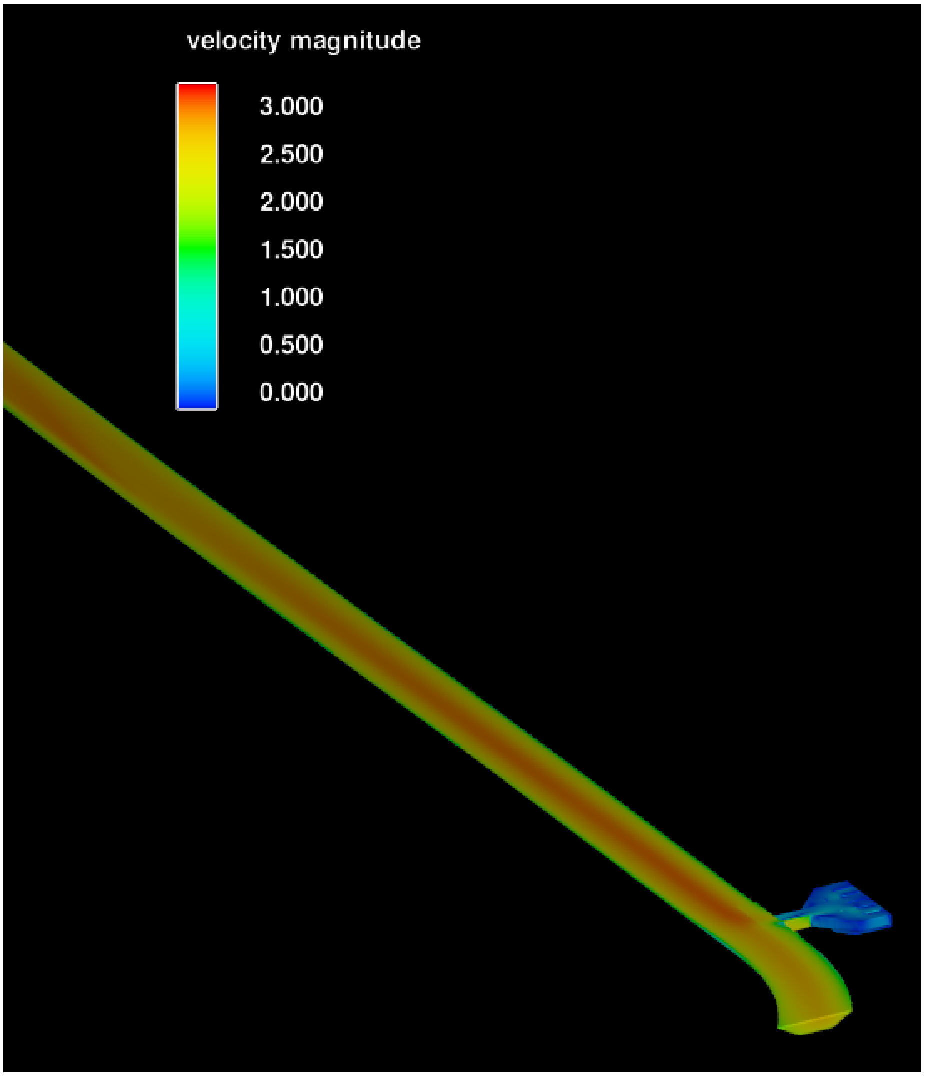

Figure 7. CFD simulation showing the upstream extents of the numerical model. The canal flow is well developed once it reaches the canal intake.

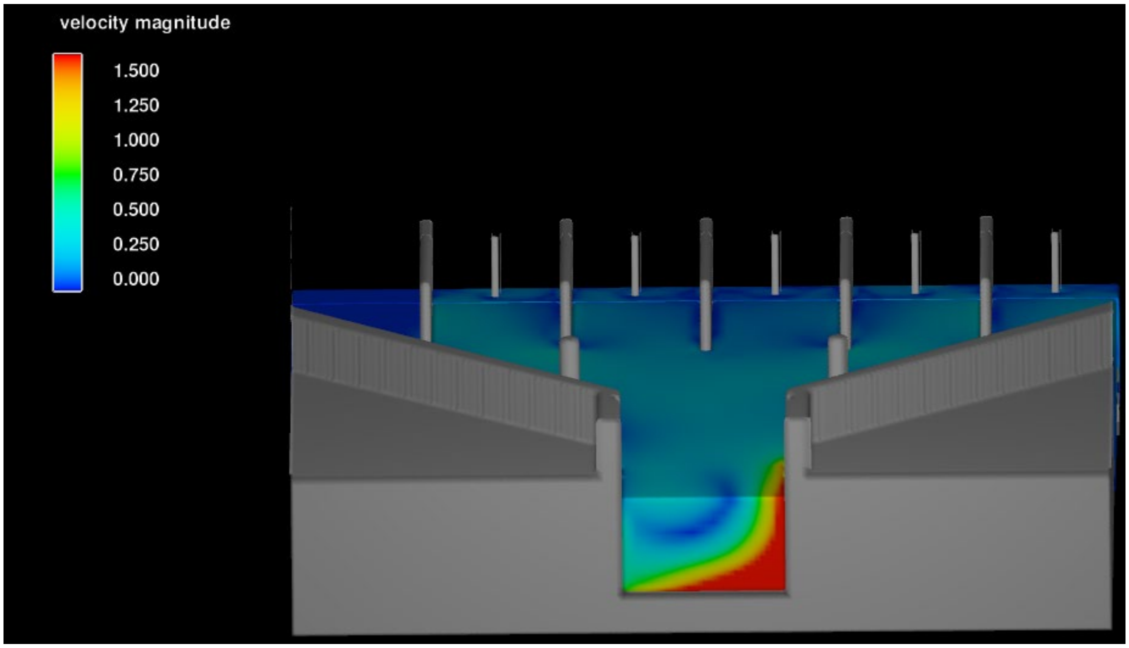

Figure 8. CFD simulation of the pump intake showing flow skewed to the right side of the intake as it makes the sharp 90-degree bend from the canal, looking downstream from the sump entrance.

