White Paper:
Report Describing Testing and Design Recommendations for the Snap-Tite® Hydro-Bell

ISCO Industries/Snap-Tite®
926 Baxter Ave
Louisville, KY 40204
1-800-CULVERT
www.culvert-rehab.com

Prepared by: Tim Toliver, PE
Advanced Pipe Services, LLC

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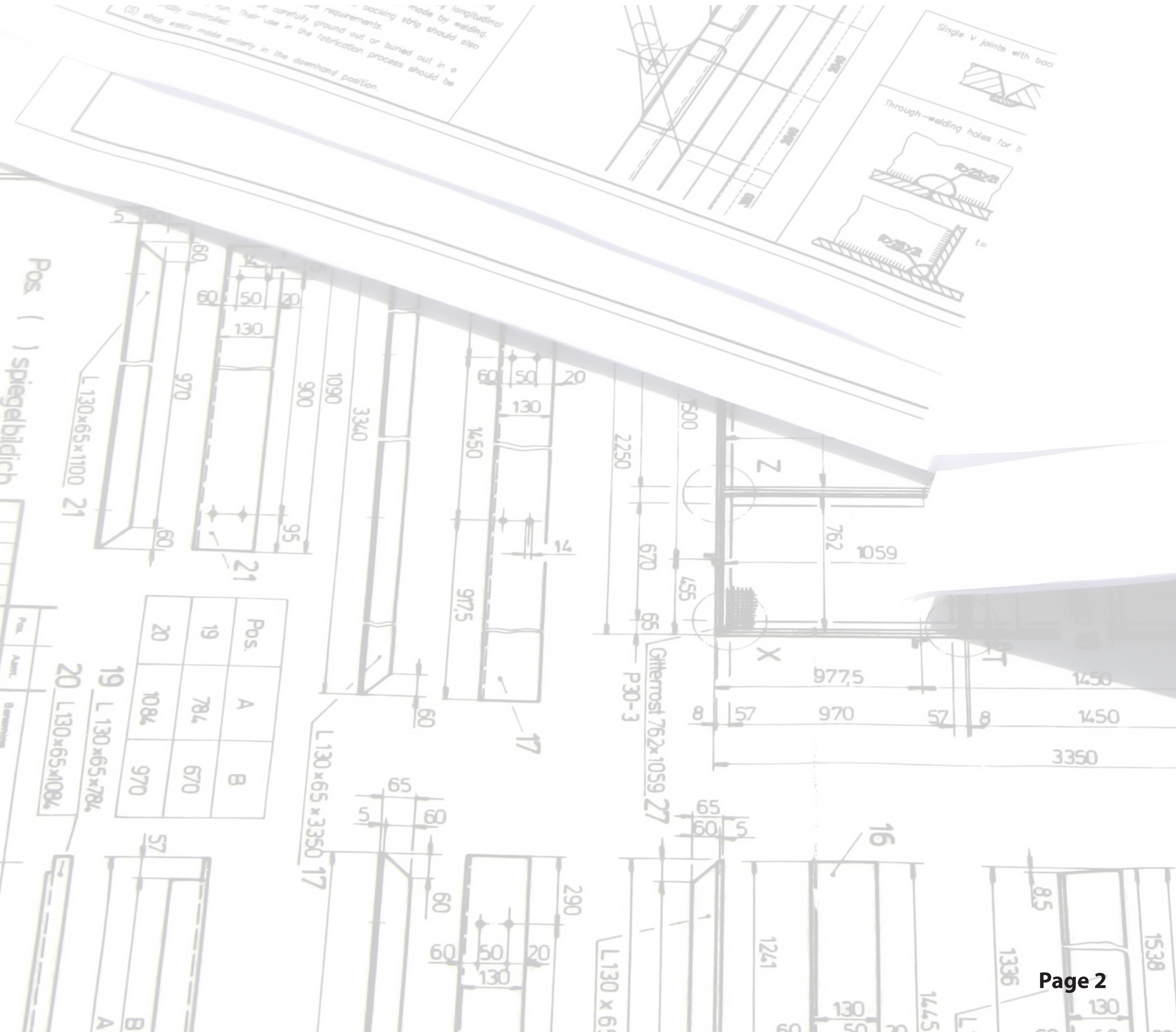
Abstract

