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ISI Cone Screen Performance in a Riverine Environment

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Background

Fish screens are commonly used to prevent entrainment of fish and other aquatic species at water diversion intakes. Resource agencies developed design standards (criteria) to protect target species from entrainment, impingement and other means of harm at fish screens. Design criteria include values for approach velocities (water velocities perpendicular to the screen face), uniformity of approach velocity distribution over all screen area, sweeping velocity (water velocity parallel to the screen face), screen opening size, and screen orientation with respect to stream flow. Cone screens are conical shaped screen units designed for small water diversions in shallow, tidal areas where ambient water velocities are slow if at all present. Cone screens proved to be highly effective in tidal areas and were soon used in back water areas along rivers and streams where little ambient water velocity existed.

In 2009 cone screens were installed at a temporary, seasonal water diversion on the Sacramento River where ambient river velocities were approximately 5 feet per second, but the location was too shallow to use other traditional screening methods such as cylindrical units. Resource agency personnel measured near-screen velocities on those cone screens and found that water could pass completely through the screen units, and approach velocities were not uniformly distributed over all areas of the screen. In addition, in some places approach velocities were an order of magnitude greater than allowed per fish screen design criteria.

Cone screens are typically equipped with baffle systems that distributed diverted flow over all screen area when installed in slack water locations, but the baffling system used in the riverine environment example above was inadequate for approach velocities to meet fish screen design criteria. To use cone screens in a riverine environment a new baffle system was needed.

In order to accomplish this objective an improved understanding of cone screen hydraulics was needed. As a result, the Hydraulics Investigations and Laboratory Services Group at the U.S. Bureau of Reclamation (Reclamation) in Denver conducted testing to develop an effective baffle design for providing an effective positive barrier for fish exclusion in a shallow river environment. This study was requested and funded by the Anadromous Fish Screen Program which is jointly implemented by Reclamation (MP Region) and U.S. Fish and Wildlife Service (Pacific Southwest Region). The study presented herein provides baseline data on the performance of an ISI (Intake Screens Inc.) cone screen tested with a flume velocity of 2 ft/s and a screen intake flow set to 5.4 ft^3/s. Based on these data, several baffle design configurations were tested to determine if screen performance could be improved under the same flow conditions. In this study a 5.5 ft diameter cone screen with 1.75 mm wedgewire and 50% open area was loaned to Reclamation by ISI for testing and performance evaluation (figure 1). This screen had no baffle or structure internal to the wedgewire surface, other than structural ribbing for support, and was designed to be placed over a flat surface with a 16 inch minimum diameter opening extending from the suction side of a diversion.

Figure 1. ISI Cone screen inside test flume.

Model Set-Up

The cone screen was installed in a 10 ft wide by 4 ft deep flume. Screen performance was evaluated based on uniformity of approach velocities distributed around the screen's surface. A test apparatus was designed to hold and rotate a SonTek acoustic doppler velocimeter (ADV probe) so that approach velocities could be measured at eight locations around the circumference of the screen at a set distance of 3 inches from screen's surface as required to meet resource agency screen velocity criteria. The test apparatus also allowed the probe to move parallel to the screen surface so that for each of the eight locations around the circumference of the screen, approach velocities could be measured at 2 inch increments from top to bottom.

The screen was installed 15 ft downstream from the entrance to the flume and was centered over a 16 inch opening in the flume floor to provide outflow from the flume through the cone screen. The screen discharge pipe, below the flume floor, transitioned from the 16 inch opening into a 12 inch pipe that extended about 28 ft downstream from the screen before depositing flow back into the laboratory sump. Flow through the cone screen was regulated with a gate valve and was set

Figure 2. Sontek ADV probe test apparatus

and measured, with a controlotron transit time acoustic flow meter. The flow rate through the screen was set to 5.4 ft^3/s for all test cases. The test flume tapered from a 10 ft width down to an 8 ft width near the downstream end of the screen to compensate for the flow lost through the screen. The flume target velocity, measured 5 ft upstream from the cone screen, was 2.0 ft/s with a flow depth of 18 inches for the initial testing with no baffle installed. To set this flow condition in the laboratory required 6 separate pumps providing flow into the flume, for a total inflow of about 36 ft^3/s .

The three brushes that normally rotate around the circumference of the screen were removed for the purpose of these tests. This was done to simplify the baffle design process since at any given time the location of the brushes may change. The effect on flow hydraulics with the brushes reinstalled may have a significant effect on the performance of the screen baffle design and will be discussed in the conclusions section of this report.