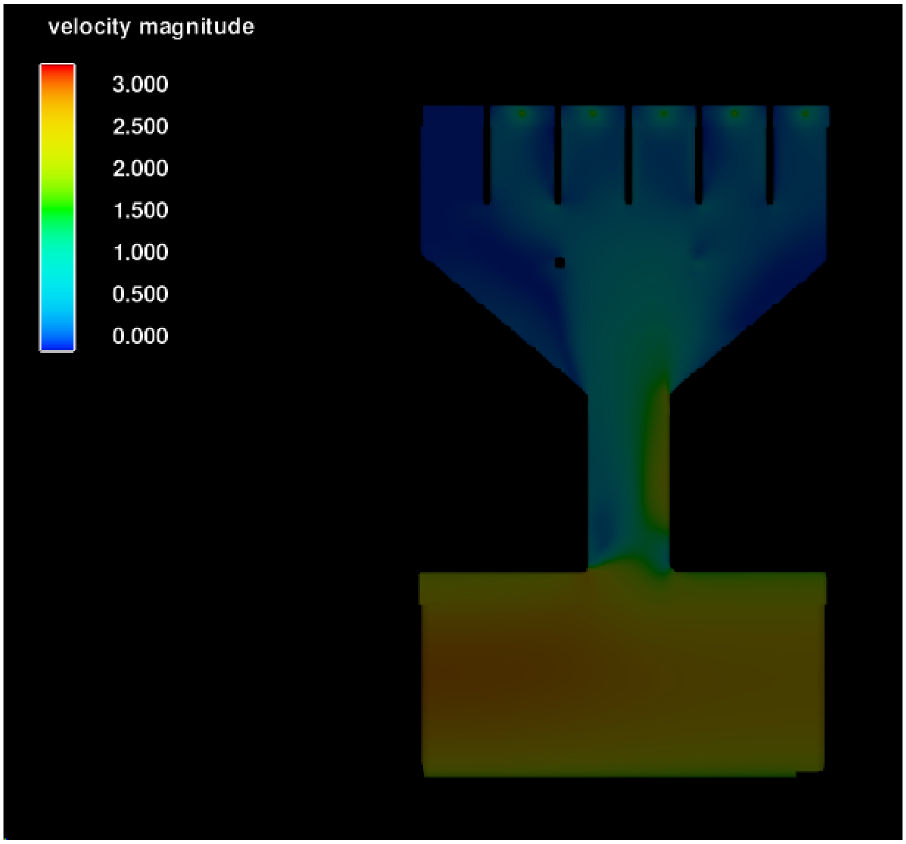

Figure 9. CFD simulation of the pump intake hydraulics. Stage 6 with pumps 2-6 active. Note dead zones (dark blue) in the pump bays and skewed flow entering from the forebay section.

Based on the initial numerical results it was decided to model 1/3 of the canal to match velocity conditions and maximize the size of the physical model. The flow in the canal was well developed at the location of the intake which allowed replicating the conditions with only 1/3 of the canal in the physical model. Furthermore, maximizing the size of the physical model would allow a larger model scale to ensure sufficient resolution of the turbulence and flow features in the forebay and pump bay sections of the intake.

Physical Modeling

Initial Design

The original design of the sump intake was tested in the physical model and produced similar approach flow conditions to the CFD model. Using flow visualization techniques, flow distribution within the sump was found to be non-uniform and would generally favor one side or the other depending on the pump staging and pump location.

All pumps at all stages were found to have some submerged vortices originating on the back wall behind the pump bells as seen in Figure 10. These were found to be stage 1 – stage 2 vortices (ANSI/HI 9.8 - 2018, 2018). Surface vortex activity was not observed in any of the stage test conditions.

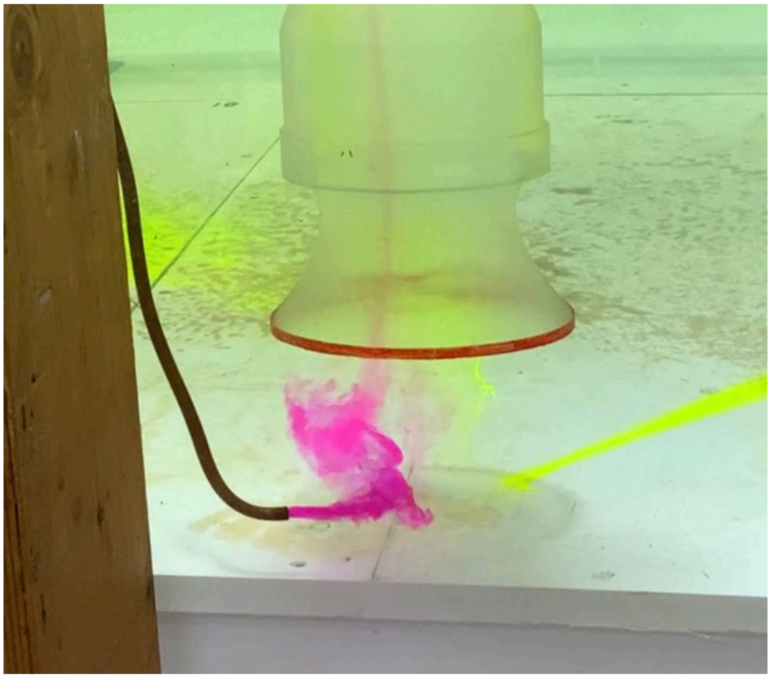

Figure 10. Type 1 vortex coming off the back wall of the pump bay.

Three pump stages were found to have swirl angles that exceeded the HI 9.8 acceptance criteria. All the failures except for one were due to a 30 second peak swirl angle above 7 degrees. The failures were stage 4 pump 2 and stage 5 pumps 3, 4, and 5 as can be seen in Figure 11. Stage 6 pump 2 failed due to having a 10-minute swirl angle above 5 degrees. This can also be seen in Table 2 below. This high level of swirl can cause non uniform loading on the impeller, bearings, or other internal components of the pumps.

Table 2. Swirl angle test matrix. A value above 7 degrees in 30 seconds or 5 degrees in 10 minutes is a failure. Stage 6 pump 2 is the 10 minute average, all others are the 30 second average.

	Pump					
Stage	1	2	3	4	5	6
6		5.17	4.89	0.84	5.45	3.78
5		4.75	10.12	14.80	8.49	
4		7.38	5.45	3.64		
3		2.89	3.82			
2		4.64				
1	3.48					