The objective of this study is to determine the inlet design coefficient for the Snap-Tite® Hydro-Bell. The inlet design coefficient is necessary to accurately predict head loss, or flow, through a high-density polyethylene (HDPE) Snap-Tite® Culvert Relining pipe using the Hydro-Bell, in submerged inlet and un-submerged outlet conditions. The inlet coefficient was determined by measuring velocity and pressure drop across the Hydro-Bell inlet device. Measurements were taken in triplicates at head pressures ranging from 1 to 7.5 feet of hydraulic head. This study determined that the Hydro-Bell's increase in flow ranged from 15% to 34% (in relation to pressure conditions). The increase in flow is compared to a standard square end inlet condition typically found in culvert applications. This report concludes that the Hydro-Bell is effective at increasing the flow in culverts.



INTRODUCTION

Hydraulic flow in short runs of pipe, such as drainage culverts, is often controlled by inlet and/or outlet conditions. The flow rate can be maximized by altering the inlet or outlet conditions in the culvert. However, in most cases, the outlet conditions are difficult to alter; but, modifying the inlet condition is both practical and feasible. This paper discusses the design and testing of an inlet flow enhancing solution that maximizes the hydraulic efficiency (and/or reduces head loss) of a pipe or culvert. Additionally, this paper provides design guidance for engineers using the Hydro-Bell.

As fluids flow into a pipe, the flow boundary layer can separate from the pipe wall creating turbulent flow and reducing the cross sectional area available for fluid flow. By creating a smooth transition into the pipe and accommodating the naturally occurring turbulent flow, the cross sectional area available for flow can be maximized. The reduction in cross sectional area (see Plane C-C' in **Figure 1** below) is typically referred to as a *vena contracta*.

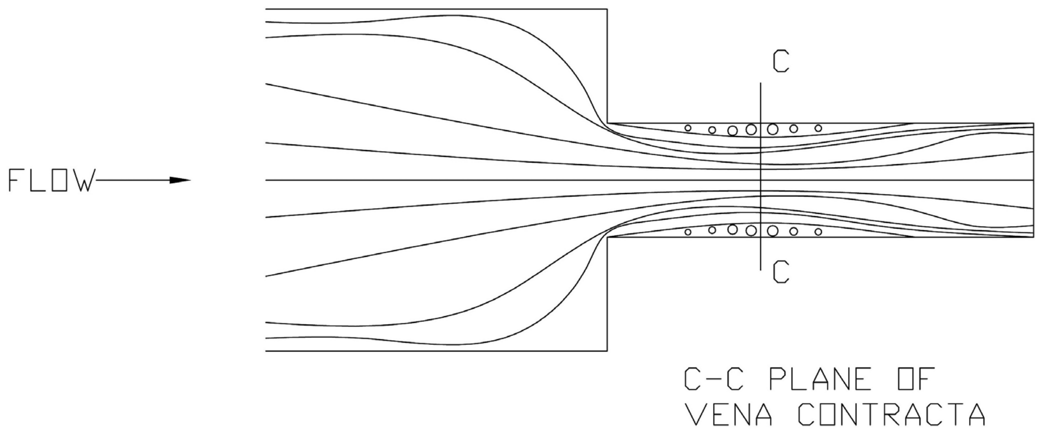


Figure 1

Verification testing of the flow improvement for the Hydro-Bell design was performed in a range of flow rates typically found in culvert drainage applications.

BACKGROUND

According to the U.S. Department of Transportation (DOT) Federal Highway Administration (FHA) "Hydraulic Design of Improved Inlets for Culverts" report (August 1972), inlets may provide substantial improvement in flow. One specific discussion regarding effective ways to save cost states:

> As previously mentioned, the culvert barrel cost usually far outweighs the cost of the inlet structure. Therefore, if a very long culvert operates in inlet control, opportunities may exist for great savings by using an improved inlet and reducing the barrel size.
>
> Short culverts should also be analyzed for possible cost reductions through the use of improved inlets. Many significant savings have been recorded for these structures, especially in cases where the capacity of an existing culvert was increased by addition of an improved inlet rather than by replacement of the entire culvert. (FHA 1972)