In each test case, approach velocity is defined as the component perpendicular to the screen surface with positive approach velocities indicating flow is going into the screen. It is worth noting that because it is impossible to measure velocities over the entire screen control surface, the velocities measured at eight locations around the screen circumference at a 3.0 in. distance from the screen face, cannot necessarily be extrapolated to represent total through-screen flow to satisfy flow continuity.

No Baffle

Initial testing was conducted without a baffle installed in the screen so that baseline data could be measured and then used to come up with an initial baffle design. The flume velocity was established at 2.0 ft/s with a screen intake flow of 5.4 ft^3/s. Approach velocities were measured at each of the eight locations, labeled L1 through L8, shown as dashed lines, in the sketch in figure 3. Figure 4 shows screen approach velocities measured, beginning near the top of the wedgewire surface, (indicated by y = 0.0) and extending down the screen surface at 2 inch increments parallel to the screen face to a distance of 28 inches (corresponding to y = -28, with the y axis oriented parallel to the screen surface). All measurements were taken at a 3 inch distance perpendicular to the screen surface and positive values indicate flow is going into the screen. The top position where measurements actually began, varied for each location depending on flow depth and drawdown on the downstream face of the screen.

Figure 4 shows the approach velocity profiles measured without a baffle at locations L1 through L8. Velocities measured front center, and right of the screen centerline (looking downstream) are indicated in shades of red and those measured rear center, and left of the screen centerline are indicated with shades of blue. Also the same symbols were used to indicate measurements located symmetrically opposite from one another (across the screen centerline, L2 to L6).

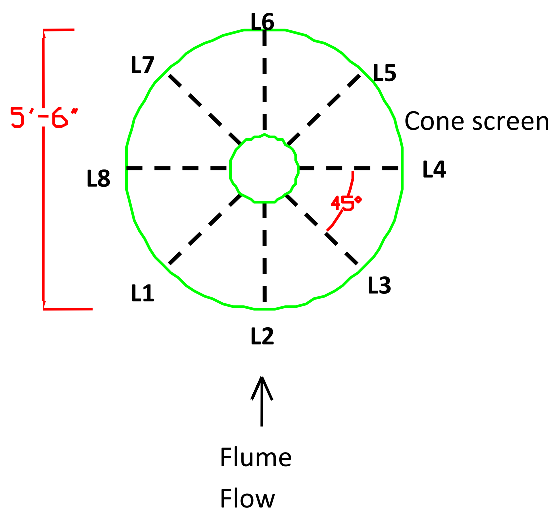

Figure 3. Cone Screen sketch, plan view showing velocity measurement locations L1 through L8.

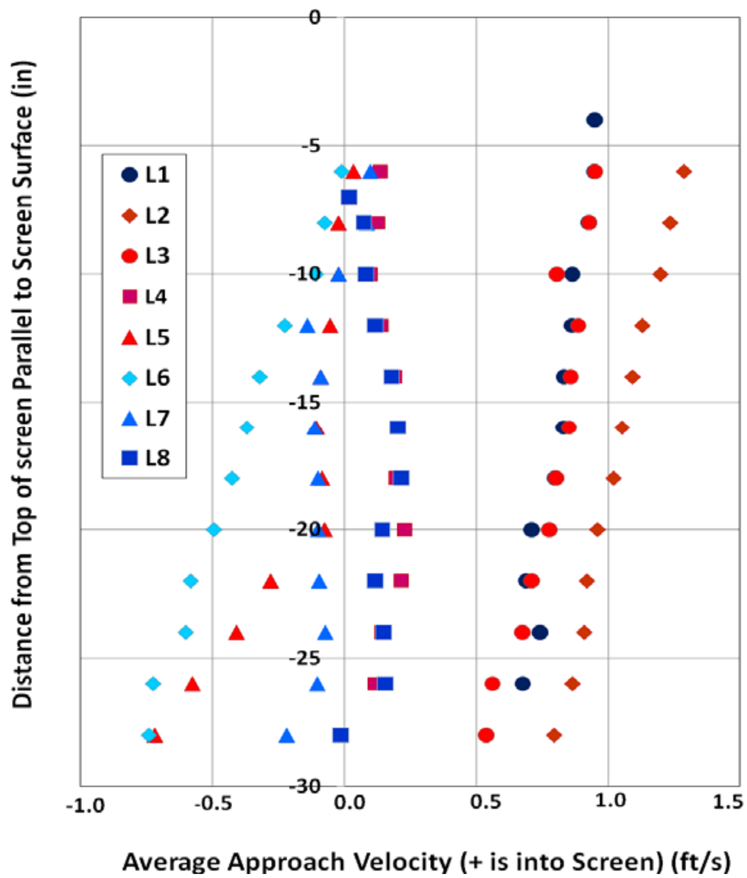

Figure 4. No Baffle --- Cone Screen approach velocity profiles measured at locations L1 through L8.