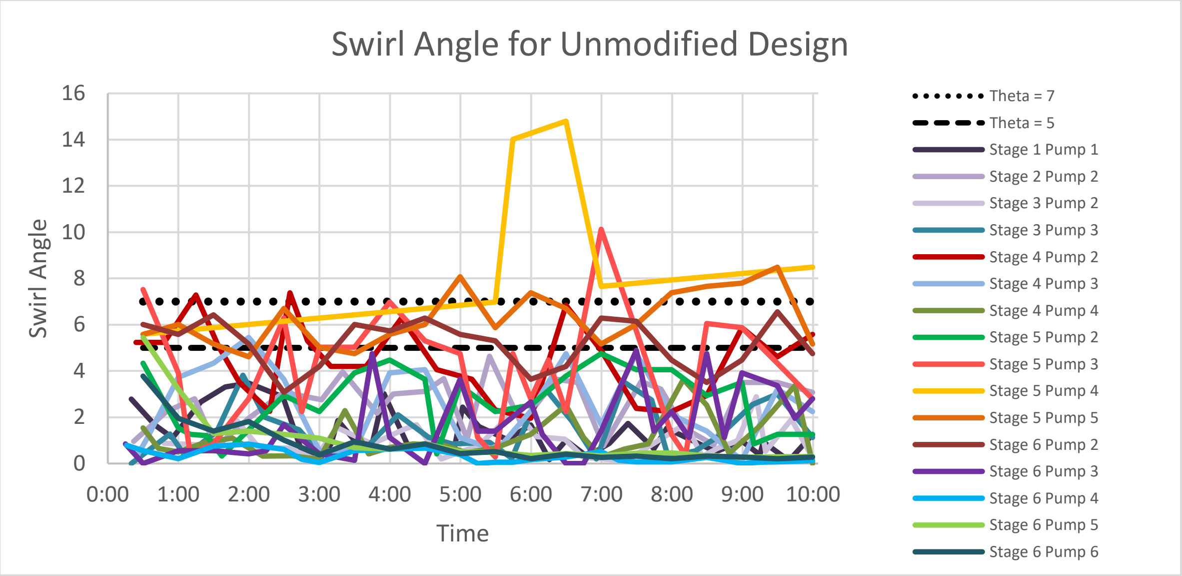

Figure 11. Swirl angle graph for the unmodified design. Any point that excessed theta = 7 in a 30 second period is considered unacceptable.

Modification for High Swirl

To meet HI compliance some modifications to the intake were needed to improve hydraulic conditions. The main goal was to increase the uniformity of the flow that the prototype impeller would experience. Several modified geometries and added features were tested to help improve the flow conditions entering the pump bell.

Narrower Pump Bays

A modified pump bay geometry was tested to keep flow accelerating toward the pump by increasing the velocity in that section and reduce swirl. The pump bay was changed to have a width equal to two times the diameter of the pump bell as recommended by HI (Figure 12) (about 3.77 ft prototype).

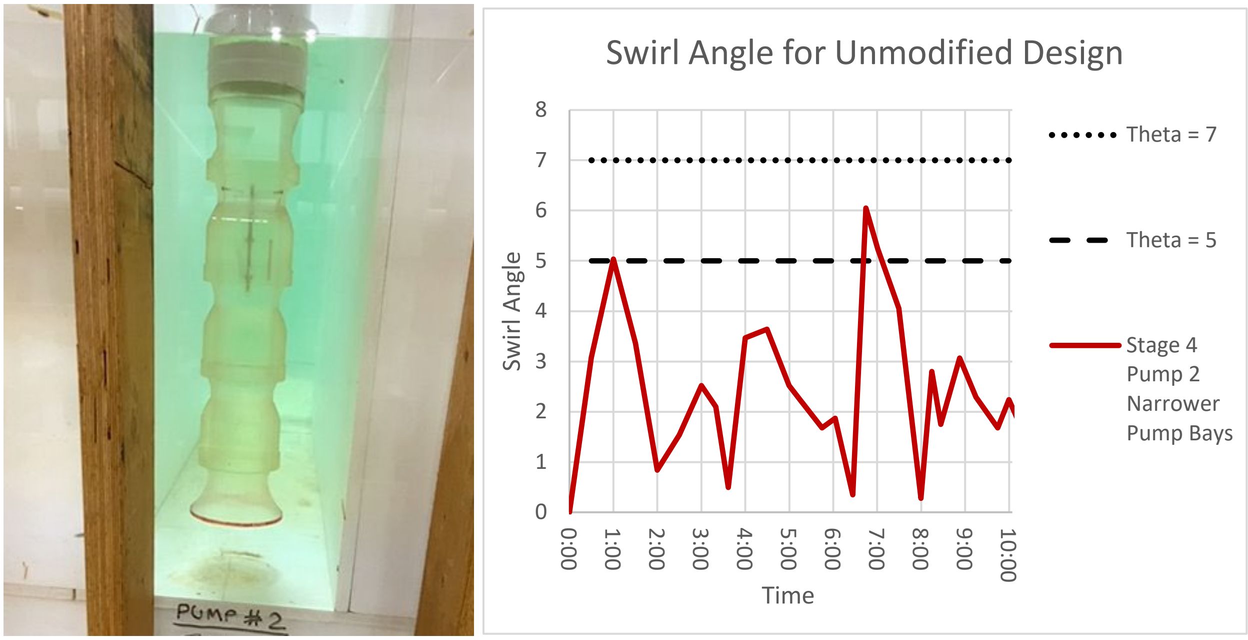

Figure 12. Left, the narrow pump bay modification. The walls were extended to make the width two times the pump bell diameter. Right, during the 10-minute swirl period the 30 second average was less than the 7 degree requirement.

This modification was tested on pump 2 with the stage 4 configuration. The narrower pump bay improved conditions enough to allow the pump to pass the swirl criteria. The flow had a significantly higher velocity through the pump bay which reduced inactive flow areas and improved uniformity of flow accelerating toward the pump. Velocities within the pump were not measured for this modification, but swirl angle measurements were within the HI 9.8 criteria and are shown in Figure 12.

Corner Fillets

A set of fillets was placed in the joint between the pump bay walls and the floor. This was done to help mobilize the flow in the stagnant regions of the pump bays. In addition, a splitter wall was installed down the middle of the pump bays to help disrupt the any floor vortices and can be seen below in Figure 13.

Figure 13. Above, corner fillets placed in the pump bay with the original design dimension for width and length. Below, graph of the 10-minute swirl test. The 30-second average exceeded the 7 degree swirl angle requirement.

This modification was also tested on pump 2 with the stage 6 flow configuration. The center splitter wall section caused flow separation due to the high amount of pre-swirl. This created a significant type 2 vortex. The resulting swirl angle was higher than the unmodified pump bay configuration.

Flow Baskets

Flow conditioning baskets are a cost-effective solution that has been recommended for Odessa pump intakes EL 22.1 and EL 47.5 to help reduce swirl and distribute flow at the bell (Hinton, 2017;

Havice, 2021). The initial flow basket configuration was circular with the same diameter of the pump bell (Figure 14). Following the virtual test demonstration, it was suggested that a rectangular basket that is mounted to the floor (similar to EL 47.5) would be preferred. Testing was repeated with the rectangular basket (Figure 15). Dimensions for the flow straightening baskets are found in the Appendix. Vortex formation, pump velocities, and swirl angles were similar for both configurations of flow baskets.

