Drop Inlet Failures

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Abstract

The Natural Resources Conservation Service (NRCS) is a federal agency that works hand-in-hand with the people of the United States to improve and protect their soil, water, and other natural resources. For decades, private landowners have voluntarily worked with NRCS to prevent erosion, improve water quality, and promote sustainable agriculture. NRCS has implemented many methods to address these concerns in a variety of situations on private and public land (NRCS website, 2005). Since the 1980's, the Oklahoma NRCS has implemented many canopy and sliced inlet grade stabilization structures to control high runoff volumes over rural land. Though proven to be very useful over the years, an increasing number of failures of the inlets have occurred. In a NRCS report, Chris Stoner outlined the first noticed collapse on a sliced inlet. The entrance of a 42" corrugated metal pipe had failed the first time it flowed. The left side had folded inward, creating a 40% blockage of flow. Since that time, other failures have been noticed and reported. These occurrences were typical of 48" diameter or greater pipes with a 16 gauge thickness. To determine what unknown circumstances where causing the pipe to fail, Vortex tested scale models to determine the vacuum pressures of the inlet and performed a strength analysis test to determine the collapse pressure of the corrugated metal pipe. A comparison was made between the forces provided by the scaled models, to those collected from the strength test. Vortex engineers concluded that the high heads were not the reason for the collapse, as initially thought. From the models, it was concluded that there were very unstable, turbulent conditions around .4 cfs (200 cfs for the prototype), which may be the cause for the failure of the drop inlet structures.

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Mission Statement

“Vortex Engineers is committed to enhancing and protecting water resources through detailed analysis and innovative design. Our superior solutions of hydraulic and hydrologic concerns aim to maintain the integrity of the natural environment while providing practical and affordable results.”

-Vortex Engineers

Introduction

The Natural Resources Conservation Service (NRCS) is a federal agency that works hand-in-hand with the people of the United States to improve and protect their soil, water, and other natural resources. For decades, private landowners have voluntarily worked with NRCS to prevent erosion, improve water quality, and promote sustainable agriculture. NRCS has implemented many methods to address these concerns in a variety of situations on private and public land (NRCS website, 2005).

During a storm event, a large amount of runoff results from developed land or land used for agriculture. Haan, et al. (1994) states that in situations where there are few abstractions to rainfall, such as soil infiltration or plant cover, runoff volumes will be much higher than on land that is undeveloped such as pasture. The peak discharge rate will also increase and the need to control these high volumes and peak flows is important to decrease soil erosion.

NRCS uses drop inlet grade stabilization structures (GSSs) as one method to control large runoff volumes (Figure 1). These structures primarily prevent gully erosion and involve placing corrugated metal pipe (CMP) with diameters as great as 60” to route water from higher to lower elevations. Per discussion with Chris Stoner, Agricultural Engineer with NRCS, implementation of these structures increases the stability of channels by preventing gully erosion and consequently reducing sediment deposition downstream. Although no laws require the use of these structures, farmers, land owners, and even county commissioners install these for the protection of land and roads.

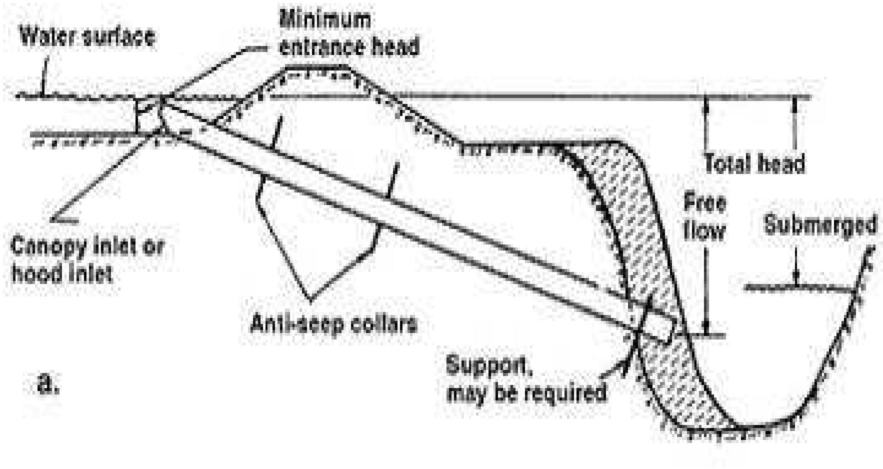


FIGURE 1 – GRADE STABILIZATION STRUCTURE (STEICHEN, 1993)

Blaisdale (1952) explains that the pipe may be designed for full or partially full flow and can be implemented either on a flat or steep slope. The outlet from the pipe can freely flow into the atmosphere or be submerged.

In the 1950's, various entrances for drop inlet GSSs were tested. It was found that canopy and sliced entrance structures were more effective in producing full pipe flow at lower heads than the conventional blunt entrance (Stoner, 2000). (Figure 2 provides an example of a sliced hood inlet, and Figure 3 depicts the canopy hood inlet in the field.) A pipe experiencing full pipe flow moves a greater volume of water in a shorter period of time than pipes flowing partially full. This is important because it reduces initial storage volume, exposure of water to soil, and is more cost effective. It was also found that vortex formation around the sliced and canopy entrances was less of a concern. (Stoner, 2000) Since the 1950's studies, these structures have been widely implemented.

Figure 2 – Sliced Inlet

Figure 3 – Canopy Inlet

Problem Statement

Since the 1980's, Oklahoma has implemented many canopy and sliced inlet GSSs to control high runoff volumes over rural land. Though proven to be very useful over the years, an increasing number of failures of the inlets have occurred. In a NRCS report, Chris Stoner outlined the first noticed collapse on a sliced inlet. The entrance of a 42" corrugated metal pipe had failed the first time it flowed. The left side had folded inward, creating a 40% blockage of flow. Since that time, other failures have been noticed and reported. These occurrences were typical of 48" diameter or greater pipes with a 16 gauge thickness. In 1995, the NRCS recommended the use of canopy inlets instead of sliced hoods, because the canopy added extra strength to the structure. In 1997, the inlet thickness was increased to 14 gauge for pipes with diameters greater than 42". However, a failure was reported in November 2000 of 14 gauge pipe.

The report by Stoner also details characteristics of the failures, which interestingly enough are all similar. Always occurring on the left side looking downstream, the pipe folded inward, consequently blocking the flow and limiting the capacity for which it was designed. Because the time of failure is difficult to determine, the magnitude of head causing the collapse is also difficult to determine.

NRCS is seeking an analysis of canopy and sliced inlets to establish criteria for providing increased strength for corrugated metal canopy inlets, including:

- Determining design parameters that govern the need for increased strength;
- Identifying pipe sizes, corrugations, and gauges that need increased strength;
- Proposing changes to the Oklahoma NRCS Conservation Practice Standards to reflect the analysis.

The NRCS also requests alternative methods for strengthening and a cost comparison of options.

Current Design Specifications for Canopy and Sliced Inlets

The NRCS has published specifications for the dimensions of canopy inlets. These can be found in Appendix B, Chapter 6 of the Engineering Field Handbook.

For conduits with slopes less than 15%, the following equation applies:

$$W = 0.2D;\ L = 0.75D. \quad (1)$$

For conduits with slopes greater than 15%:

$$W = 0.3D;\ L = 1.25D \quad (2)$$

where:

W = height of the canopy (ft)

L = length of the sliced section (ft)

D = diameter of the pipe (ft).

The auxiliary spillway elevation must be at least *1.8D* above the bottom of the pipe. The riser on the drop inlet must be at least *5D* if the conduit slope is greater than the friction slope, or at least *2D* if the conduit slope is less than or equal to the friction slope. The thickness of the pipe is determined based on the fill height of the grade stabilization structure and the diameter.

Research & Literature Review

Patent Search and Pipe Flow Research

For the patent search Vortex Engineers went to the United States Patent website and searched for patents pertaining to pipe inlet reinforcements. Only one patent was found when running the search. The patent found was for internally reinforcing an extruded plastic pipe. An abstract of the patent is as follows:

> An internally reinforced extruded plastic pipe is adapted for use as an underground infiltration, collection, or transport conduit for liquids and gases. The pipe is provided with at least one integral reinforcing stem and the critical mode of failure is buckling rather than deflection. The pipe is not dependent upon surrounding backfill for lateral support as with conventional pipe or conventional reinforced pipe. The same amount of plastic is usable per lineal unit as is used in comparable conventional pipe sizes, however, the cross-section is redistributed, which achieves greater loading capacity.

This patent is a possible solution to the problem; therefore, consideration will be taken so that patent infringement will not occur. Further information on this patent can be found in Appendix C.

A search was also conducted through the Oklahoma State University, Edmon Low Library databases on fluid flow in pipes. An article entitled “Experimental study of turbulent swirling flow in a straight pipe” was found. Kitoh (1991) concentrated on velocity distribution and vortices that arise in pipe flow. The experimental investigation introduced free-vortex-type swirling flow in a long straight circular pipe. Kitoh also stated that the swirling component decayed downstream as a result of wall friction, though velocity distributions continuously changed as they approached fully developed parallel flow. The article maintained that swirling flow through a pipe was highly complex, turbulent, and challenging to predict. These conclusions might give Vortex Engineers insight into the phenomena that occurs while water flows through pipe at high velocities. The velocity distributions and vortex characteristics discussed in the article could be a possible cause of failure in the CMP canopy and sliced entrances.

Structural Analysis of Corrugated Metal Pipe

The corrugation of flat steel plates has not only been proven to increase the stiffness of steel plates, but also improve their strength. Corrugated metal pipe has been used for over 100 years mainly due to its characteristically light weight and structural durability. The use of CMP will also determine the size of the corrugation and whether or not it is helical or annular. A schematic of two corrugation sizes are provided in Figure 4.

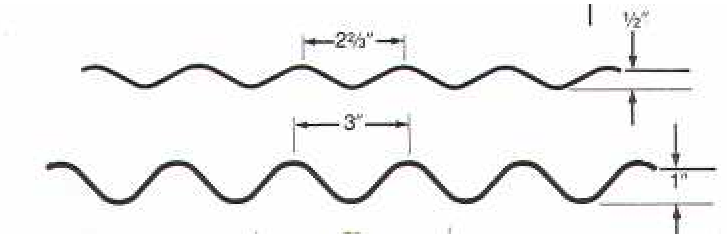


FIGURE 4 – CORRUGATION DIMENSIONS (AISI, 1994).

The majority of research that has been done on CMP has been limited to the pipe characteristics under soil cover depths. The ability of CMP to support a load is derived from loads of soil placed upon them. The inherent strength of each corrugation to resist external pressures and form passive forces is provided by the earth that surrounds the pipe. These passive forces cause stresses in the pipe ring in directions opposite to those produced by the vertical loads, therefore assisting the pipe in supporting vertical loads (Spangler, 1941). Two types of these loads are:

1) Dead loads- Developed by the embankment or trench backfill, plus stationary superimposed surface loads, uniform or concentrated.
2) Live Loads- Moving loads, including impacts (AISI, 1994).

Spangler (1941) says that since CMP has relatively little inherent strength, a significant source in its ability to support load, is the passive pressures induced when the sidewalls begin to move outwards. Because CMP will readily deform, it consequently utilizes the passive pressures of the earth on all sides of the pipe. According to Spangler, this structural characteristic accounts for the fact that such a relatively lightweight pipe will support earth fill of considerable heights. It is assumed that loads are distributed uniformly over the top and bottom of the pipe. Loads which are caused by passive pressures of the earth are said to be greater toward the center of the pipe and can be seen in Figure 5.