Inlet devices currently used in the construction industry have relied on the same designs for over 40 years as shown in **Figure 2 (a-d)** below:

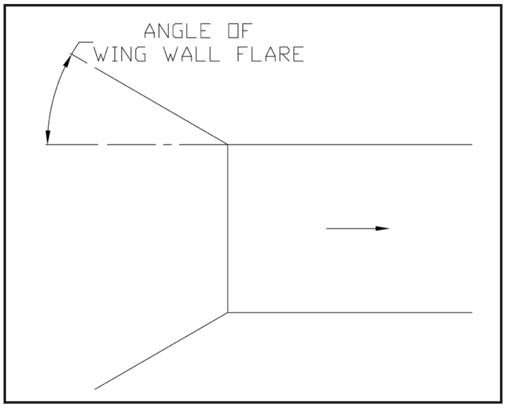


Figure 2a Flared Wing Walls

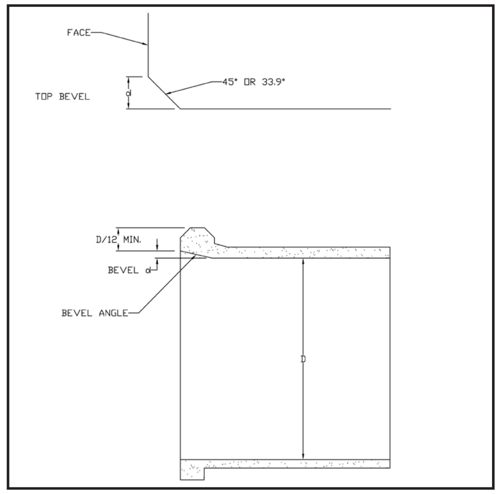


Figure 2b Inlet Top Beveled Edge

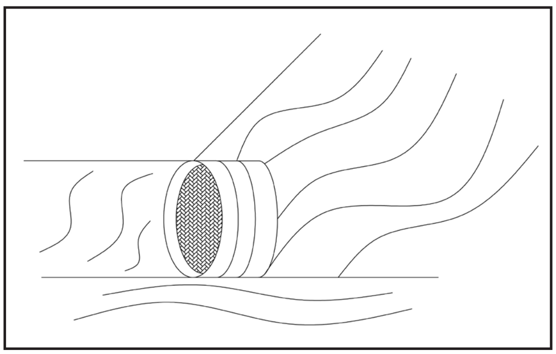


Figure 2c Culvert Inlet Projecting

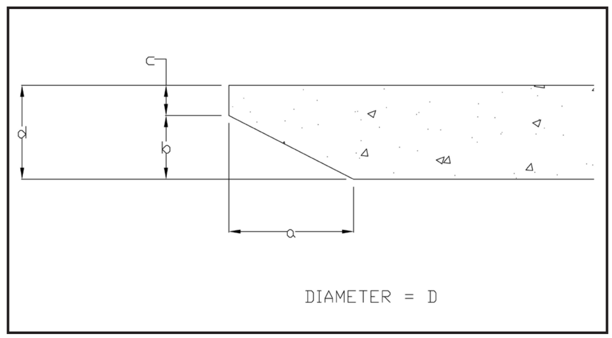


Figure 2d Culvert Inlet w/Beveled Ring

The Hydro-Bell inlet device represents the first device introduced in recent years that uses newer materials to capitalize on the effects of culvert fluid dynamics.

The Hydro-Bell device design consists of rounding the inlet with a leading radius, which transitions to a diametrical recess in the interior of the Hydro-Bell structure. **Figure 3** illustrates the primary features of the device.