Figure 14. 3D printed flow baskets designed to attach to the bottom of the pump bells.

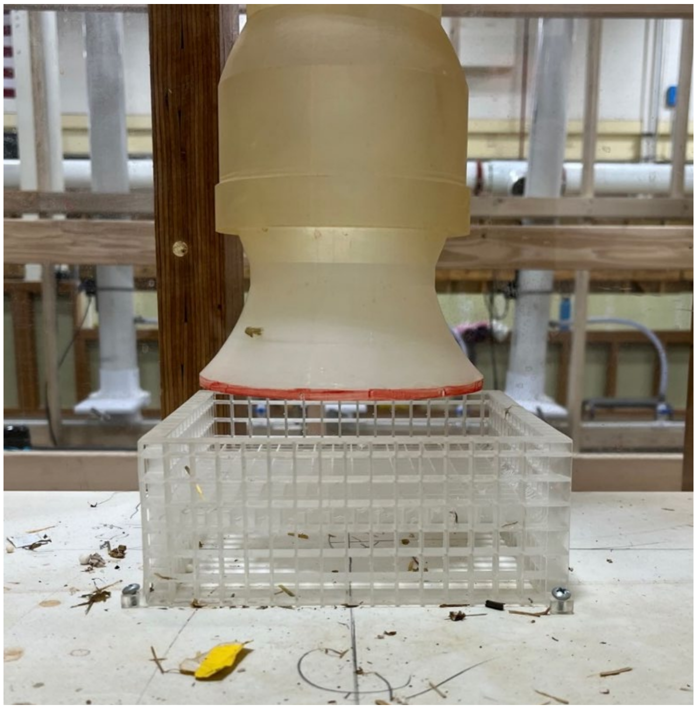

Figure 15. Rectangular flow baskets mounted to the floor below the pumps.

The flow baskets reduced swirl in the pumps by an order of magnitude from the original design. As a result, the modification passed the swirl acceptance criteria for every pump at every stage. This can be seen below in Table 3. Due to the relative simplicity and improvement of hydraulic conditions of this modification it was chosen as the final configuration for final acceptance testing.

Table 3. Swirl angle test matrix for the flow basket modification.

	Pump					
Stage	1	2	3	4	5	6
6		0.84	0.42	0.70	1.12	0.42
5		0.70	0.84	0.70	0.84	
4		0.56	0.84	0.70		
3		0.70	0.70			
2		0.56				
1	0.28					

Acceptance Test

Acceptance testing was performed on the final configuration with the flow straightening baskets installed. This testing included vortex formation, swirl angle measurements, and uniform axial velocity within the pump bells. Vortex formation was similar to previous testing with a type 1 vortex forming off the back wall at every pump (Figure 16).

Swirl angle measurement were found to be very minimal and as shown in Figure 17. For all pumps at every stage the swirl angle was found to be below the 5-degree 10-minute average and 7-degree 30 second average that is required by the HI acceptance criteria.

Figure 16. Dye visualization of flow distributed by the rectangular flow straightening basket before entering the pump bell.

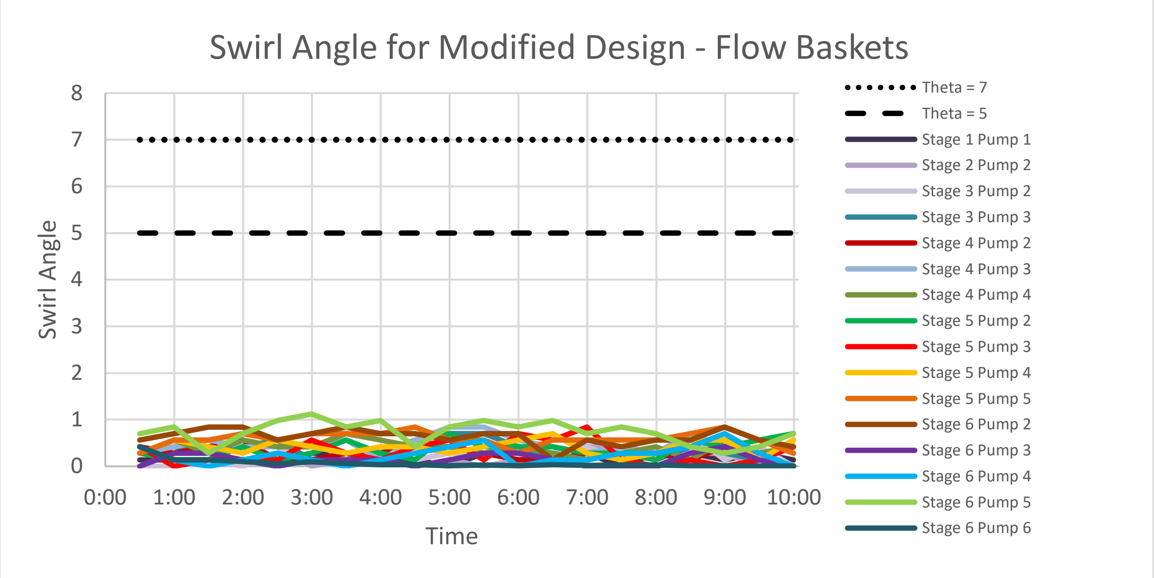

Figure 17. Graph of the swirl count during the 10-minute observation period for the modified design using the flow straightening baskets.

Velocity testing was performed on the worst-case hydraulic conditions for each pump at the 8 locations shown in Figure 4. The velocity distribution and peaks were found to be well within the acceptance criteria of +/- 10%. These data were normalized (ratio of measured velocity to the average of all measurements) and shown in Table 4.

Table 4. Normalized velocity around the pump bell with the flow straightening baskets installed.

Test Location	Normalized Velocity					
	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6
1	1.01	1.00	0.99	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00	1.00	0.99
3	1.00	1.00	1.00	1.00	0.99	0.99
4	1.00	1.00	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00	1.00	1.01
6	1.00	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.01	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00

Screen Sensitivity Testing

A screen was added to the entrance of the pump intake from the canal with a similar open area percentage to the prototype screen design. A sensitivity test was performed with the screen fully open, and each side blocked off to assess hydraulic conditions within the intake and effects to the performance within the pump bell. This testing was performed for Stage 2 with pumps 2 through 6 operating. Photos of dye illustrate the flow patterns at the entrance to the intake in Figures 17, 18, and 19.