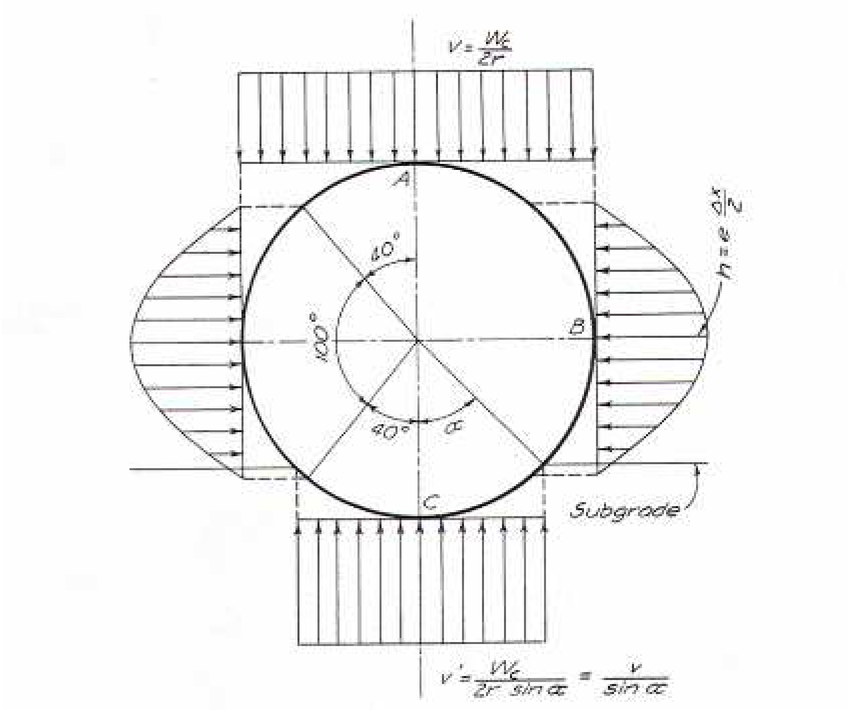


FIGURE 5 – CMP LOAD DISTRIBUTIONS

The above figure does not necessarily give the characteristics of CMP under hydrostatic conditions, but it does give an idea on how CMP reacts under load stresses. Chris Stoner feels that Vortex could use the data provided from buried conduits in calculating the hydrostatic forces on CMP. With further research and modeling techniques, Vortex will determine whether or not this method will represent the forces of water acting on CMP.

The following equations illustrate the load distributions that are applied to CMP under soil compression.

Vertical unit load on the pipe ,*v*, (Spangler, 1941):

$$v=\frac{W_C}{2r} \quad (3)$$

where:

Wc = distributed load across top portion of pipe

r = radius of the pipe.

Vertical unit reaction on the bottom of the pipe ,v', (Spangler, 1941):

$$v' = \frac{v}{\sin(\alpha)} \quad (4)$$

where:

α = bedding angle with respect to the vertical axis.

Passive horizontal pressures on the side of the pipe, h, (Spangler,1941):

$$h = e\frac{\Delta x}{2} \quad (5)$$

where:

e = modulus of passive pressure of side fill

Δx = horizontal deflection of the pipe.

CMP not buried in compacted soil and subjected to external hydrostatic pressure must be designed for buckling as circular tubes under uniform external pressures (AISI, 1994). If the above method cannot be used, the two formulas below can be used to determine the critical pressure on the surface of the pipe.

Critical pressure, P_{cr}, of a corrugated metal pipe (AISI, 1994):

$$Pcr = \frac{3EI}{(1-\mu^2)R^3} \quad (6)$$

where:

E = modulus of elasticity (lb/in^2)

I_{pw} = pipe wall moment of inertia (in^4)

μ = Poisson's ratio (specific to material)

R = mean pipe radius (in).

The equation below calculates the estimated collapse pressure, *PE,* of corrugated metal pipe (AISI, 1994):

$$PE = \frac{(49.5 \times 10^6) \times I}{R^3} \quad (7)$$

Chapter 52 of the NRCS National Engineering Handbook (NEH) (2005) details basic properties for any type of flexible conduit. It includes corrugated metal pipe and also gives methods to calculate pressures and stresses on a pipe.

The maximum allowable pressure should be limited to 20 feet of head for annular pipe and 30 feet of head for helical pipe. The vacuum load per length of pipe, W_v (lb/ft) is determined by the following equation:

$$W_v = P_v \frac{D_i}{12} \quad (8)$$

where:

P_v = internal vacuum pressure (lb/ft^2)

D_i = inside diameter of the pipe (in).

If the pipe is below the water elevation, external hydrostatic pressure, P_g (lb/ft^2) can be found by:

$$P_g = y_w \times h_w \quad (9)$$

where:

γ_w = unit weight of water (lb/ft^3)

h_w = height of water above top of pipe (ft).

S_b (lb/in^2) or the maximum bending stress in the pipe wall of an unsupported pipe is:

$$S_b = \frac{MD_o}{2I} \quad (10)$$

where:

M = bending moment (in-lb)

D_o = outer pipe diameter (in).

The hoop stress, S_p, caused by internal pressure (lb/in^2) is:

$$S_P = \frac{PD_o}{2t} \quad (11)$$

where:

P = pressure in the pipe (lb/in^2)

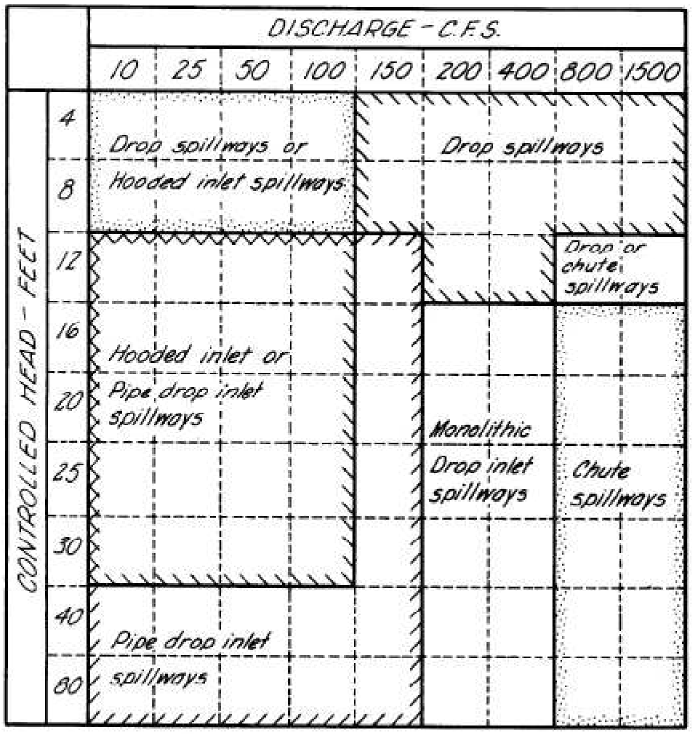
t = pipe wall thickness (in).

Appendices to NEH-Ch. 52 give section properties for corrugated pipe, such as areas and moments of inertia for different gauges.

NRCS Current Guidelines for Designing Pipes and Spillways in Structures

This section details NRCS publications that contain guidelines used in constructing these pipes and spillways.

Figure 6 (NEFH, 1984) aids in deciding what type of spillway should be used based on discharge and head. NEFH, Ch. 6, also gives capacity charts for discharge based on head and diameter specifically for corrugated metal pipe.



Note: Chart shows most economical structure as related to discharge and controlled head providing site conditions are adequate.

Figure 6 – Discharge vs. Head for determination of inlet structure (NEFH, 1984).

Section 11 of the National Engineering Handbook titled Drop Spillways, details information about the design of various types of drop spillways. Technical Release 3 from NRCS documents, titled “Hood Inlets for Culvert Spillways” summarizes original research preformed on hooded inlets, including dimensions and capacities.

Statement of Work

The NRCS has contacted Vortex Engineers to evaluate the problems associated with sliced and canopy entrances, determine the cause of collapse, and propose design solutions to prevent future failures. The following is a brief summary of work that has been conducted and what is planned in the future.

First a field tour in western Oklahoma of these structures was taken to help the team visualize these structures in the field. Next, at the United States Department of Agriculture, Agriculture Research Service Hydraulics Lab in Stillwater, Oklahoma, a demonstration flume that utilizes scaled Plexiglas replicas of the inlet structures was observed. The demonstration model allowed Vortex Engineers to observe flow characteristics of the pipe with different inlet structures attached (Figure 7). Vortex Engineers performed another demonstration using red transparency film to test if failures will occur under similar conditions, but of a different material (Figure 8). In the model, the same failures occurred with red film as those reported from the field: after a certain head was reached, the left side of the film folded inwards.

It is worth noting that though this model was helpful in demonstrating the process of how the pipe entrances failed, the model was not to scale, nor were the materials similar to that of corrugated metal pipe. Therefore, the model did not produce any measurable or useful data, but was useful in illustrating the phenomenon.

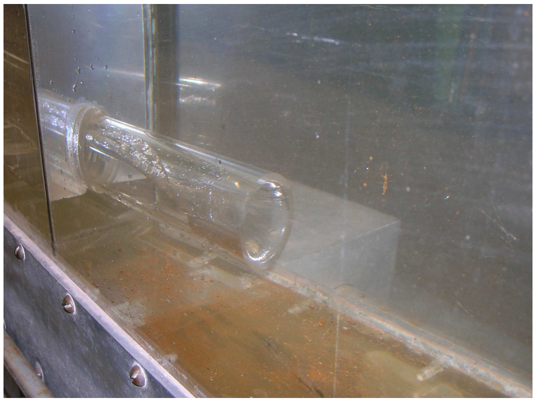


FIGURE 7 – BLUNT INLET

FIGURE 8 – RED TRANSPARENCY FILM

To aid in determining where failures are occurring, Vortex has performed preliminary calculations for pressure and head analysis. These calculations will identify pressure distributions which are needed to determine forces throughout a pipe.

A scale model will be built of Plexiglas pipe. The scale models will aid in observing what the entrances are experiencing under different flows. Vortex Engineers also hopes to gain actual pressure and velocity measurements from the scale models. Upon completion of these tasks, Vortex can determine whether the current designs are sufficient as specified or if they need to be modified.

Initial Investigation

To aid Vortex Engineers in trying to solve the source of the collapse of the CMP drop inlet structures, the following procedures were performed. These procedures were successful in providing a better understanding of how the structure functions as well as an initial analysis of the problem.

Field Tour of Installation Sites

On October 4, 2005, Vortex Engineers toured several installed GSS sites in western Oklahoma with Chris Stoner and Baker Eeds, engineers with the NRCS. The first failed inlet in the state occurred in Eeds' service area and he has been involved with the investigation of the failures since.

The first stop on the tour was a GSS owned by Gelene Schreck. The Schreck GSS had a 48" sliced hooded drop inlet with 16 gauge metal thickness (see Figure 9). It was constructed in 1993, failed in 1995, and has since not been repaired. The inlet collapsed on the left side (looking downstream), which is consistent with the other documented failures. Because of the reduced flow of the inlet, a noticeable amount of erosion had occurred in the auxiliary spillway, defeating the purpose of a GSS.

FIGURE 9 – SCHRECK'S FAILED DROP INLET STRUCTURE

The other three GSSs toured had not failed, though it was beneficial to see the design of the structures and how they operated. All three GSSs had had auxiliary flow in the past but had no visible detrimental effects. One GSS owned by Mr. Alexander had angle iron stiffeners installed on each side directly following construction to prevent any failures from occurring.

Baker Eeds shared valuable information that helped Vortex understand the problem more fully. Mr. Eeds felt that the difference between the inlet and outlet water heads was a big factor in the failure of the pipe. He stated that structures with submerged outlets were less likely to fail due to the smaller difference between the two water heads.

Demonstration Flume

For preliminary investigation, Vortex went to the ARS Hydraulics Lab in Stillwater, Oklahoma to make observations on pipe flow using a demonstration flume (see Figure 10).