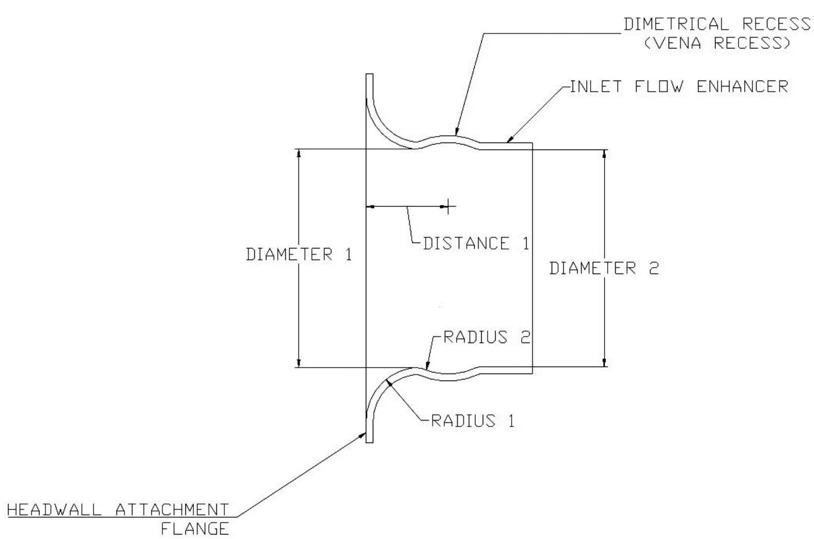


Figure 3

The test fixture was comprised of a 42-inch diameter stand pipe with an 8-inch diameter outlet pipe. The transition from the tank to the outlet pipe was replaceable with several geometric forms. The three geometric forms of most importance are: a square end inlet; a rounded inlet; and the Small *Vena* inlet. These inlet geometric forms are shown in **Figure 4** below:

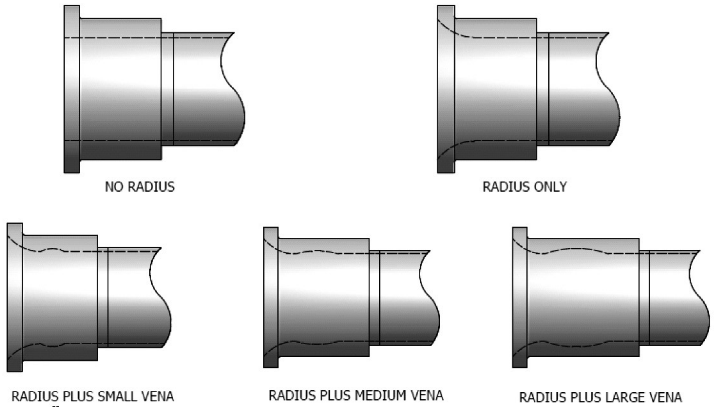


Figure 4 - Inlet Geometric Forms Tested

METHODOLOGY

Empirical (or experiential) tests were performed to determine the inlet coefficient. The test fixture was devised with various instruments to determine flow velocity, flow rate and pressure in the system. **Figure 5** shows the test fixture and the location of the instruments. A total of 15 tests were performed to collect flow and pressure data.

INSTRUMENTATION FOR DATA ACQUISITION

The data acquisition system and instrumentation designated specifically for this project are summarized as follows:

1. 1-MHz, 16-Bit, Data Acquisition Module
2. 4-solid state pressure transducers, max 30 psi, 0.25% accuracy
3. Omega linear 24-volt power supply
4. DaqView Data Acquisition Software
5. Dell M20, 2 MHz, Laptop computer

The accuracy of the pressure transducers was checked with a known elevation, or "head", of water over the pressure transducer. An example of an instrumented inlet is also shown in **Figure 5** (below). Additionally, all instruments were certified as accurate by the supplier (Omega Engineering).