Flow patterns with the screen fully open and the left half of the screen blocked were very similar. This was due to the flow concentrated on the right side as it turned into the intake as was shown in the CFD modeling results. With the right half of the screen blocked the flow appeared to be more uniform as it approached the individual pump bays. While flow did leave the screen concentrated on the left side of the entrance for this condition, there was reduced angular momentum to drive the flow to one side or the other and cause recirculation. Regardless, the level of swirl and velocity distribution within in the pump were unaffected by the intake conditions which shows the flow straightening ability of the baskets at the pump bells and demonstrates the robustness of this recommended modification to the design.

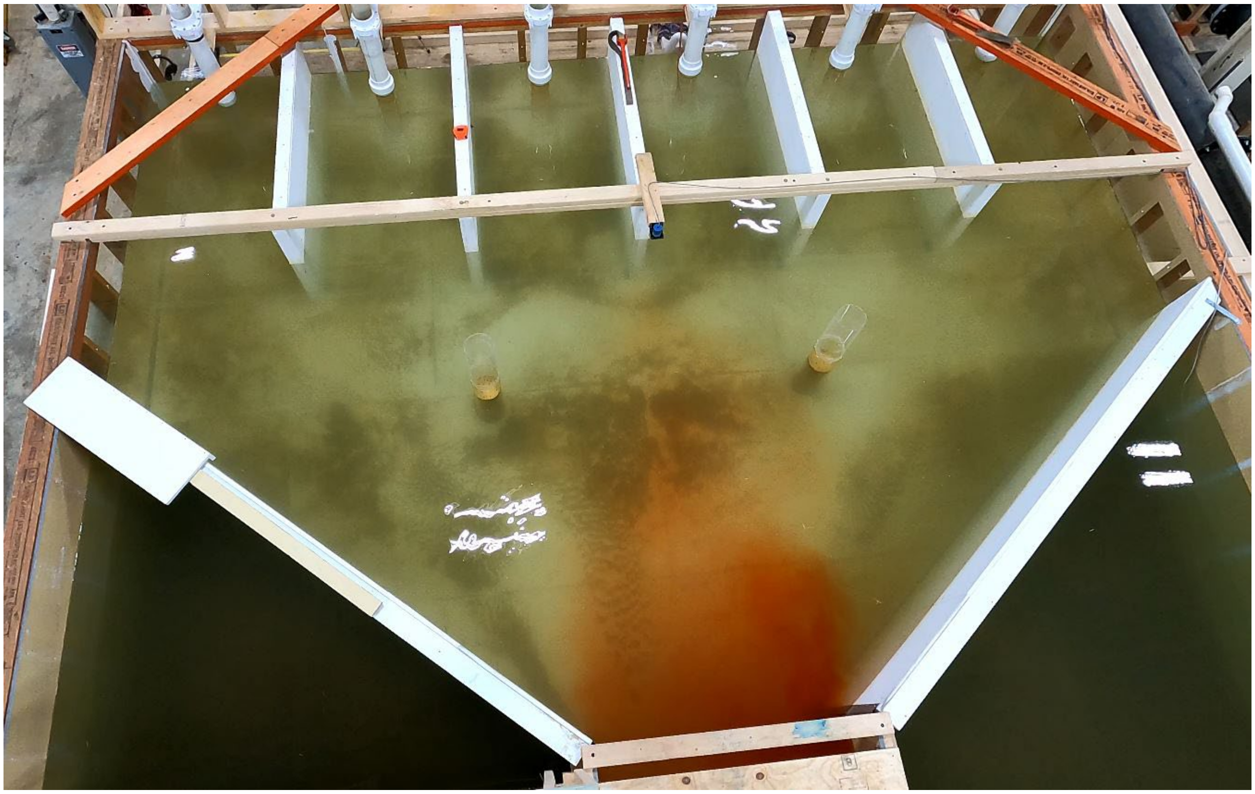

Figure 18. Photo of dye entering the sump intake with the intake screen unblocked.

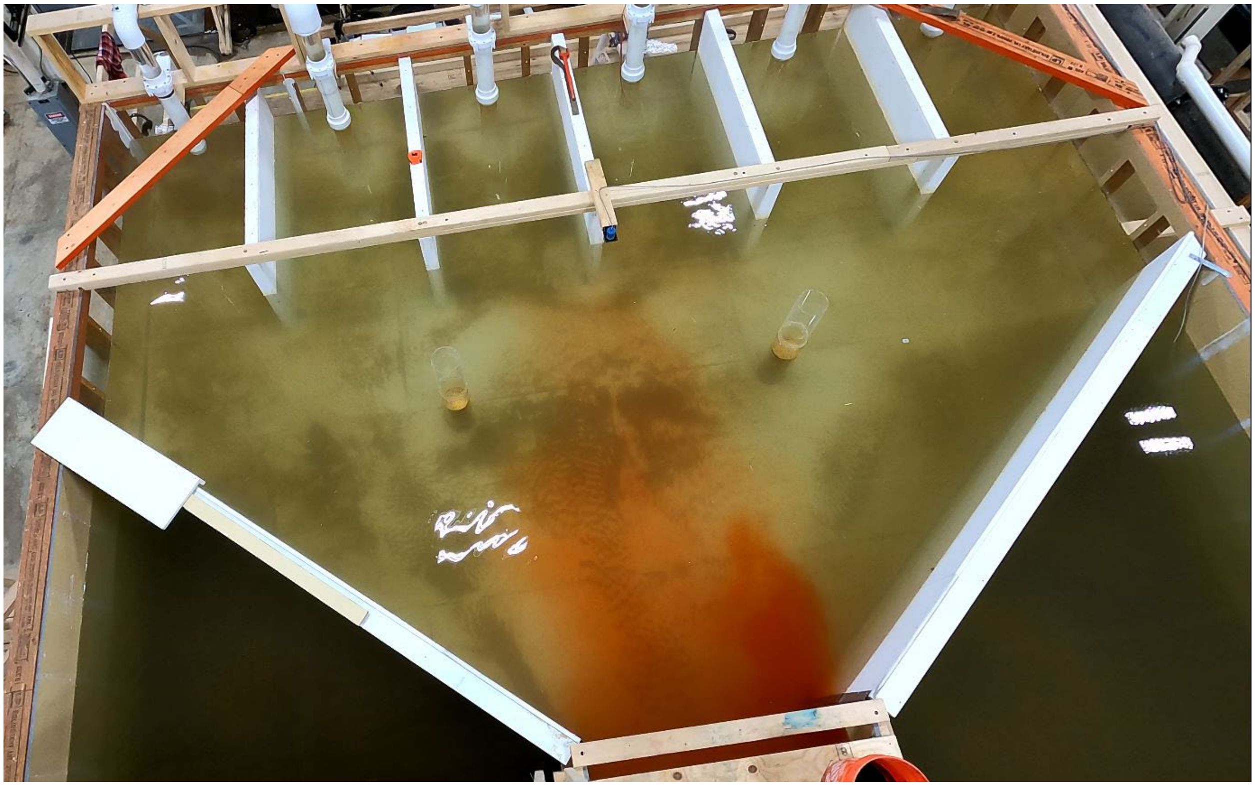

Figure 19. Photo of dye entering the sump intake with the left side of the intake screen blocked.