FIGURE 10 – DEMONSTRATION FLUME

The flume consists of a tank with a recirculating reservoir. It allows demonstrations of pipe flow through various detachable replicas of pipe inlets; such as canopy, sliced, and blunt. The demonstration flume also is capable of adjusting pipe slope and water head. Figure 11 is an example of a canopy inlet. Vortex was able to observe water flow characteristics and how they differed through the various inlets.

FIGURE 11 – CANOPY PIPE INLET REPLICA

Following the observation of flow in the pipe models, the team marked each of the three inlet replicas with lines every 0.2 inches along the perimeter of the inlet with a permanent pen (see Figure 12). After drawing the lines on the inlet models, the team began taking pressure measurements at each increment marked around the inlet.

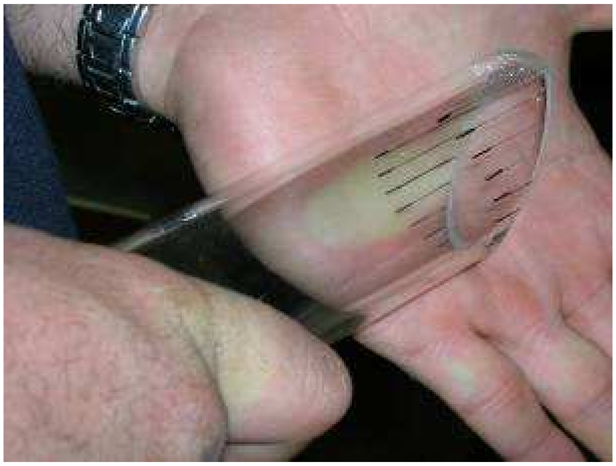


FIGURE 12 – PRESSURE MEASUREMENT LAYOUT

To obtain these pressure measurements Vortex Engineers used a simple manometer constructed of a small clear plastic tube open on one end and an air pump needle attached to the opposite end. Each pressure measurement was calculated by how much the water level in the manometer changed in relation to the water level at the inlet. Measurements were taken as the needle was moved each 0.2 inch increment around the circumference of the pipe. This process was preformed twice for each inlet model.

The sliced and canopy inlets displayed pressures that were slightly higher on the right side of the inlet. The blunt inlet had much more equal pressures than the other two inlets.

The pressure measurements using this method are not considered to be hard and accurate data, and will not be treated as such by the design team. However, these data do give Vortex Engineers an idea of what the different inlets are experiencing as far as pressure is concerned. It also allows Vortex to get an idea of what forces could be resulting from these pressures.

Physical Modeling

To further investigate the pressures and forces seen by the inlets in the field, Vortex conducted two different tests: scale models to measure pressures under normal flow conditions and a full-scale model to test the structural integrity of the sliced CMP inlets.

Scale Models

The following sections describe the process of construction and testing of the scale models and lastly the results gathered from these tests.

Construction

The pressures that CMP inlets would experience needed to be determined. Because the flow characteristics for the two inlets would differ, the pressures would also be affected. Therefore, it was important to build and test both a sliced and canopy inlet.

Vortex Engineers' goal was to determine the vacuum and static pressures on a scaled down version of a structure implemented in the field. In doing this, the team could build a model from actual design dimensions. Following testing, forces determined from the model could then be scaled to prototype values.

Initially, the team contacted Baker Eeds, who was able to provide several designs that have been implemented in western Oklahoma. After reviewing the designs, the team decided to model a structure that contained a 48” barrel, because it is currently the most common pipe size being implemented in these drop inlet structures. The design of the inlets follows the specifications outlined by the NRCS and were modeled after the Loyd Atkinson GSS no. 1 installation (found in Appendix D), which is on a slope of 11.3%. This meant that all of the design dimensions for the model would be based off structures having a slope less than 15%.

To determine the dimensions of the model and the various flow rates that would be tested, Froude scaling was used. The Reynolds number was calculated as 1.35×10^8.

The following scale ratios were used from Henderson (1966):

$$L_r = Dp / Dm \quad (12)$$

where:

L_r = length ratio (in/in)

Dp = diameter of prototype (in)

Dm = diameter of the model (in)

$$v_r = L_r^{1/2} \quad (13)$$

where:

v_r= velocity ratio between model and prototype

$$Q_r = L_r^{5/2} \quad (14)$$

where:

Q_r = discharge ratio between model and prototype

Using these scaling equations, dimensions for the two models were determined to be a 12:1 ratio. Figure 13 illustrates the dimensions for the two models.

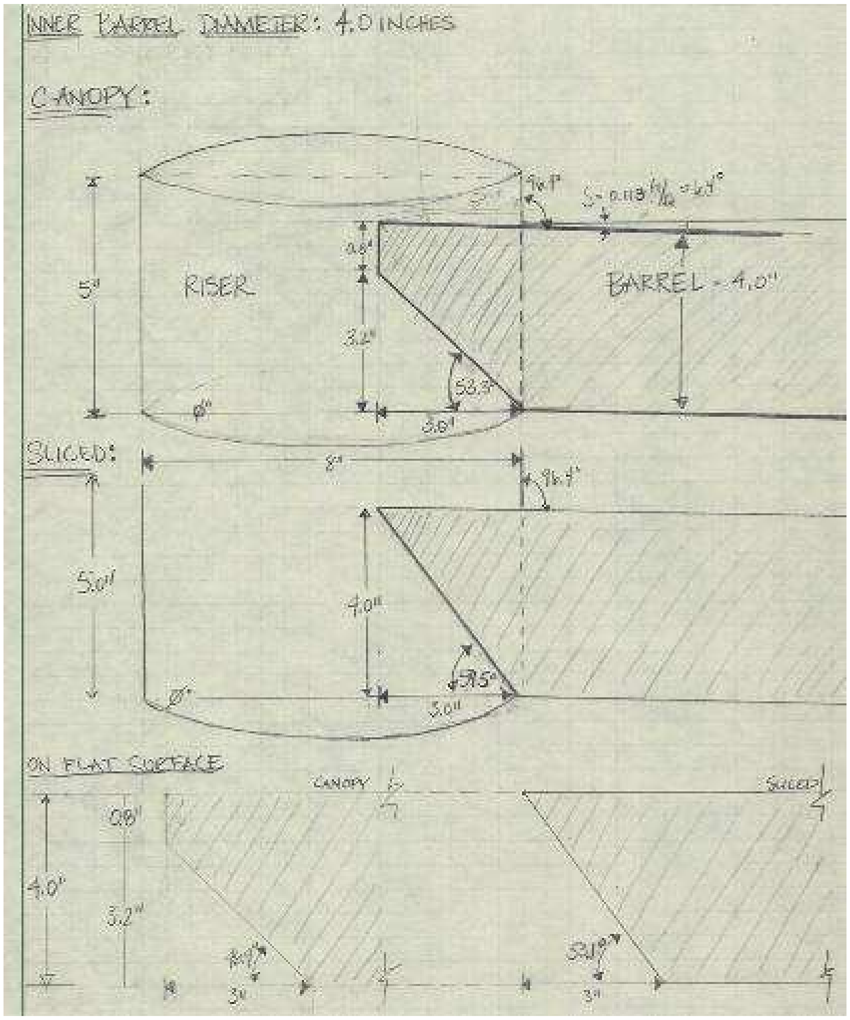


FIGURE 13 – DIMENSIONS OF SLICED AND CANOPY MODELS

It was not only important to use these formulas to determine the dimensions of the model but to also determine the flow rates as well. Because the model tank at the Hydraulics Lab could produce a maximum flow of 1.0 cfs, the flow rates through the models could not exceed this. After visiting with Baker Eeds, he stated the maximum flow a 48” pipe would experience was approximately 270 cfs, while a minimum flow rate would be around 150 cfs. This information allowed Vortex Engineers to come up with a range of flows that would not only model the flow rates provided by Mr. Eeds, but also be under the 1.0 cfs flow rate of the model tank. This corresponds to a range of prototype flow rates from 150 cfs to 320 cfs, and 0.30 to 0.64 cfs respective model flows.

Once the initial parameters of the models were determined, the next step was to determine how the vacuum pressures would be measured. It was important to have the measuring device be flush with the inner wall so velocity head would not also be measured. The initial concept for measurement was a manometer type setup. This setup included a needle, which would be attached to a tube of water that would be inserted into a septum material located around the inlet of the structure. The vacuum pressures would then be measured by taking the difference between the initial and final water levels within the tube. Vortex Engineers realized that this technique could have a lot of error due to variations in the needle placement every time a measurement was taken. The next idea considered was brought to their attention by Wayne Kiner, BAE Lab Manager. This idea came from a model airplane that was being tested in a wind tunnel. Along the wings of the model were ports that had tubes running to gages that measured the pressures the model plane experienced under different conditions.

With Dr. Glenn Brown’s help, a professor in the OSU Biosystems and Agricultural Engineering department, Vortex Engineers decided to take pressure readings at twelve different locations around the circumference of the inlet. Each location would be spaced 30 degrees from each other and contain four ports per location. A schematic of the setup can be seen in Figure 14.

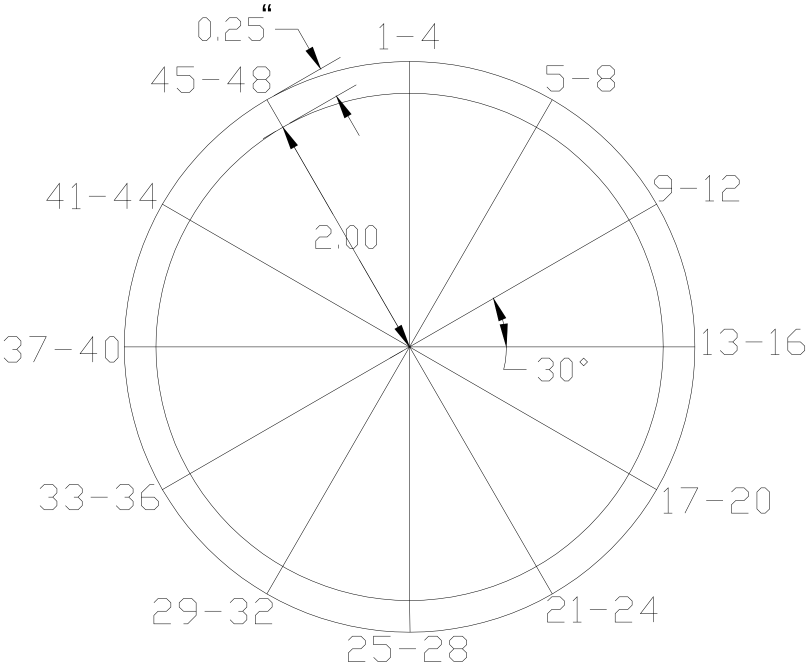


FIGURE 14 - DOWNSTREAM VIEW OF MODEL PRESSURE PORT LAYOUT

Each of the models was built of Plexiglas pipe. They consisted of an inlet along with a riser pipe. The inlet and barrel portion of the models had an internal diameter of four inches, a wall thickness of ¼ inch, and was approximately one foot in length. To measure the vacuum pressures of the inlets, holes 3/32" wide were drilled and counter bored in the milled out areas around the circumference of the pipe. These milled out areas were approximately ½ inch wide and 1/16 of an inch deep.

Figures 15 and 16 show the ports and milled locations for each of the models.

FIGURE 15 - SLICED INLET MODEL

FIGURE 16 - CANOPY INLET DESIGN

As seen from figures 15 and 16, the length of the milled areas depended on how far that particular area of the pipe was inserted into the riser. The purpose of these milled areas was to imbed the tubes within the Plexiglas, so the flow around the inlets was not affected due to disturbances on the pipe surface.