As would be expected, Figure 4 shows that velocities are highest going into the screen at locations L1, L2 and L3 where the flume flow is directly impinging on the upstream face of the screen. Velocities are also slightly higher at those locations near the top of the screen, where screen surface area around the screen is least and is closest to the centered outflow circumference. Figure 4 shows that on the downstream side of the screen, velocities are going outward as flow goes through the upstream side and out the downstream face of the screen. These baseline velocities were used to come up with an initial baffle design to provide a more even distribution of approach velocities around the screen surface.

Baffle Concepts

Baffle Concept 1

The initial concept for an internal screen baffle consisted of a 17 inch diameter vertical cylinder extending the height of the screen, centered inside the screen, and positioned over the 16 inch discharge opening in the bottom of the flume. The cylinder was designed with graduated openings to help control flow through the screen. Then six partitions extending outward from the cylinder were used to prevent flow-through through the screen and to better control flow into the individual sections. This concept is illustrated in figure 5 with the partitions shown as solid blue lines and labeled as P1 through P6. The actual hole pattern layout used for the initial cylinder design is shown in figure A-1, Appendix A, and was based on the baseline velocities measured at the eight locations around the perimeter of the screen. Once this arrangement was installed, flow conditions were set as they had been previously. However, drawdown on the back side of the screen was significant because the percent open area through the cylinder reduced flow intake on the upstream face of the screen. As a result, tailboards used to control flow depth in the flume, were added until the downstream flow depth was only about an inch lower than the upstream depth. This water surface differential was similar to what it had been previously without a baffle installed and resulted in a reduced flume velocity of 1.87 ft/s (measured 5 ft upstream from the screen) for this configuration. Once this set-up was complete, approach velocity measurements were repeated. The velocity profiles measured for locations L1 through L8 are shown in Figure 6.

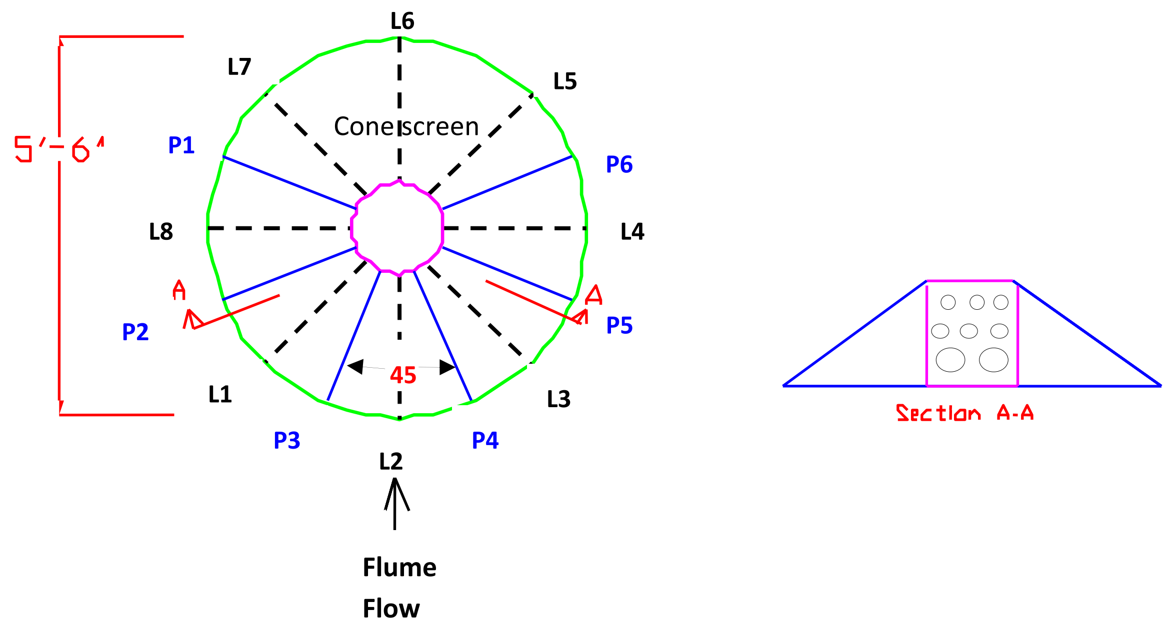

Figure 5. Baffle Concept 1 Illustration showing partition positioning and measurement locations L1 through L8. Actual Cylinder hole pattern shown in A1, Appendix A.