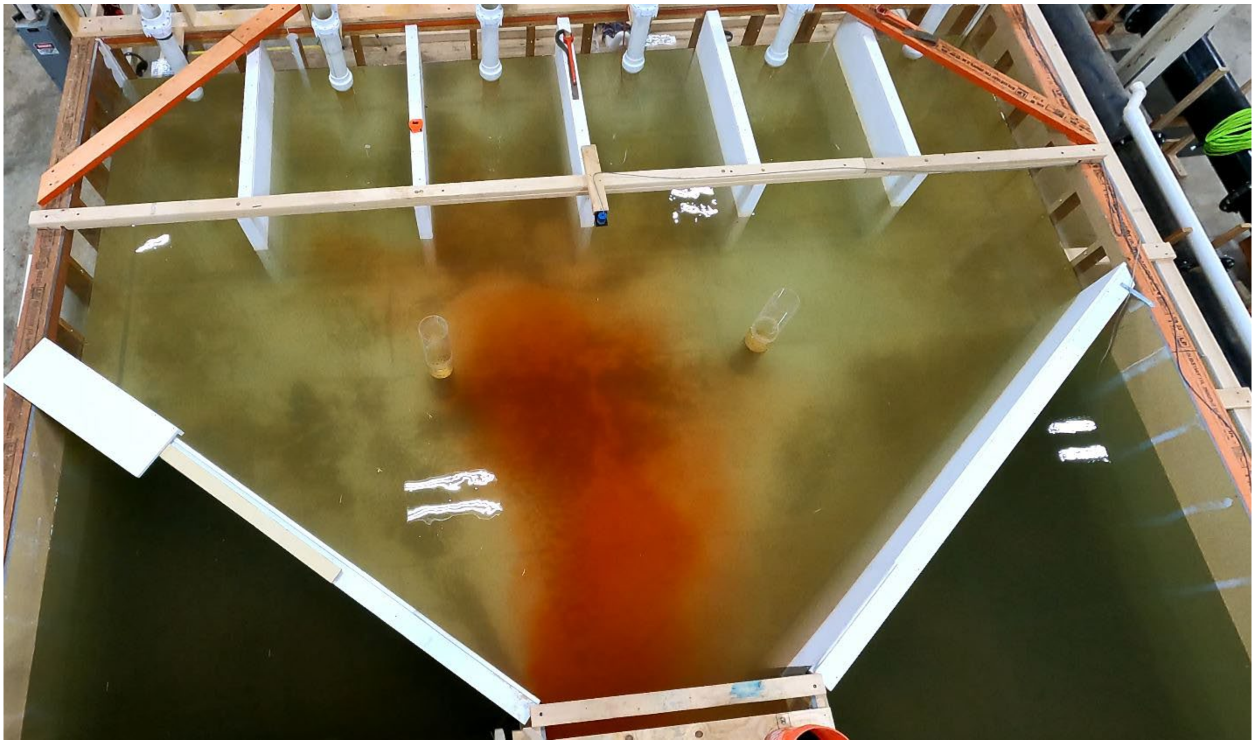

Figure 20. Photo of dye entering the sump intake with the right side of the intake screen blocked.

Conclusions and Recommendations

A physical hydraulic model study was conducted to assess and improve hydraulic performance of the pump intake for the EL 84.7 pumping plant. Testing on the original design revealed hydraulic conditions that did not pass HI 9.8 acceptance criteria. This was due to nonuniform flow from the canal through the 90-degree bend into the sump intake. The oversized forebay section of the intake allowed for significant dead zones and back eddies that caused the flow to be skewed as it approached the pump bays. The large pump bays did not allow the flow to evenly accelerate towards the pumps which led to significant amounts of pre-swirl. Every pump also had a type 1 – type 2 vortex that originated on the back wall of the bay. As a result, several modified designs were tested to improve the hydraulic conditions in the intake. These included fillet and splitter sections, narrower pump bays, and flow conditioning baskets.

Of the modifications tested, the flow conditioning baskets are recommended for final design. The baskets significantly reduced swirl within the pumps to levels within the HI acceptance criteria. The time averaged and time varying velocities in the throat of the pump bells were found to be well within the +/- 10% variance as stated in the acceptance criteria. Type 1 vortices were still present with this modification but were within the allowable limits.

It is recommended that this modification be installed with the final selected pumps to ensure acceptable hydraulic performance and longevity of the pumps and intake.

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Appendix - Pump Bell and Flow Basket Drawings