Tygon tubes were used for measuring pressure and were inserted into the ports and held with super glue within the milled areas. Once the tubes were in place, Bondo® was applied to the milled areas over the Tygon tubing and smoothed to the surface of the pipe. After the Bondo® had hardened, additional tubing was added, by gradually increasing the internal diameter of the tubing and inserting them into the previous tube. Four different sizes of tubing were used to get the inside diameter to 3/16”. This process was done to match the size of the gage fitting that was used to measure the pressures.

To finalize the models, the inlet entrances were beveled back to sharp edges that would most closely model the flow path. An anti-vortex baffle was applied to the sliced inlet. Figures 17 and 18 show the final setups for each of the models.

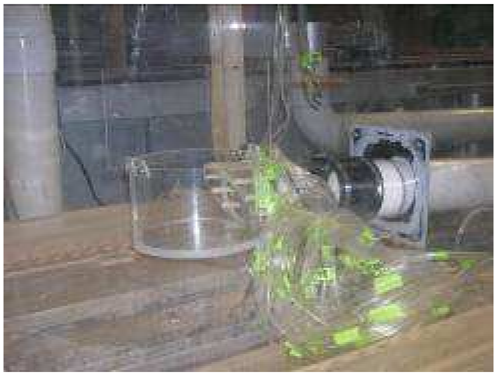


FIGURE 17 - FINAL SETUP FOR SLICED INLET

FIGURE 18 - FINAL SETUP FOR CANOPY INLET

Setup

The scale models were setup and tested in a demonstration tank located at the USDA ARS Hydraulics lab (Figures 17 and 18). The model setup consisted of the sliced or canopy inlet, 4'' rubber pipe coupler, hose clamps, roof vent, 7' of 4'' PVC, and a 4'' PVC coupler. Once a hole was cut into the tank, the roof vent was attached to the tank and the PVC pipe was inserted approximately 6 inches into the tank. After the pipe was inserted, it was siliconed and hose clamped to insure that no leaks would occur around the entrance of the pipe. To get a total length of 8 feet of barrel pipe for each of the inlets, an additional 7 feet of PVC pipe had to be added via a coupler. An additional 2 feet of pipe was added to the initial 5 feet that had been inserted into the tank.

The rubber coupling was used to transition between the two inlets easily. Hose clamps were used to attach the coupling to the PVC and the model. To change out the model, it took nothing more than to loosen the clamp and remove the model. Figure 19 shows an illustration of how the rubber coupling was used to attach the PVC pipe to the model.

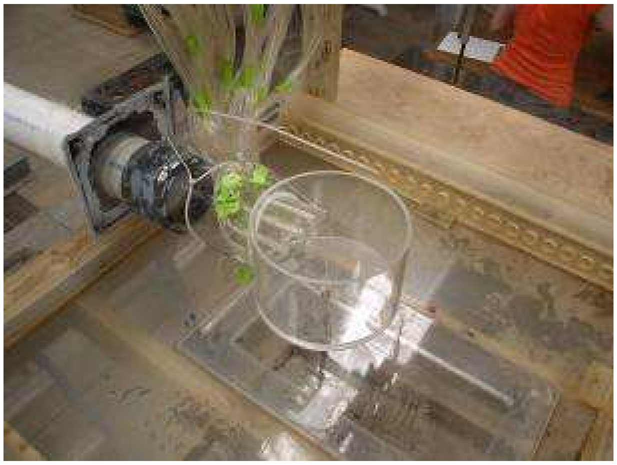


FIGURE 19 - ATTACHMENT OF MODEL TO PVC

Once the model was inserted into the coupling, a turn buckle was attached to the bottom of the model to the tank. This was done to insure that the model would not rise when water entered the tank and to also insure that the riser bottom was level.

As described in the construction section of the scale models, tubes were inserted into ports to measure the vacuum pressures of the inlets. To help keep the tubes organized, numbers were applied to each of the tubes. In addition to numbering the tubes, they were inserted onto nails that were on a numbered board. A complete setup of the scale model testing can be seen in Figure 20.

FIGURE 20 - COMPLETE MODEL SETUP

To determine the flow rates of the models, a 4 inch orifice plate was used to calibrate the flows. This calibration process consisted of a gate valve and a manometer. Once the valve was opened, the difference in water levels in the manometer was read and compared to the sheet of calibrated flows for the 4 inch orifice plate at 70 degrees Fahrenheit.

Pressure Tests

Pressures were recorded for each model at five different flow rates: 0.65, 0.6, 0.5, 0.4, and 0.3 cfs. Test flows were delivered to the model tank in a continuous flow recirculation system. Flow entered a constant head tank and was then delivered through a 12" pipeline where the flow rate was measured with a combination of an orifice plate and air-water differential manometer. Each port was tested by forcing air through the tube with a syringe to make sure that no water was in the tube, and then connecting the tube to the pressure gage, which gave readings in inches of water. Figures 21 and 22 illustrate the clearing out of tubes and the pressure gage.

FIGURE 21 - CLEARING OUT TUBES

FIGURE 22 - PRESSURE GAGE

All ports were read and three sets of data were taken for each inlet at each flow rate in order for average pressures to be determined. Each average pressure was then converted from inches of water to psi. The pressure on the prototype was calculated by multiplying the model pressure by 12, from the 12:1 scale ratio. The pressure on the pipe from static water head was also measured. See Table 1 for head measurements for each inlet at different flow rates. This was added to the pressure measurements to get the total pressure applied at that port. Forces for the scale and model prototype were calculated by using the pressure in psi and applying it over an average area, to get the force in lbs. This area was calculated from the orientation of the ports, where each port was 0.5” apart and the arc length between rows was 1.05”, therefore the area that each pressure was applied over was (0.5” x 1.05”) = 0.525”, assuming the port was in the center of the area.

Inlet Type	Model Flow (cfs)	Model Head (ft)	Prototype Flow (cfs)	Prototype Head (ft)
Sliced	0.3	0.55	150	6.6
Sliced	0.4	0.59	200	7.08
Sliced	0.5	0.77	250	9.24
Sliced	0.6	0.98	300	11.76
Sliced	0.64	1.45	320	17.4
Canopy	0.3	0.54	150	6.48
Canopy	0.4	0.59	200	7.08
Canopy	0.5	0.64	250	7.68
Canopy	0.6	1.00	300	12.00
Canopy	0.64	1.58	320	18.96

TABLE 1 - HEAD MEASUREMENTS. HEAD WAS MEASURED FROM THE INVERT OF THE PIPE TO THE WATER SURFACE.

Results of Pressure Testing

The highest pressures on both models at the highest flow rates were recorded at ports 9 and 10, on the right side, 2” from the top of the pipe. Lowest pressures were recorded on ports 25-28 which are at the bottom of the pipe. See Figure 14 for a schematic of pipe numbers and Figure 23 for a pressure graph for the canopy inlet at 320 cfs. All other pressure graphs and data collected from the models are in Appendix’s E and F.

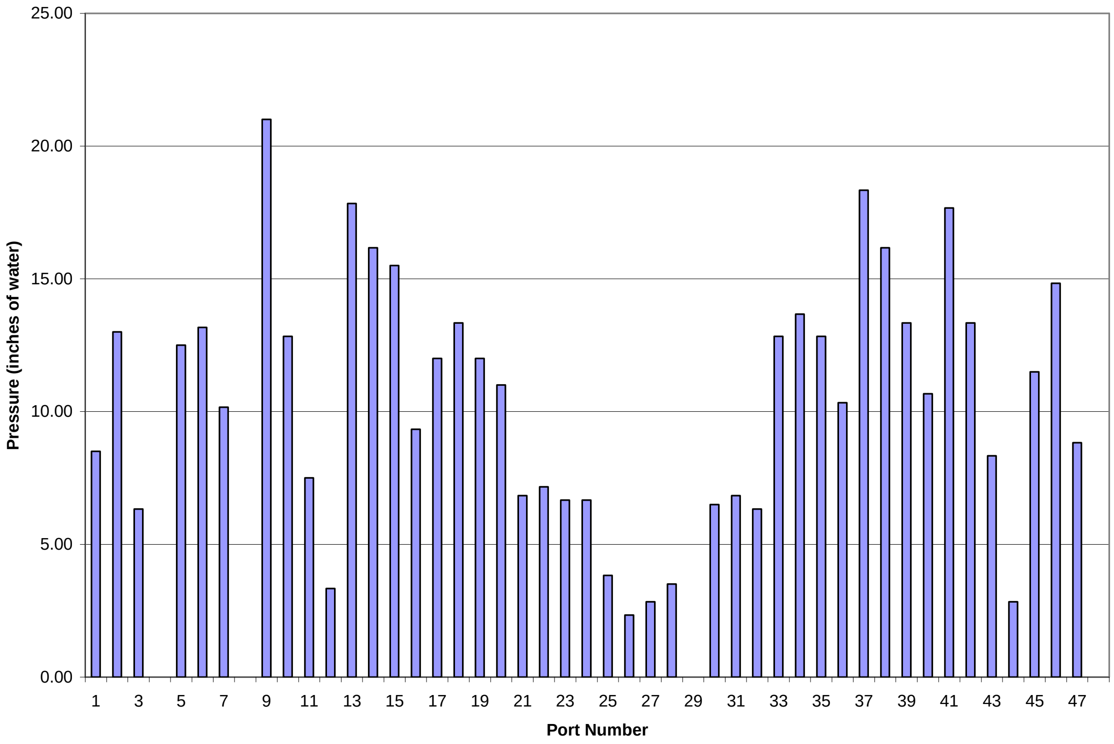


FIGURE 23 - PRESSURE READINGS FOR CANOPY INLET AT 320 CFS (0.64 CFS).

After combining the forces from the internal vacuum pressure and the static water pressure, the highest force seen by the model at one port was 0.7 lbs at port 9 on the canopy inlet at 0.64 cfs, which scales up to 1,211 lbs at 320 cfs on the prototype. Lower flow rates produced lower pressures.

When running these tests, it was noticed that the flow was steadier at higher flow rates than at lower flow rates. Vortex Engineers believe that the lower flow rates were unsteady because the pipe would transition from being fully primed to not being fully primed. This created some fluctuation of pressures, similar to a water hammer.

It was also noticed that more vortices formed at 150-250 cfs when testing the canopy inlet than were expected. The vortices were most violent at 200 cfs, which could cause pressure fluctuations within the pipe. Since the canopy was developed partially to help prevent vortex formation, it was assumed that it would have less vortex formation. However, it was observed that the canopy inlet had more vortex formation than the sliced inlet that was tested. The sliced inlet was tested with an anti-vortex baffle in place according to current design specifications.

Dye Testing

To observe flow characteristics around and inside these inlet structures, Vortex Engineers performed a dye test with the assistance of Dr. Glenn Brown. The dye used to perform the tests was red Rhodamine. This test was performed only on the canopy drop inlet. The dye was injected into the water with a syringe. The dye allowed Vortex Engineers to see the unstable conditions of the water inside the riser and as the water exited through the inlet. The team noticed that there was significant turbulence as the water flowed downward into the riser. As it entered the inlet, the water velocity increased tremendously; as a result of the increased velocity, the dye disappeared very quickly from the inside of the inlet structure in a surging fashion. This test was helpful in allowing Vortex Engineers to see the actual flow characteristics in and around the inlet structures and could possible give implications into the cause of the vortices seen inside the inlets.

Testing of Baffle Arrangement

During the scale model testing, Vortex Engineers took the anti-vortex baffle off of the sliced inlet model and placed it on the canopy inlet model to see if any changes in vortex formation could be observed. There were no significant changes in vortex formation upon adding the anti-vortex baffle to the canopy inlet model. The vortex formations were cut in two, but not eliminated. Vortex Engineers changed the position of the baffle to be perpendicular to the inlet to see if that had any affect on the vortex formations as well as using other flat pieces of Plexiglas to create possible baffle designs that might be implemented. This did not reduce vortex formation either, but simply changed the location of the vortices inside the riser. This tinkering with the anti-vortex baffle did not produce any changes that could lead to a possible redesign; however, this was a very informal investigation because it only involved moving pieces of Plexiglas around by hand and observing any changes in turbulence.