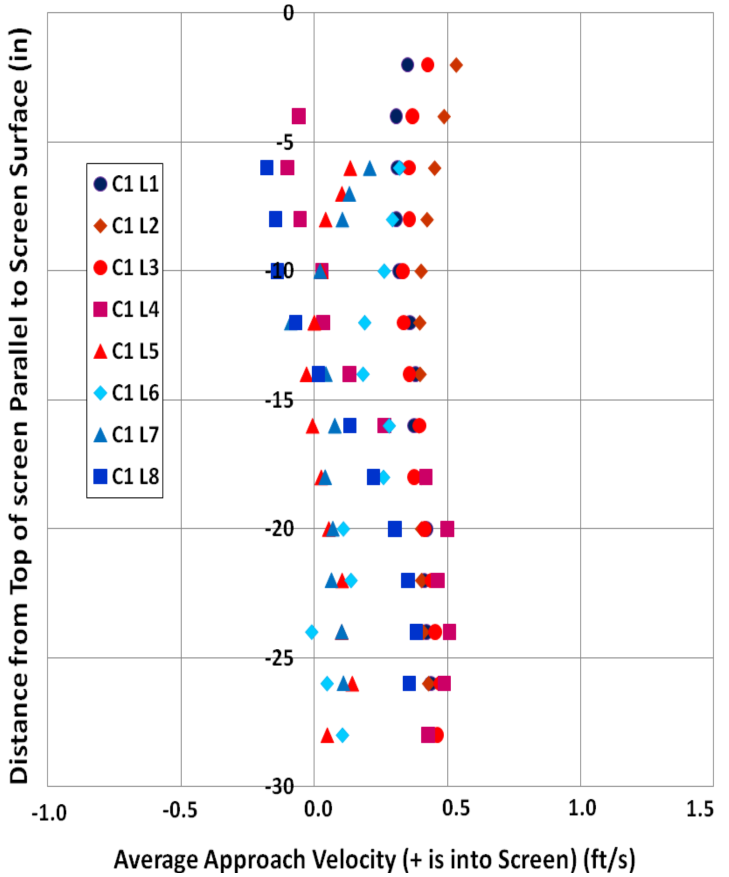

Figure 6. Baffle Concept 1 - Cone Screen approach velocity profiles measured at locations L1 through L8.

The velocity profiles measured with Baffle Concept 1 installed are significantly improved over having no baffle. Approach velocities measured at locations L1 through L3 have been reduced from over 1.0 ft/s in some places to about 0.5 ft/s or less at all locations. Velocities coming out of the screen on the downstream side have also been significantly reduced.

Baffle Concept 2

The next step was to see if approach velocities on the upstream face of the screen could be further reduced while also reducing reverse flow on the back side of the screen. To accomplish this, all openings in sections L1 through L3 were reduced in size by 50%. All other openings and the six partitions were left unchanged. This time when flow conditions were set as they had been previously, drawdown on the downstream side of the screen again increased because of the reduced percent open area in the cylinder. Additional tailboards were added until the downstream flow depth was only about an inch lower than the upstream depth, this time reducing average flume velocity to 1.59 ft/s.