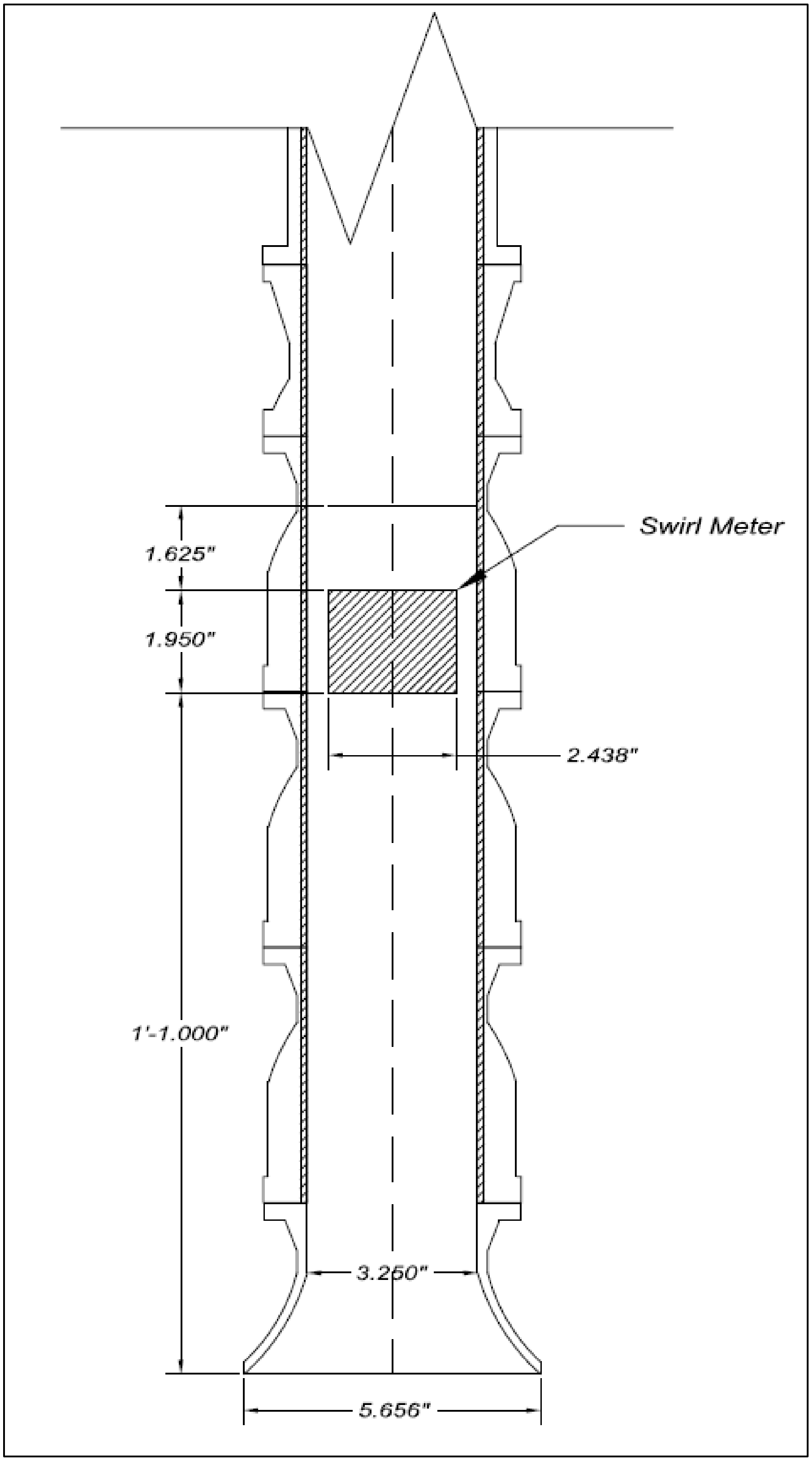

Figure 21. Section-view of the large pump bell geometry and model dimensions used in the physical model.

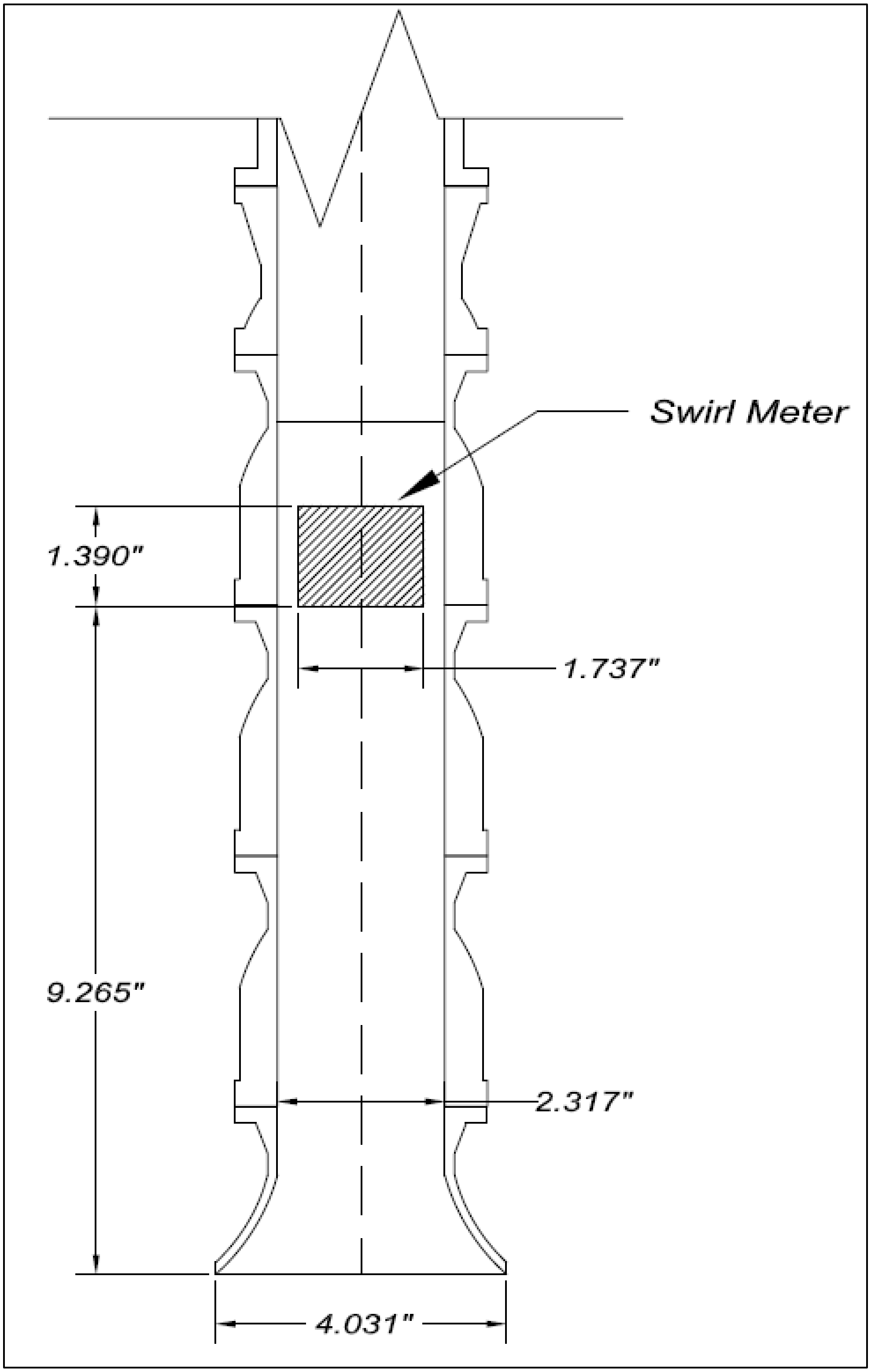

Figure 22. Section-view of the small pump bell geometry and model dimensions used in the physical model.