Strength Test on Full Scale CMP Inlets

The objective of the strength test was to experimentally determine the collapse force of full size sliced and canopy inlets. This was done to provide experimental data that could be related and compared to the data obtained from the pressure tests. To accomplish this task, Vortex Engineers along with the expertise of Wayne Kiner and the BAE lab staff recreated the inlets as closely as possible to those installed in the field. A hydraulic cylinder was used to place a load on one side of the inlet, while a load cell measured the force being applied. A hand-held monitor displayed the readings from the load cell and each test was filmed.

Materials and Setup of Test

Corrugated metal pipe that is 48” in diameter, with a thickness of 14 gauge (0.079”) and 3” by 1” corrugations, was obtained from Dub Ross Company in Oklahoma City, OK. Three sliced and three canopy inlets were constructed at the BAE lab on the Oklahoma State University campus. The construction of the inlets follows the specifications outlined by the NRCS and were modeled after the Loyd Atkinson GSS no. 1 installation (Appendix D). Figure 13 shows the angles used for the full scale construction and lengths were increased by a factor of 12, since the full scale is 12 times greater than the size of the model. The only deviation from those specifications is the added length at the base of the inlets. In the field, the pipe is flush with the riser at the invert, which means there is not a full circle at the bottom. Therefore, 1” was added to the total length of the pipe so there would be a full ring of metal at the base and enough metal to drill through to bolt to the plate on the floor.

To test these inlets as accurately as possible, it was paramount for their installation to mimic that in the field. Steel plate, 1/4“ thick was used as a base for the inlets, which was then bolted flat to the floor. This meant that the inlet would need to stick up vertically, with the load being applied horizontally. This was deemed the best configuration for several reasons. First, having the plate bolted to the floor provided the best structural support for the inlet without having to construct anything further. Secondly, if a load was applied vertically, there would be deflection due to the load pushing downward and also from the floor pushing upward on the pipe. This possibly may have caused a collapse that was not similar to those seen in the field. To remedy this problem, more time and money would have been needed to construct an additional structure or apparatus, which would only add to the complexity of the tests.

Though typically the inlets are welded to the drop inlet risers, Vortex Engineers needed to find an alternative method to attach it to its support that was less permanent and more manageable. It was also important for the team to be able to switch the inlets out themselves without needing a welder present, while also not compromising any strength the base gives the inlets. Therefore, the inlets were bolted to the plate instead of being welded. This was done by using 1/8” steel slats with 3/8” holes that were welded on the 1/4” support plate, along the circumference of a 48” diameter. See Figures 24 and 25 for pictures of this construction.

FIGURE 24 – METAL SLATS WELDED TO SUPPORT PLATE FOR INLET ATTACHMENT

FIGURE 25 – CLOSE UP OF METAL SLATS WITH DRILLED HOLES

For each test, 23/64” holes were drilled through the base of an inlet and secured tightly with 5/16” nuts and bolts. This method of securing the inlet accomplished a number of things. To begin, the team members could switch out the inlets quickly and easily themselves by simply bolting and unbolting the pipe. The bolts and welded steel slats also provided ample stability and structural strength for the test. Finally, the amount of materials needed was greatly reduced because the same 1/4” plate could be reused over and over again. This also saved time, since the plate did not need to be set and reset for each run.

The load was applied via a 3.5” diameter hydraulic cylinder. To provide pressure for the cylinder, it was connected to a portable pump with an electric power supply. The hydraulic cylinder was attached to a 4 foot I-beam that had been bolted to the floor with 1/2” bolts. A brace that had been fabricated in the lab for this test was attached to the I-beam and used in conjunction with a bolt and eye to support the cylinder. With this brace, the cylinder could be moved up and down to allow for proper placement. A second I-beam was bolted down and set directly behind the first one and a metal bar was wedged between them for extra support and added safety. The setup can be seen in Figure 26.

FIGURE 26 – SET-UP OF HYDRAULIC CYLINDER AND I-BEAM SUPPORTS

To prevent the cylinder from creeping upward during testing, a long steel plate with a support arm back to another brace was extended over the length of the cylinder.

To attach the cylinder to the load cell, a nut was welded to a 1/2” bolt which made the connections rigid. From the load cell, another bolt was welded to a ball joint connection. This ball joint attached to a round metal plate 5.5” in diameter, which was the device that applied the load to the inlet. See Figures 27 and 28 for a close up picture of the ball joint and overall load cell setup.

FIGURE 27 – BALL JOINT MECHANISM

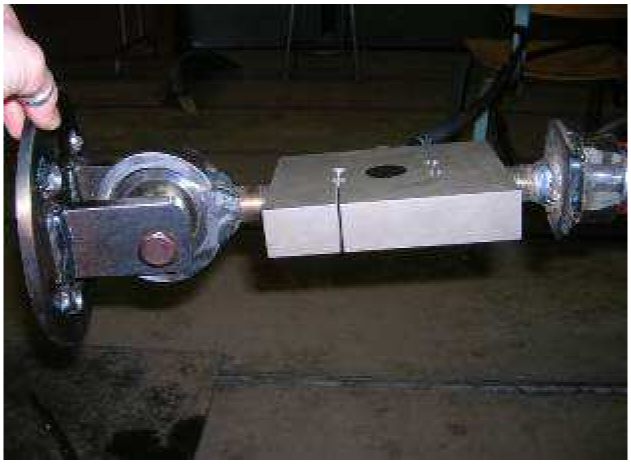


FIGURE 28 – LOAD CELL SETUP

The ball joint mechanism enabled the point of contact of the load to rotate with the pipe as it deflected. This also protected the load cell from undergoing any torque, which can damage the load cell. To prevent slipping when a load was applied, the 5.5” round plate was bolted to the pipe with four 5/16” bolts. In all instances other than the first test run on a sliced inlet, the load was applied at 24” from the bottom of the inlet and 8” from the edge.

The load cell used was a Chatillon load cell with a 10,000 lb capacity in both tension and compression. A Chatillon handheld display monitor was linked up to the load cell so that forces could be read and recorded.

Testing

To run the tests, the electric pump was first turned on, and a lever was used to displace the cylinder. As pressure was applied to the CMP inlet, it began to deflect. At the point where permanent deformation was noticed, the test ceased. Because the round 5.5” plate was bolted to the inlets, the cylinder rod had to be retracted back to a point where the load cell monitor read close to zero. Therefore, in pulling the cylinder back, some of the deformation in the metal was corrected, though the permanent deformation can still be seen.

First tests on the sliced inlets were run, followed by the three canopy inlets. The data on the first sliced inlet may have been somewhat compromised because Vortex needed to use it as means to perfect the procedure and several trials were run before a failure was achieved.

For most of the sliced inlets, Vortex Engineers tested both the right and the left side. The team wanted to investigate whether a failure on the left affected the strength on the right. Therefore, the right side on the next inlet was tested first and then compared to the previous test. The canopy inlets were tested only on the left side.

Results and Discussion

The deformation of the pipe between the sliced and canopy inlets was somewhat different. For the sliced inlet, once the hydraulic cylinder began applying the load to the inlet, the metal started to deform gradually, with the top portion of the pipe folding inwards. After the pipe had bent inwards at almost a 30 degree angle, it began to structurally fail. At this point, the corrugations were crimped or had collapsed.

Figure 29 shows the area at which the collapse occurred for a canopy inlet. The distance from the bottom of the pipe to where the corrugation collapsed can be seen in Tables 2 and 3. After the pipe reached this point of failure, the load applied to the pipe gradually began decreasing because the yield point of the metal had been surpassed.

FIGURE 29 - AREA OF COLLAPSE

The top portion of the slice inlet deformed more than the canopy inlet. From this observation, the team realized that the canopy inlet was more structurally stable than the sliced inlet.

The results of the strength tests are found in Tables 2 and 3.

Sliced Inlet : Results of Strength Test for Full Scale Inlets

	Force Applied	**Pressure (Force/Area)**	**Failure Occurred** (measured from bottom)	**Notes**
Inlet 1	Left: 2500 lb Right: 2000 lb	Left: 2834 psi Right: 2268 psi	Left: 13.5”	Tested left side first; ran 4 or 5 tests before achieved a failure
Inlet 2	Left: 2200 lb	Left: 2494 psi	Left: 17.0 “	Only tested left side.
Inlet 3	Left: 2350 lb Right: 2650 lb	Left: 2664 psi Right: 3005 psi	Left: 16.5”	Tested right side first.
Average	Left: 2350 lb	Left: 2664 psi	Left: 15.5”	

TABLE 2 - SLICED INLET RESULTS

Canopy Inlet : Results of Strength Test for Full Scale Inlets

	Force Applied	**Pressure (Force/Area)**	**Failure Occurred** (measured from bottom)	**Notes**
Inlet 1	Left: 2950 lb	Left: 3345 psi	Left: 13.5”	
Inlet 2	Left: 3200 lb	Left: 3628 psi	Left: 13.5 “	Canopy slightly bent
Inlet 3	Left: 2640 lb	Left: 2993 psi	Left: 12.5”	Canopy bent and left sides bent
Average	Left: 2930 lb	Left: 3322 psi	Left: 13.2”	

TABLE 3 - CANOPY INLET RESULTS

The load applied for these tests was a point load. Though Vortex Engineers understands this load is different than that which an inlet would experience in the field, it was important to determine how much force would cause these inlets to collapse. Due to the difficulty presented by the corrugations, the best way to apply loads without causing slippage was bolting a flat plate to the pipe. The points of contact between the plate and the pipe are the points where the load was actually applied.

To determine this area of contact, blue paint was sprayed on a piece of spare corrugated pipe and the plate was laid on top of the paint then rocked back and forth. When removed from the paint, the paint left a mark on the plate where there had been contact. This area, along with the area of four 5/16” bolts was calculated and summed to give the total area. See the calculations in Table 4. From this area, pressures could be calculated from pressure equals force divided by area.

Area of four 5/16” bolts	0.307 square inches
Area of plate in contact with pipe (2.3”x0.25”)	0.575 square inches
Total Area	0.882 square inches

TABLE 4 – CALCULATION OF PLATE CONTACT AREA

To make CMP, sheets of metal are corrugated and then interlocked together, making a seam that is four layers thick of metal and approximately 1” wide, and located every 21” along the pipe. This seam is therefore four times stronger than any where else on the pipe. For the sake of consistency during testing, the load was applied in the same location of the inlet, regardless of where the seam fell in relation to the load.

After all tests had been completed, failure locations were measured from the bottom of the pipe and up from the closest seam. The location of failure was also measured from the closest seam. It was found that the load applied closest to the midline of the seams was the lowest force that caused a collapse in both the sliced and canopy inlets. The following figures, Figures 30 and 31 summarize the collapse force and its location on the inlets in relation to the nearest seam for the canopy and sliced inlets respectively.