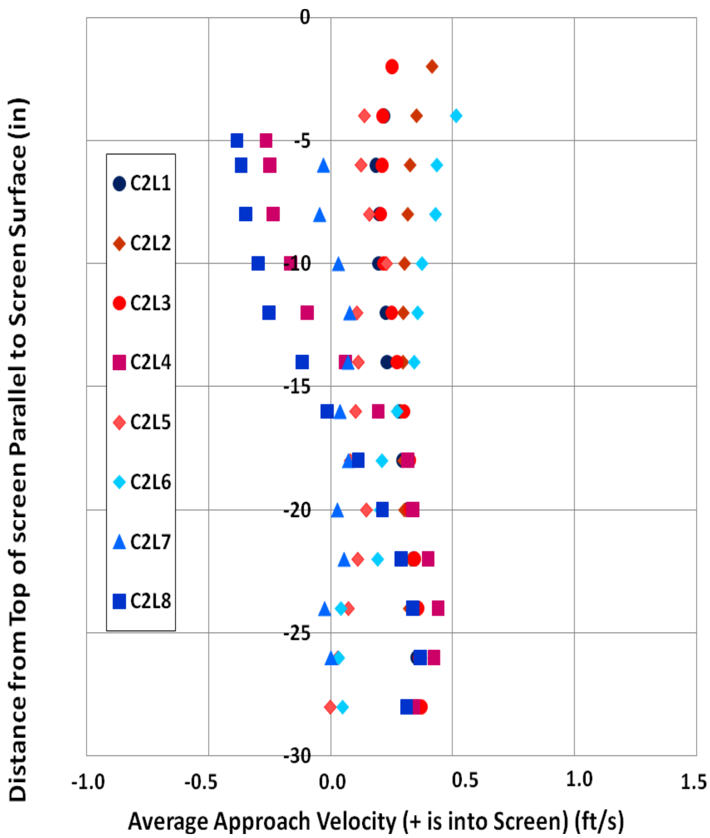

Figure 7 Baffle Concept 2 - Cone Screen approach velocity profiles measured at locations L1 through L8.

Approach velocity profiles measured at locations L1 through L8 are shown in figure 7 for the Concept 2 configuration. Velocity profiles for locations L1 through L3 are slightly improved over Concept 1. However velocity profiles for locations L5 through L7 are not changed significantly and velocity profiles for locations L4 and L8 are slightly worse.

Baffle Concept 3

A third concept was tested with the screen rotated 22.5 degrees counterclockwise so that Partitions 1 and 5 lined up 90 degrees to the flume flow. All partitions on the backside of the screen were eliminated so that flow could move freely across the downstream side of the screen (figure 8) Since this caused the 8 measurement locations (centered between partitions) to shift by 22.5 degrees they were relabeled as locations A1 through A8 to avoid confusion. This time measurement locations right of the screen centerline are indicated with symbols in shades of red and those measured left of the screen centerline are indicated in shades of blue. Again the same symbols were used for measurements located symmetrically opposite one another. The cylinder hole pattern was redesigned based on what was learned from the previous concepts and is shown in Figure A-2, Appendix A. Once again flow depth in the flume was controlled by downstream tailboards and was set for a downstream flow depth about an inch lower than the upstream depth. As a result, the average flume velocity was 1.69 ft/s for this configuration. The approach velocities measured at the new measurement locations for Baffle Concept 3 are shown in figure 9.

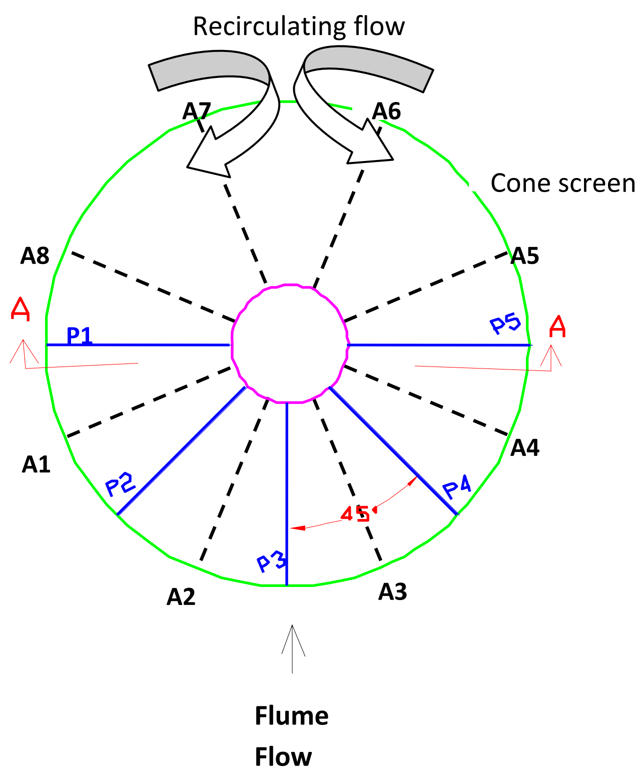

Figure 8 Baffle Concept 3 Illustration showing partition P1 through P5 positioning and measurement locations A1 through A8. Cylinder hole pattern shown in figure A-2, Appendix A.