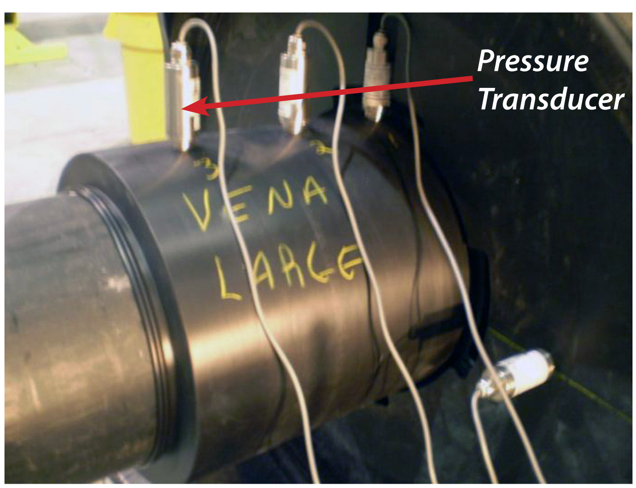


Figure 5 - Instrumented Inlet

FLOW AND DATA ANALYSIS

The 10-foot high 42-inch diameter stand pipe was filled with water and discharged through an 8-inch outlet pipe. The head up to the centerline of the outlet pipe varied from 1 to 7.5 feet. The outlet pipe was temporarily plugged during the stand pipe filling operation and dispensed to atmospheric pressure. Once the plug was removed, flow through the test fixture began and data was collected. **Figure 6** (below) illustrates a typical flow rate through the test fixture.

The Hydro-Bell is designed to fit on the inlet end of a pipe. During the development, five inlet flow enhancer designs were tested to determine the relative improvement in flow. The base line device was a typical pipe inlet with the end squarely cut. **Table A** below describes the five inlet conditions tested and the inlet fixture.

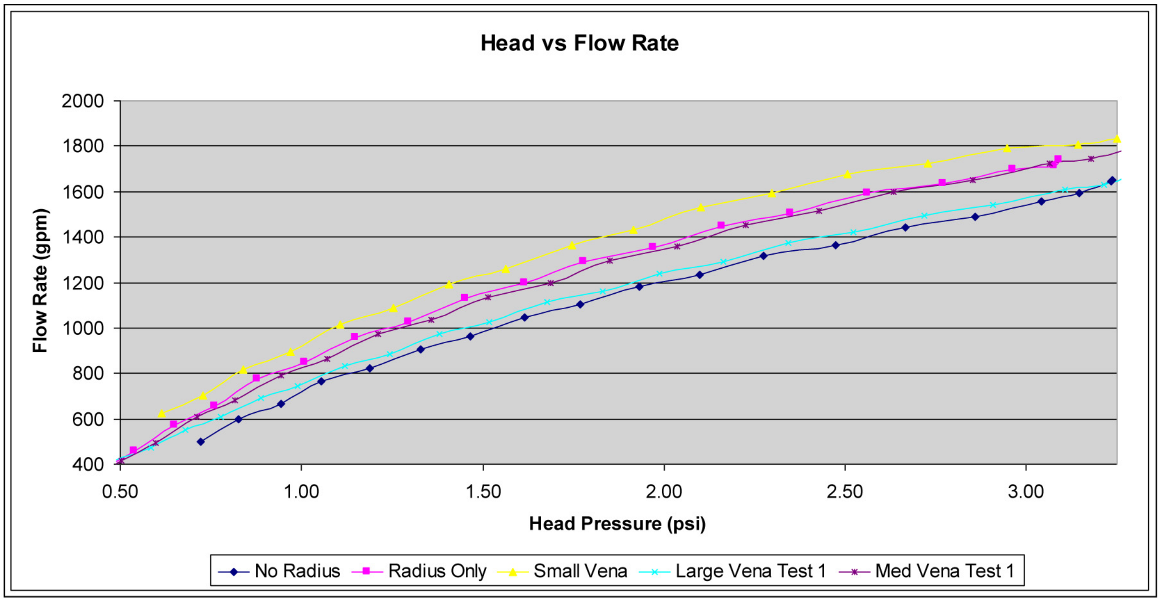
Inlet Flow Enhancer Type	Description
No radius	Inlet fixture with a squarely cut end. See **Figure 3**.
Radius only	Inlet fixture with a rounded leading edge. The radius of the leading edge is equal to the pipe inside diameter divided by four (i.e. Radius One =ID/2).
Radius plus Small *Vena*	Inlet fixture with rounded leading edge (Radius One = ID/2. The radius of the *vena* recess equals the pipe inside diameter multiplied by 0.31 (i.e. Radius two = 0.31*ID)).
Radius plus Medium *Vena*	Inlet fixture with rounded leading edge (Radius One = ID/2. The radius of the *vena* recess equals the pipe inside diameter multiplied by 1 (i.e. Radius two = 1*ID)).
Radius plus Large *Vena*	Inlet fixture with rounded leading edge (Radius One = ID/2. The radius of the *vena* recess equals the pipe inside diameter multiplied by 1.5 (i.e. Radius two = 1.5*ID)).