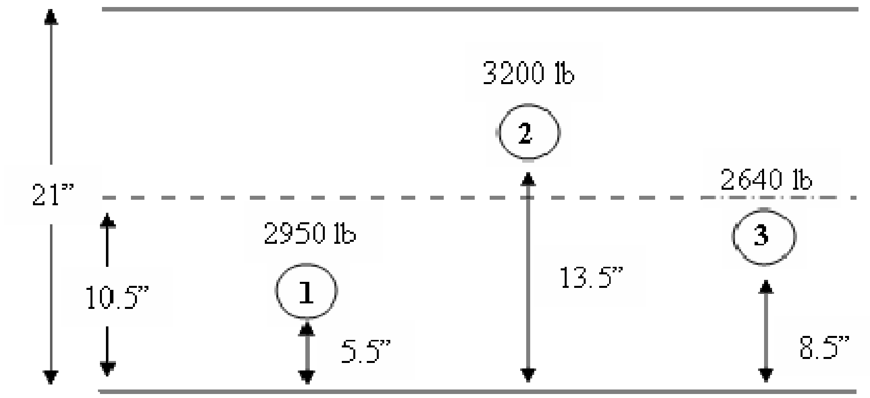


FIGURE 30 – CANOPY INLET STRENGTH TEST DATA – LOCATION AND AMOUNTS OF LOAD

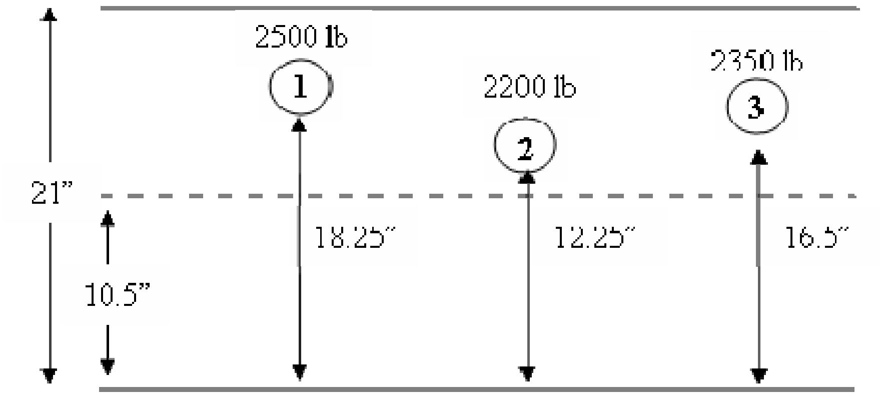


FIGURE 31 – SLICED INLET STRENGTH TEST DATA – LOCATION AND AMOUNTS OF LOAD

Though more testing needs to be performed to confirm this finding, it is possible that the placement of the seam will affect the inlets ability to withstand loads. It was also concluded that the variation in failure location son the sliced inlet was due to the seam. The canopy, on the other hand, has an upper support from the canopy, resulting in a more uniform failure location for the canopy inlet tests.

Since the drop inlet structures in the field were failing on the left side of the pipe when looking downstream, the team decided initially to test the left side of the structure. After just testing the left side of the first sliced inlet, the team was interested to see if the overall strength of the pipe was weakened once one side of the pipe had failed. So the inlet was rotated and the right side was tested. Table 2 shows that after the left side of the pipe had failed it didn’t take as much force to fail the opposite side of the pipe. After seeing these results, the team decided to just test one side of the structure. But after testing the second inlet, the team wondered if testing the right side of the pipe affected the overall collapse force of the left side. The reason for this idea was based off of the helical formation of the pipe. With this helical formation of the pipe and the way the inlet was sliced, the corrugations of the pipe varied slightly from one side to the other. After visiting with Steve Ross, from Dub Ross Company, he stated that when looking at the left side of the pipe, the corrugations are cut completely in two, while the right side was either cut down the valley or peak of the corrugations. The team wanted to know if this variation on corrugations affected the strength of the pipe from one side to the other.

So for the testing of the final sliced inlet, the right side of the pipe when looking downstream was tested first. From looking at Table 2, it indicates that the right side, which was tested first failed at a greater force than the left side, which was tested second. This test indicated that once one side of the pipe had failed, it wouldn’t take as much force to collapse the other side. As far as the corrugations affecting the strength of the pipe from one side to the other, the team felt that more tests should be ran to determine this effect on the pipe.

Implications

There are some significant implications that arise as a result of the scale model tests and the full scale strength tests that Vortex Engineers performed. For the scale model tests, the flow characteristics the team observed within the drop inlet differ from what was initially thought, such as vortex formation and location of highest pressures. This could lead to future design modifications by the NRCS such as modifying the riser and or the inlets themselves. Also, further testing of the drop inlet structures could be made with more advanced measuring equipment such as a pressure transducer. The instantaneous pressure changes throughout the inlet structure as a result of vortex formation could be measured.

The full scale strength tests that Vortex Engineers performed on the canopy and sliced models of the corrugated metal pipe could have many worthwhile design implications. The tests show how and where the canopy and sliced inlets failed and what forces resulted in permanent deformation. These results could have possible implications for strengthening the structures in the field and giving the NRCS an idea of how much water pressure it takes to fail the inlet structures. In addition, the full scale strength tests confirmed that the canopy addition to the inlet structures did in fact strengthen the sliced inlet design. This could lead to the canopy remaining as part of the design, but modifying it to further reduce vortex formation, as shown from the scale models.

Budget

The cost for our project consisted of the scale modeling materials, lab equipment usage charges, and materials for the full-scale strength testing. The materials needed and usage charges are shown in Table 5. Other materials and devices the team used for the scale modeling and strength testing were available through the ARS Hydraulics Lab and the BAE department, such as the hydraulic cylinder, the load cell, and the flume used for the scale modeling.

Cost for Scale Modeling	**Cost**	**Description**
Equipment Usage	$123	BAE Lab
Materials	$310.75	5” Plexi-Glass Tubing
Materials	$66.00	PVC/Adhesive/Fittings
Materials	$98.00	Small Plastic Tubing for Manometer
Additional Supplies	$319.05	Misc. Building Supplies
Total for Scale Modeling	$916.80	
Cost for Full-Scale Strength Test	**Cost**	**Description**
Equipment Usage	$240.00	BAE Lab-Cutting Pipe/Building
Crush Test Setup	$96.00	BAE Lab-Hydraulic Cylinder/Stabilizer
Materials	$50.00	¼” Steel Plate
Materials	$500.00	48” Corrugated Metal Pipe
Total for Full-Scale Strength Test	$886.00	
Grand Total for Project	$1802.80	

TABLE 5 - BUDGET

Recommendations

After completing the scale modeling and the full-scale strength testing, Vortex Engineers came up with recommendations to help the NRCS combat the problem. These recommendations are listed below.

Scale Modeling

In the testing of the scale models, it was noticed that the flow patterns of the inlets were very unstable at medium flow conditions, between 200 and 250 cfs. To help combat this problem, the head on the pipe should be raised or lowered. Three solutions to change the head on the pipe are:

1. Increase tailwater. This will cause an increase of the head on the pipe.
2. Decrease pipe size and increase dam height. This will decrease the flow rate through the pipe and create more head.
3. Increase pipe size and keep same dam height. This will move the water through the pipe faster so that the flow rate will never reach the 200-250 cfs range.

Vortex Engineers recognizes though, that these are engineering solutions but might not be very practical for the landowner. Another observation made during the scale model testing was that the levelness of the riser made a difference in the flow pattern and formation of vortices. Keeping the riser as level as possible during installation will help reduce disturbances in the flow pattern and decreases the amount of vortices formed.

Full-Scale Strength Testing

Some recommendations derived from the full-scale strength testing are:

1. Current Solution – Angle Iron. Vortex Engineers believes that the current solution of reinforcing the pipe with angle iron is sufficient to prevent collapse.
2. One-Piece Angle Iron, two arcs on each side. One way to make installation of angle iron easier would be to use one bent piece of angle iron, as opposed to three separate pieces, as is currently the standard.
3. Seam placement. It was found that a seam where the pipe is fused resists more force than normal corrugations. If the inlet could be cut so that a seam is located on the left side of the pipe near the area of concern, the inlet could withstand more force.

The final recommendation would be to complete further testing and analysis of the design and specifications for the inlets. This might include a complete redesign of the drop inlet structure.

References

American Iron and Steel Institute 1994. Handbook of Steel Drainage & Highway Construction Products. Washington D.C.: AISI.

Blaisdale, F. Hydraulics of closed conduit spillways: Part I. Technical Paper No. 12, Series B. St. Anthony Falls Hydraulic Laborotory. United Stated Department of Agriculture. 1952.

Haan, T., B. Barfield, J. Hayes, *Design Hydrology and Sedimentology for Small Catchments.* Academic Press, San Diego, CA. 1994.

Henderson, F.M. *Open Channel Flow*. Macmillan, New York, NY. 1966.

Kitoh, Osami. 1991. "Experimental study of turbulent swirling flow in a straight pipe". *Journal of Fluid Mechanics.* (225):445-479.

Spangler, M.G. December 24,1941. The Structural Design of Pipe Culverts. Bulletin 153. Ames, Iowa: Iowa State College of Agriculture and Mechanic Arts.

Steichen, J. 1993. Design Criteria for Canopy and Hood Inlet Spillways. Columbia, Missouri: University of Missouri.

Stoner, C. December 15, 2000. Memo: Research Needs –Canopy Inlet Drop Structures to Johnny Green, State Conservation Engineer, NRCS. USDA – NRCS.

USDA-NRCS. 1984. National Engineering Field Handbook, Ch. 6: Structures. USDA Natural Resources Conservation Service.

USDA-NRCS. 1968. National Engineering Handbook, Section 11: Drop Spillways. USDA Natural Resources Conservation Service.

USDA-NRCS. 2005. National Engineering Handbook, Ch. 52: Structural Design of Flexible Conduits. USDA Natural Resources Conservation Service.

USDA-NRCS. 1956. Technical Release 3: Hood Inlets for Culvert Spillways. USDA Natural Resources Conservation Service.

USDA-NRCS. www.nrcs.usda.gov, accessed September 2005.

Appendices

A. Gantt Chart

B. NRCS Standards and Specifications
   1. Grade Stabilization Structure Conservation Practice Standard
   2. Pond Conservation Practice Standard
   3. Engineering Field Handbook, Chapter 6 – Structures
   4. OK-Dwg-205 – Canopy Drop Inlet
   5. OK-Dwg-203 – Hooded Drop Inlet

C. Patent – Internally Reinforced Extruded Plastic Pipe

D. Loyd Atkisson GSS Drawings

E. Pressure Graphs

F. Scale Model Data

Drop Inlet Failures

Brian Dillard Rachel Oller Ryan Stricklin Mary Womack

Client

- Natural Resources Conservation Service
  - Federal agency that provides assistance to private landowners.
  - Helps improve and protect the soil, water, and natural resources of the land.

NRCS Natural Resources Conservation Service

Drop Inlet Structure

Problem Definition

- Inlet folds inward, creating a blockage of flow.
- Always occurring on the left side.
- Typically 48” diameter or greater; 16 gauge thickness.