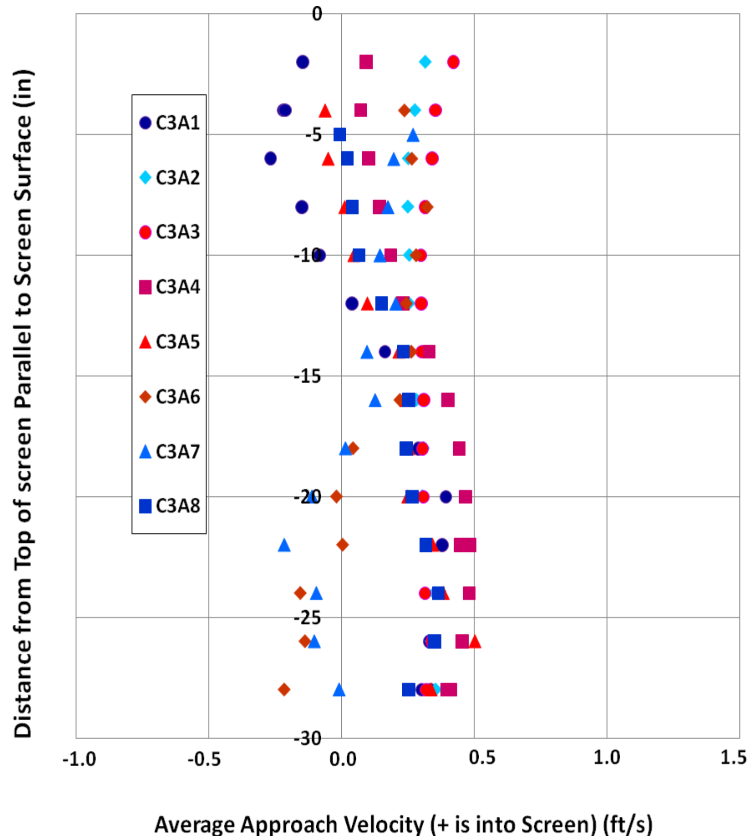

Figure 9 Baffle Concept 3 - Cone Screen approach velocity profiles measured at locations A1 through A8.

Figure 9 shows that for Baffle Concept 3, there is a reasonably tight grouping of approach velocity distributions. Figure 10 shows the velocity distribution of 3000 samples measured at location A2 measured 16 inches down and parallel from the top of the screen. This is an example of a typical distribution with an average velocity of 0.28 ft/s (velocity used to meet required criteria) and with most of the samples (within 2 standard deviations) falling in the range of 0.46 and .11 ft/s.

At the A1 location some outflow (confirmed with dye testing) occurs near the top of the screen where flow is nearly perpendicular to the inner partitions. This could be due to some upwelling occurring inside the screen or it may be due to a horizontal eddy deflecting off the partition and cylinder where the percent open area is very small (or a combination of both). At locations A6 and A7, located symmetrically on the downstream side of the screen, measured velocities for the lower portion of the screen are also negative. This time dye could not be traced because of turbulence that occurs on the backside of the screen. For these two cases a large fluctuation in velocity samples indicate that the recirculating flow pattern and large eddies that form on the downstream side of the screen are contributing to average velocities that vary from positive to negative along the screen surface and therefore may not be a direct indication of flow drawn into or flowing out of the screen. Thus any additional modifications to the hole patterns in the cylinder baffle at this location may be insignificant in further improving screen performance.

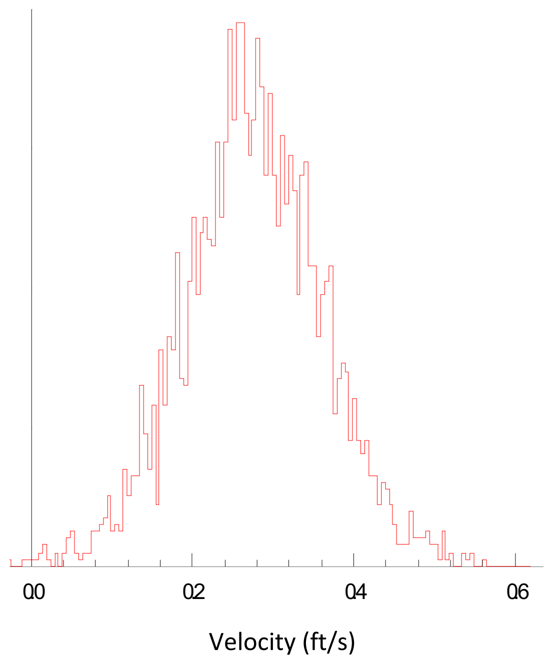

Figure 10. Histogram for approach velocity distribution of 3000 samples. Average velocity = 0.28 ft/s, Baffle Concept 3, Location A2, Y= -16