Table A - Devices Tested

Hydraulic testing was performed at a range of head pressures varying from 1 to 7.5 feet. The testing was performed in a transient flow condition to cover a wide range of flow rates. The test fixture for the flow testing is shown in **Figure 6** below:

Figure 6

Each of the inlet devices described in **Table A** was tested three times. Data was collected and graphed to illustrate the flow rate attributable to each device tested. **Graph 1** illustrates one series of the tests performed:



Graph 1 - Test Results for Flow Series

As shown in **Graph 1**, the flow at approximately 1 psi of head resulted in a flow rate of 705 gpm for a traditional inlet, which has square edges (i.e. no radius inlet fixture); whereas an inlet with the Small *Vena* had a flow rate of approximately 945 gpm. This represents an increase of 34% in flow rate for the inlet with the Small *Vena*, compared to the traditional inlet.

When the performance of the Hydro-Bell was evaluated relative to the traditional designs (i.e. square inlet and rounded inlet), it was determined that the Hydro-Bell inlet had the greatest percent improvement in flow rate as shown in the **Table B** below:

Inlet Type	Headwater (feet)	Discharge (gpm)	% Improvement
Square-edge	2.3	705	0
Round-edge	2.3	830	17.7
Hydro-Bell	2.3	945	34.0

Table B - Flow Comparison at Constand Head Pressures

Based on testing it was determined that as the head pressure decreased, flow rate increased. However, even at high head pressures, flow rate improvements were substantial. **Table C** illustrates the percent change in flow for three head pressure conditions -- for both the traditional inlet and the new Hydro-Bell inlet.

Head Pressure (psi)	Hydro-Bell (gpm)	Flow Rate No Radius (gpm)	% Change
1	945	705	34
2	1,474	1,233	19.5
3	1,787	1,542	15

Table C - Flow Comparison at Various Head Pressures

DESIGN GUIDE FOR HYDRO-BELL

For a submerged entrance and unsubmerged outlet, the culvert inlet behaves like an aperture. Discharge through the culvert is related to the head at the center of the aperture as described in **Equation 1**:

$$Q = C_d \bullet A \bullet \sqrt{2 \bullet g \bullet h}$$

Equation 1

Where C_d is the coefficient of discharge, h is the vertical distance from the center of the culvert entrance to the water surface at the entrance, Q is the flow rate and A is the cross-sectional area of the culvert entrance.

Equation 1 is also expressed in the form of **Equation 2** as:

$$Q = C_d \bullet B \bullet D \bullet \sqrt{2 \bullet g \bullet \left(h - \frac{D}{2} \right)}$$

Equation 2

Where h is the upstream headwater, B is the culvert width and D is the interior height of a culvert barrel (feet). The discharge coefficient is approximately equal to $C_d = 0.6$ for square-edge entrance conditions.

The critical term for predicting flow with the Hydro-Bell is to determine the coefficient of discharge. This study determined that the discharge coefficient for the Hydro-Bell inlet device is a function of head pressure acting on the system. For flow conditions where the inlet is submerged, the coefficient of discharge is described in accordance with **Equation 3**:

$$C_d = 0.6 + \left(0.6 * \sqrt[1.4]{\frac{0.5}{h}} \right)$$

Equation 3

Where *h* is the vertical distance from the center of the culvert entrance to the water surface at the entrance and $h \geq D$.

Substituting **Equation 3** into **Equation 2** flow is expressed in the form of **Equation 4**:

$$Q = \left(0.6 + \left(0.6 * \sqrt[1.4]{\frac{0.5}{h}}\right)\right) \bullet B \bullet D \bullet \sqrt{2 \bullet g \bullet \left(h - \frac{D}{2}\right)}$$

Equation 4 - Culvert Flow With Hydro-Bell Inlet Device

CONCLUSION

Based on the testing and data presented in this study it is concluded that Hydro-Bell is effective at improving flows in culvert applications. As demonstrated in the report, the flow rate improvements range from a high of 34% in low head conditions to 15% for high head conditions, when compared to traditional culvert inlets.

- END -

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Contact us at:

1-800-CULVERT

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