NRCS Desired Results

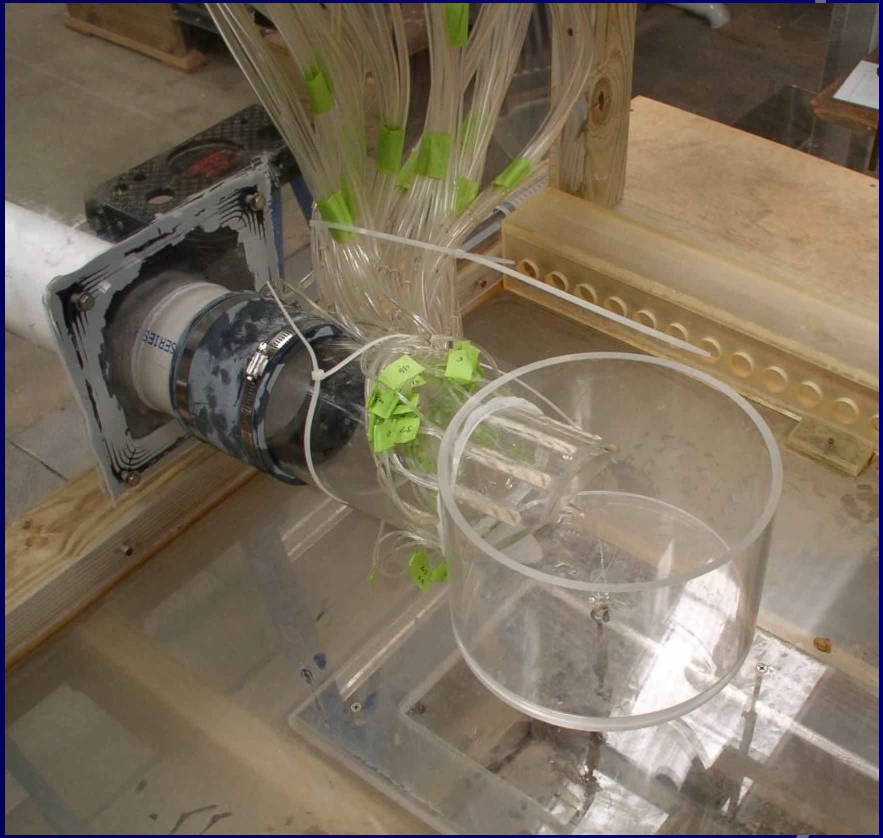
- Determine causes of inlet failures
    - Canopy inlets
    - Sliced inlets
- Develop design recommendations

Approach

- Cause of Failure
  - Hypothesis – high heads create high vacuum pressures and high velocities through pipe causing it to fail
- Test Hypothesis
  - Hydraulic Scale Modeling
  - Strength Experiments
  - Compare forces from two tests and draw conclusions

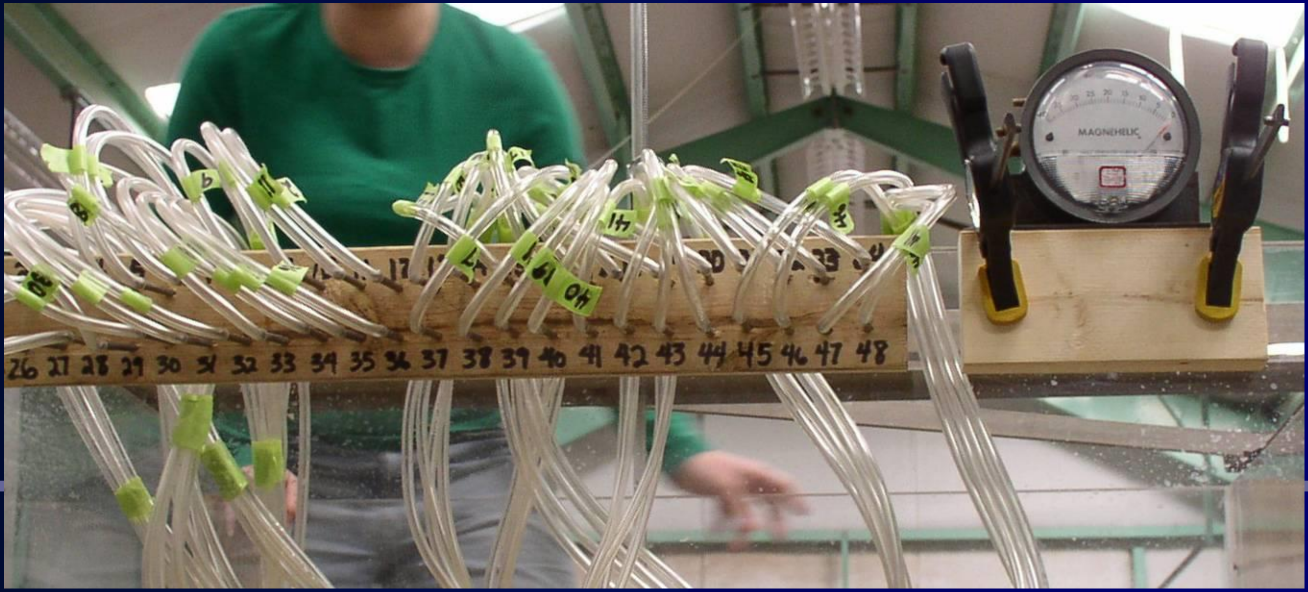
Pressure Tests

- 4” scaled models
- Made from ¼” Plexiglas
- 48 measurement ports total
- Tygon tubing used to measure pressures



Pressure Test - Testing

- Placed in tank at ARS lab
- Ran varying flows to simulate rainstorm events
- Gage measured vacuum pressure
- 3 runs at each flow; averaged results



Pressure Testing - Results

- Calculated force from pressure using Excel
- As expected, greatest head caused greatest total force (static + vacuum)
  - Maximum calculated force of 1200 lbs
- Visual Observations
  - Greatest vortices occurred at 0.4 cfs (200 cfs)
  - High heads (> 250 cfs) reduced vortex formation

Additional Scale Model Tests

- Varying Baffle Arrangements
- Rhodamine Dye Tests

Strength Test of Full Scale CMP

- 48” CMP, 14 gauge
- 3 sliced and 3 canopy inlets
- Load cell for forces
- Load applied via a hydraulic cylinder
- Inlets bolted to floor
- Applied load till pipe yielded

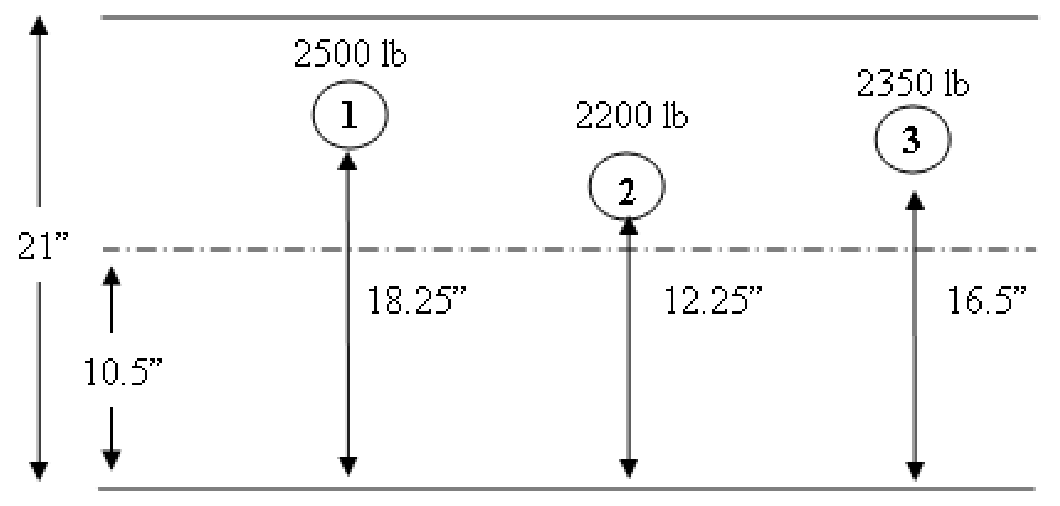
Strength Test of Full Scale CMP

Strength Test Results

Inlet	Force Applied (lbs)	Failure Location	
Sliced #1	2500	Left	13.5”
Sliced #2	2200	Left	17.0”
Sliced #3	2350	Left	16.5”
Average	2350	Left	15.5”
Canopy #1	2950	Left	13.5”
Canopy #2	3200	Left	13.5”
Canopy #3	2640	Left	12.5”
Average	2930	Left	13.2”

Seam Placement

- Seam
  - Four times thickness of pipe
  - 1” wide
  - 21” between each seam
- Seam affects location and amount of load causing failure



Conclusions

- Canopy and anti-vortex baffles do not reduce vortices as expected by the NRCS
- Canopy does provide extra strength
- CMP can withstand maximum head
- Force due to unstable flow may cause failure; not force due to high heads

Possible Solutions

- Redesign structure
- Change level of head on pipe
  - Increase tailwater
  - Decrease pipe diameter, increase dam height
  - Increase pipe diameter
- Keep riser level
- Angle iron
  - 1 piece of bent angle iron on each side
  - Current solution – three pieces of angle iron on each side

Further Investigation

- Instantaneous pressure testing with a pressure transducer

- Test inlets with different dimensions
  - Angle of slice
  - Height of canopy
  - Size and orientation of anti-vortex baffle
  - Different riser configurations

- Location of seams during inlet construction

Acknowledgments

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- Dub Ross Company, Inc.

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BAE 4012-Senior Design
December 9, 2005

Table of Contents

Mission Statement

“Vortex Engineers is committed to enhancing and protecting water resources through detailed analysis and innovative design. Our superior solutions of hydraulic and hydrologic concerns aim to maintain the integrity of the natural environment while providing practical and affordable results.”

-Vortex Engineers

Introduction

The Natural Resources Conservation Service (NRCS) is a federal agency that works hand-in-hand with the people of Oklahoma to improve and protect their soil, water, and other natural resources. For decades, private landowners have voluntarily worked with NRCS to prevent erosion, improve water quality, and promote sustainable agriculture. NRCS has implemented many methods to address these concerns in a variety of situations on private and public land. (NRCS website, 2005)

During a storm event, a large amount of runoff results from developed land or land used for agriculture. Haan, et al. (1994) states that in situations where there are few abstractions to rainfall, such as soil infiltration or plant cover, runoff volumes will be much higher than on land that is undeveloped such as pasture. The peak discharge rate will also increase and the need to control these high volumes and peak flows is important.

NRCS uses drop inlet grade stabilization structures (GSSs) as one method to control large runoff volumes. See Figure 1 for an example of a GSS. These structures primarily prevent gully erosion and involve placing corrugated metal pipe (CMP) with diameters as great as 60” to route water from higher to lower elevations. Per discussion with Chris Stoner, Agricultural Engineer with NRCS, implementation of these structures increases the stability of channels by preventing gully erosion and consequently reducing sediment deposition downstream. Although no laws require the use of these structures, farmers, land owners, and even county commissioners install these for the protection of land and roads.

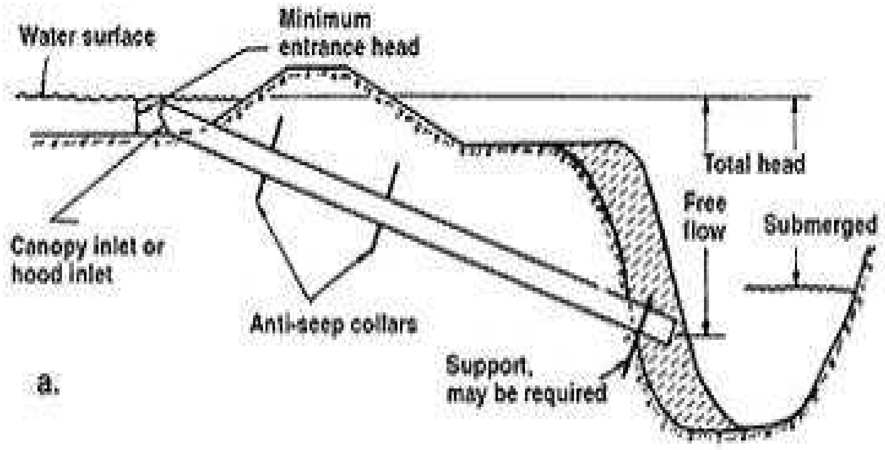


Figure 1. – Grade Stabilization Structure (Steichen, 1993)

Blaisdale (1952) explains that the pipe may be designed for full or partially full flow and can be implemented either on a flat or steep slope. The outlet from the pipe can freely flow into the atmosphere or be submerged.