Conclusions

All three Baffle Concept configurations provided a significant improvement in the performance of the ISI cone screen with sweeping flows in the range of 1.6 ft/s to 2.0 ft/s. Differences in performance between the three designs may be due in part by the difference in flume velocity approaching the screen. Further improvement to the performance of the screen may be accomplished with additional testing, however it is not clear how much improvement may be gained. Also, because the screen was tested without the brush attachments, it is important to note that the effect of reinstalling the brush arms will reduce the effective area of the screen. Since the brush arms are not stationary and rotate around the circumference of the screen, designing the baffle to compensate for this effect is not practical. However, under these flow conditions where there is a strong sweeping component, compared with approach velocities around the circumference of the screen, minimal debris is expected to accumulate on the screen surface compared with a tranquil environment. With this in mind, it may be reasonable to consider reducing the number of brushes to one or two, parked on the back side of the screen where hydraulic effects would be minimal, and to reduce the number or frequency of rotation cycles for cleaning.

Another concern to note is that the screen was tested with the baffle cylinder and partitions oriented a specific direction with respect to the main flow stream. Any deviation from this alignment may have a significant effect on screen approach velocities, so care should be taken to make sure the screen is aligned properly. Further testing may be desired to determine how far off of alignment can be allowed without reducing performance significantly. In addition further testing may be desired to determine the increased headloss associated with the installation of an internal baffle arrangement.