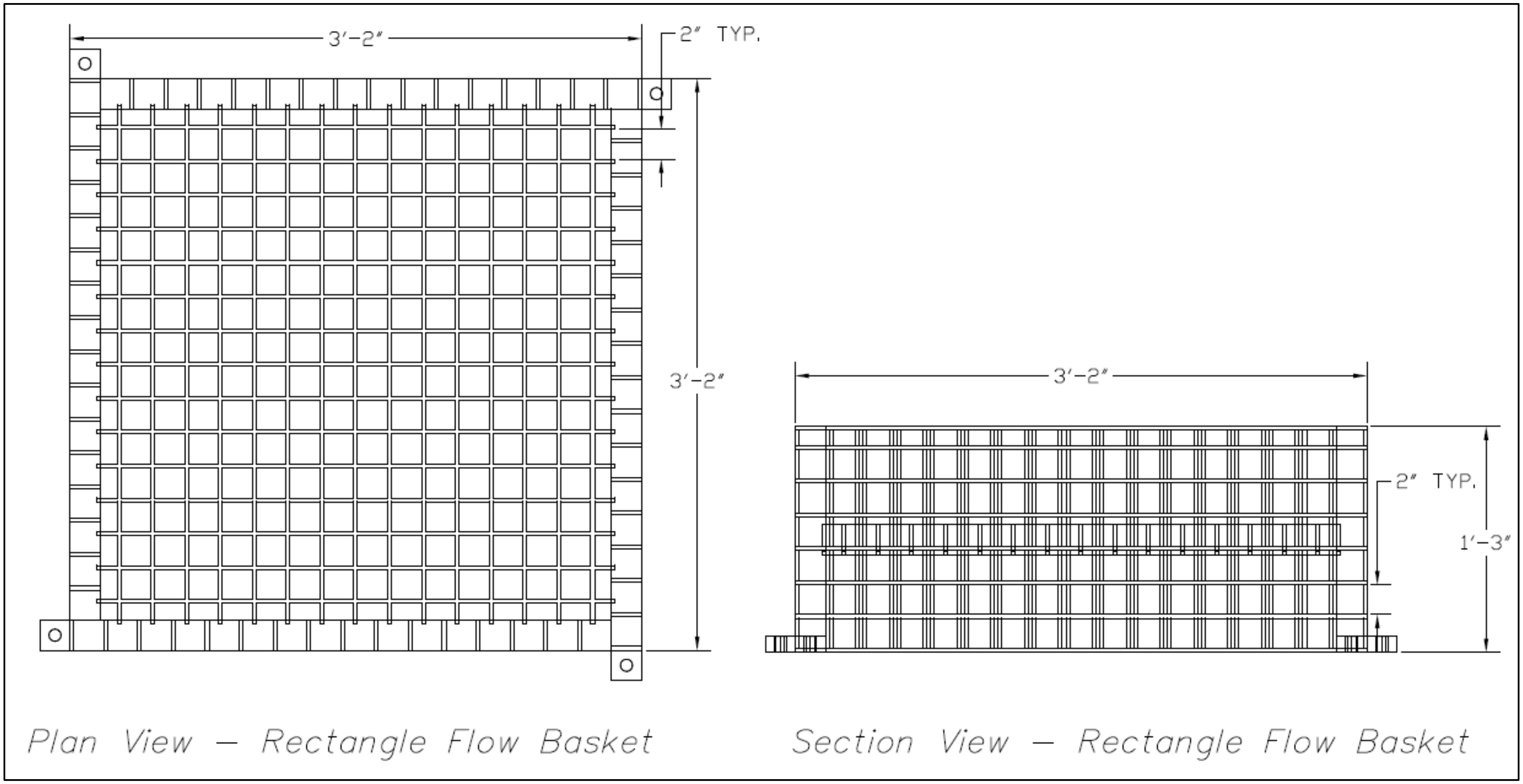

Figure 23. Dimensions at the prototype scale of the floor mounted rectangular flow basket configuration testing in the physical model.

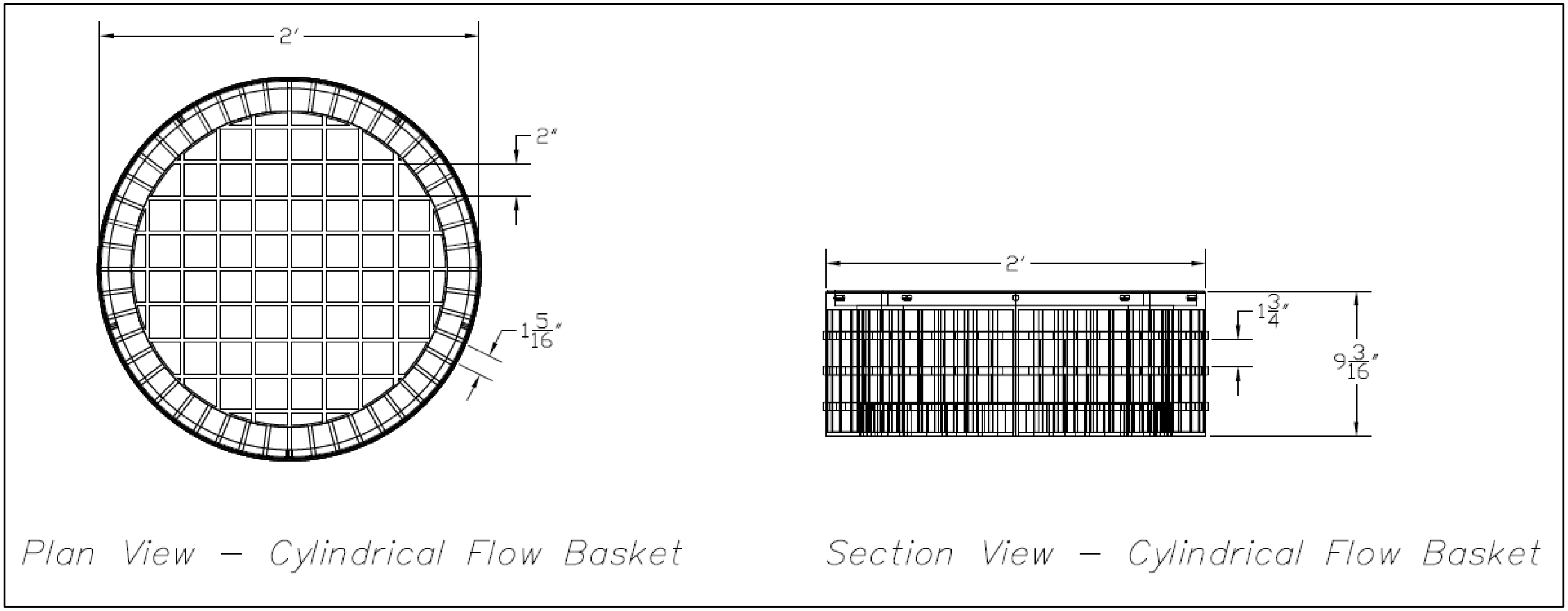

Figure 24. Dimensions at the prototype scale of the pump mounted cylindrical flow basket configuration testing in the physical model.