Appendix A

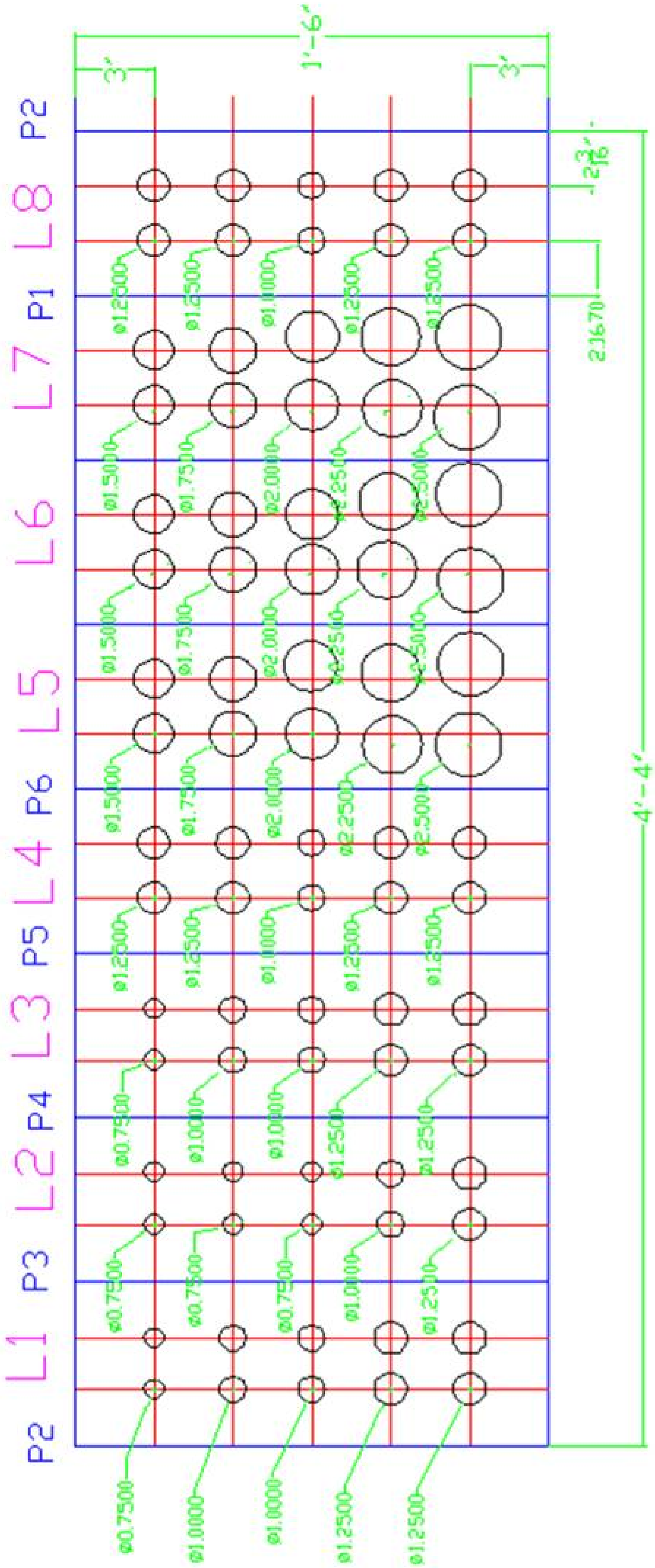

Figure A -1. Cylinder hole pattern design for Baffle Concept 1.

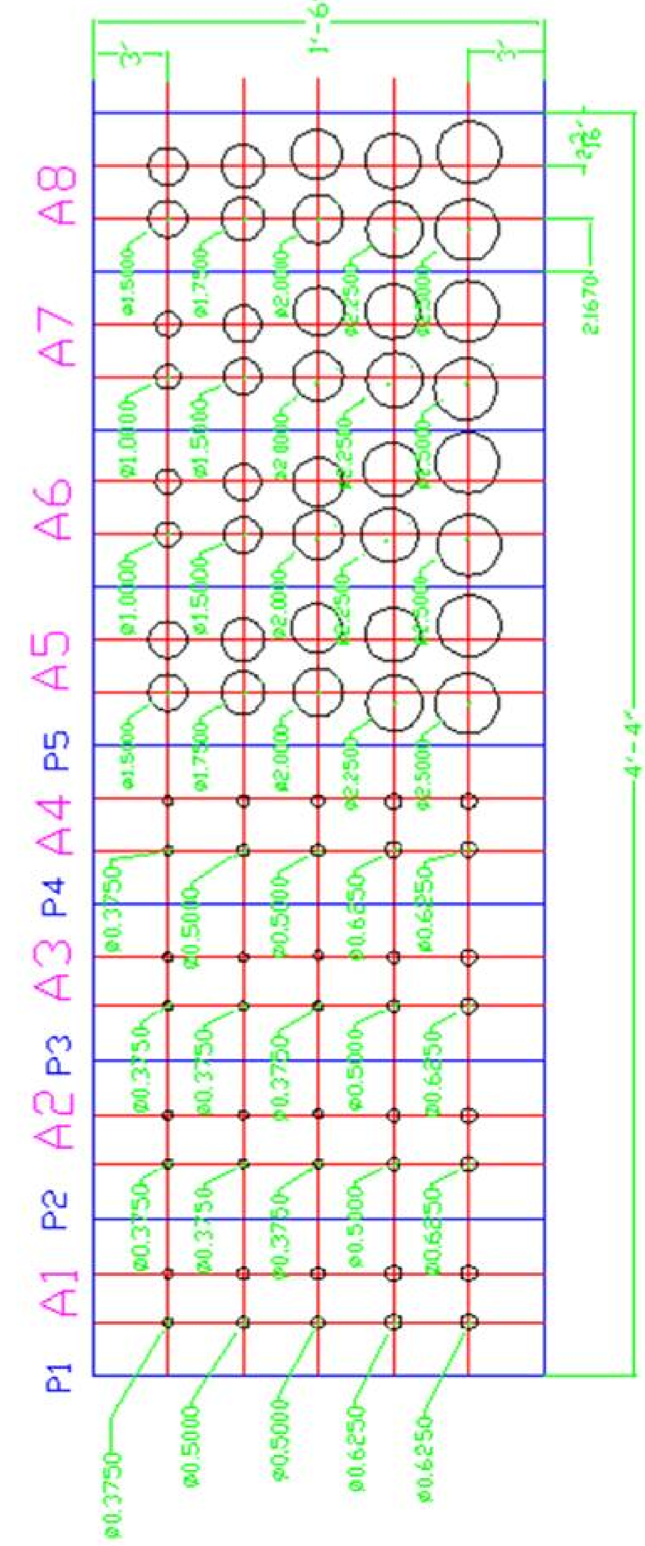

Figure A-2. Cylinder hole pattern design for Baffle Concept 3.