In the 1950's, various entrances for drop inlet GSSs were tested. It was found that canopy and sliced entrance structures were more effective in producing full pipe flow at lower heads than the conventional blunt entrance. (See Figures 2 and 3 for examples of sliced and canopy hood inlets in the field.) A pipe experiencing full pipe flow moves a greater volume of water in a shorter period of time than pipes flowing partially full. This is important because it reduces initial storage volume, exposure of water to soil, and is more cost effective. It was also found that vortex formation around the sliced and canopy entrances was less of a concern. (Stoner, 2000) Since the 1950's studies, these structures have been widely implemented.

Figure 2. – Sliced Inlet

Figure 3. – Canopy Inlet

Problem Statement

Since the 1980's, Oklahoma has implemented many canopy and sliced inlet GSSs to control high runoff volumes over rural land. Though proven to be very useful over the years, an increasing number of failures of the inlets have occurred. In a report, Chris Stoner outlined the first noticed collapse on a sliced inlet. The entrance of a 42" corrugated metal pipe had failed the first time it flowed. The left side had folded inward, creating a 40% blockage of flow. Since that time, other failures have been noticed and reported. These occurrences were typical of 48" diameter or greater pipes with a 16 gauge thickness. In 1995, the NRCS recommended the use of canopy inlets instead of sliced hoods, because the canopy added extra strength to the structure. In 1997, the inlet thickness was increased to 14 gauge for pipes with diameters greater than 42". The report by Stoner also details characteristics of the failures, which interestingly enough are all similar. Always occurring on the left side looking downstream, the pipe folded inward, consequently blocking the flow and limiting the capacity for which it was designed. Because the time of failure is difficult to determine, the magnitude of head causing the collapse is also difficult to determine.

NRCS is seeking an analysis of the canopy inlet to establish criteria for providing increased strength for corrugated metal canopy inlets, including:

- Determining design parameters that govern the need for increased strength;
- Identifying pipe sizes, corrugations, and gauges that need increased strength;
- Proposing changes to the Oklahoma NRCS Conservation Practice Standards to reflect the analysis.

The NRCS also requests alternative methods for strengthening and a cost comparison of options.

Current Design Specifications for Canopy and Sliced Inlets

The NRCS has published specifications for the dimensions of canopy inlets. For conduits with slopes less than 15%, the following equation applies:

$$W = 0.2D;\ L = 0.75D. \quad (1)$$

For conduits with slopes greater than 15%:

$$W = 0.3D;\ L = 1.25D \quad (2)$$

where:

W = height of the canopy (ft)

L = length of the sliced section (ft)

D = diameter of the pipe (ft).

The auxiliary spillway elevation must be at least $1.8D$ above the bottom of the pipe. The riser on the drop inlet must be at least $5D$ if the conduit slope is greater than the friction slope, or at least $2D$ if the conduit slope is less than or equal to the friction slope. The thickness of the pipe is determined based on the fill height of the grade stabilization structure and the diameter. For more detailed information on NRCS specifications, see Appendix C.

Research & Literature Review

Patent Search and Pipe Flow Research

For the patent search Vortex Engineers went to the United States Patent website and searched for patents pertaining to pipe inlet reinforcements. Only one patent was found when running the search. The patent found was for internally reinforcing an extruded plastic pipe. An abstract of the patent is as follows:

> An internally reinforced extruded plastic pipe is adapted for use as an underground infiltration, collection, or transport conduit for liquids and gases. The pipe is provided with at least one integral reinforcing stem and the critical mode of failure is buckling rather than deflection. The pipe is not dependent upon surrounding backfill for lateral support as with conventional pipe or conventional reinforced pipe. The same amount of plastic is usable per lineal unit as is used in comparable conventional pipe sizes, however, the cross-section is redistributed, which achieves greater loading capacity. (Dietzer, 1987)

This patent is a possible solution to the problem; therefore, consideration will be taken so that patent infringement will not occur. Further information on this patent can be found in Appendix D.

A literary search was also conducted through the Oklahoma State University, Edmon Low Library databases on fluid flow in pipes. An article entitled “Experimental study of turbulent swirling flow in a straight pipe” was found. Kitoh (1991) concentrated on velocity distribution and vortices that arise in pipe flow. The experimental investigation introduced free-vortex-type swirling flow in a long straight circular pipe. Kitoh also stated that the swirling component decayed downstream as a result of wall friction, though velocity distributions continuously changed as they approached fully developed parallel flow. The article maintained that swirling flow through a pipe was highly complex, turbulent, and challenging to predict. These conclusions might give Vortex Engineers insight into the phenomena that occurs while water flows through pipe at high velocities. The velocity distributions and vortex characteristics discussed in the article could be a possible cause of failure in the CMP canopy and sliced entrances.

Structural Analysis of Corrugated Metal Pipe

The corrugation of flat steel plates has not only been proven to increase the stiffness of steel plates, but also improve their strength. Corrugated metal pipe has been used for over 100 years mainly due to its characteristically light weight and structural durability. The use of CMP will also determine the size of the corrugation and whether or not it is helical or annular. Refer to Figure 6 for examples of two sizes of corrugations (AISI, 1994).

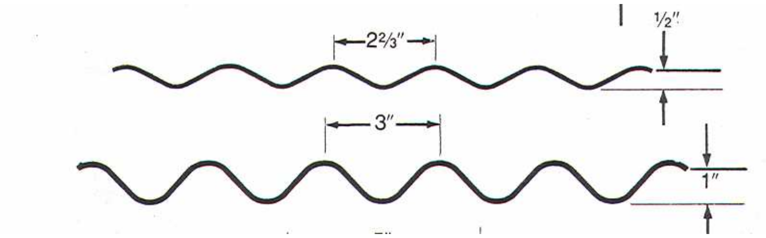


Figure 6. – Corrugation dimensions

The majority of research that has been done on CMP has been limited to the pipe characteristics under soil cover depths. The ability of CMP to support a load is derived from loads of soil placed upon them. The inherent strength of each corrugation to resist external pressures and form passive forces is provided by the earth that surrounds the pipe. These passive forces cause stresses in the pipe ring in directions opposite to those produced by the vertical loads, therefore assisting the pipe in supporting vertical loads (Spangler, 1941). Two types of these loads are:

1) Dead loads- Developed by the embankment or trench backfill, plus stationary superimposed surface loads, uniform or concentrated.
2) Live Loads- Moving loads, including impacts (AISI, 1994).

Spangler (1941) says that since CMP has relatively little inherent strength, a significant source in its ability to support load, is the passive pressures induced when the sidewalls begin to move outwards. Because CMP will readily deform, it consequently utilizes the passive pressures of the earth on all sides of the pipe. According to Spangler, this structural characteristic accounts for the fact that such a relatively lightweight pipe will support earth fill of considerable heights. It is assumed that loads are distributed uniformly over the top and bottom of the pipe. Loads which are caused by passive pressures of the earth are said to be greater toward the center of the pipe and can be seen in Figure 7.

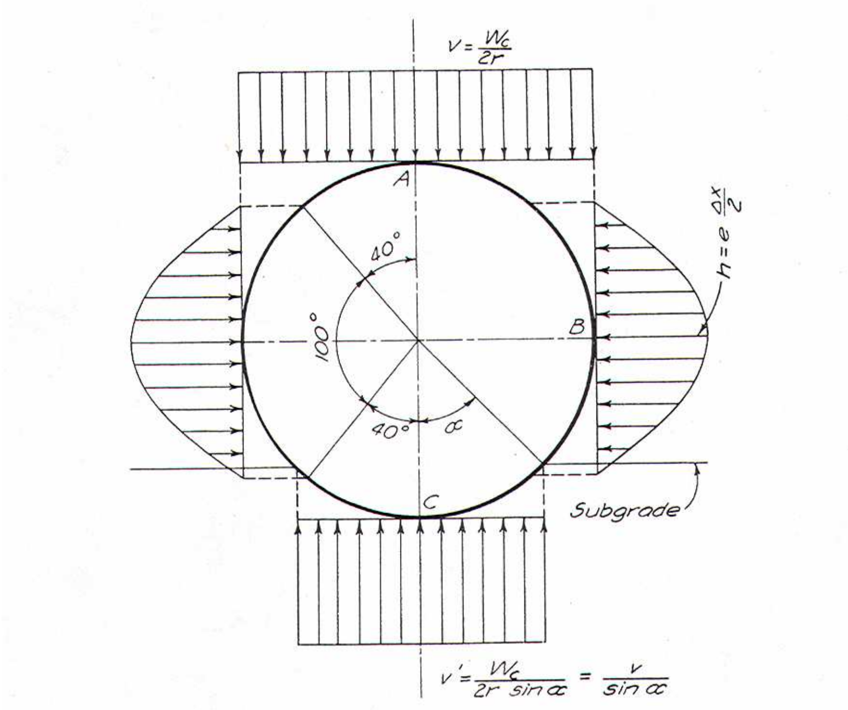


Figure 7. – CMP load distributions

The above figure does not necessarily give the characteristics of CMP under hydrostatic conditions, but it does give an idea on how CMP reacts under load stresses. Chris Stoner feels that Vortex could use the data provided from buried conduits in calculating the hydrostatic forces on CMP. With further research and modeling techniques, Vortex will determine whether or not this method will represent the forces of water acting on CMP.

The following equations illustrate the load distributions that are applied to CMP under soil compression.

Vertical unit load on the pipe ,v, (Spangler, 1941):

$$v = \frac{W_C}{2r} \quad (3)$$

where:

W_C = distributed load across top portion of pipe

r = radius of the pipe.

Vertical unit reaction on the bottom of the pipe ,v', (Spangler, 1941):

$$v' = \frac{v}{\sin(\alpha)} \quad (4)$$

where:

α = bedding angle with respect to the vertical axis.

Passive horizontal pressures on the side of the pipe, h, (Spangler,1941):

$$h = e\frac{\Delta x}{2} \quad (5)$$

where:

e = modulus of passive pressure of side fill

Δx = horizontal deflection of the pipe.

CMP not buried in compacted soil and subjected to external hydrostatic pressure must be designed for buckling as circular tubes under uniform external pressures (AISI, 1994). If the above method cannot be used, the two formulas below can be used to determine the critical pressure on the surface of the pipe.

Critical pressure, P_{cr}, of a corrugated metal pipe (AISI, 1994):

$$Pcr = \frac{3EI}{(1-\mu^2)R^3} \quad (6)$$

where:

E = modulus of elasticity (lb/in^2)

I_{pw} = pipe wall moment of inertia (in^4)

μ = Poisson's ratio (specific to material)

R = mean pipe radius (in).

The equation below calculates the estimated collapse pressure, PE, of corrugated metal pipe (AISI, 1994):

$$PE = \frac{(49.5 \times 10^6) \times I}{R^3} \quad (7)$$

Chapter 52 of the NRCS National Engineering Handbook (NEH) (2005) details basic properties for any type of flexible conduit. It includes corrugated metal pipe and also gives methods to calculate pressures and stresses on a pipe.

The maximum allowable pressure should be limited to 20 feet of head for annular pipe and 30 feet of head for helical pipe. The vacuum load per length of pipe, W_v (lb/ft) is determined by the following equation:

$$W_v = P_v \frac{D_i}{12} \quad (8)$$

where:

P_v = internal vacuum pressure (lb/ft^2)

D_i = inside diameter of the pipe (in).

If the pipe is below the water elevation, external hydrostatic pressure, P_g (lb/ft^2) can be found by:

$$P_g = y_w \times h_w \quad (9)$$

where:

γ_w = unit weight of water (lb/ft^3)

h_w = height of water above top of pipe (ft).

S_b (lb/in^2) or the maximum bending stress in the pipe wall of an unsupported pipe is:

$$S_b = \frac{MD_o}{2I} \quad (10)$$

where:

M = bending moment (in-lb)

D_o = outer pipe diameter (in).

The hoop stress, S_p, caused by internal pressure (lb/in^2) is:

$$S_P = \frac{PD_o}{2t} \quad (11)$$

where:

P = pressure in the pipe (lb/in^2)

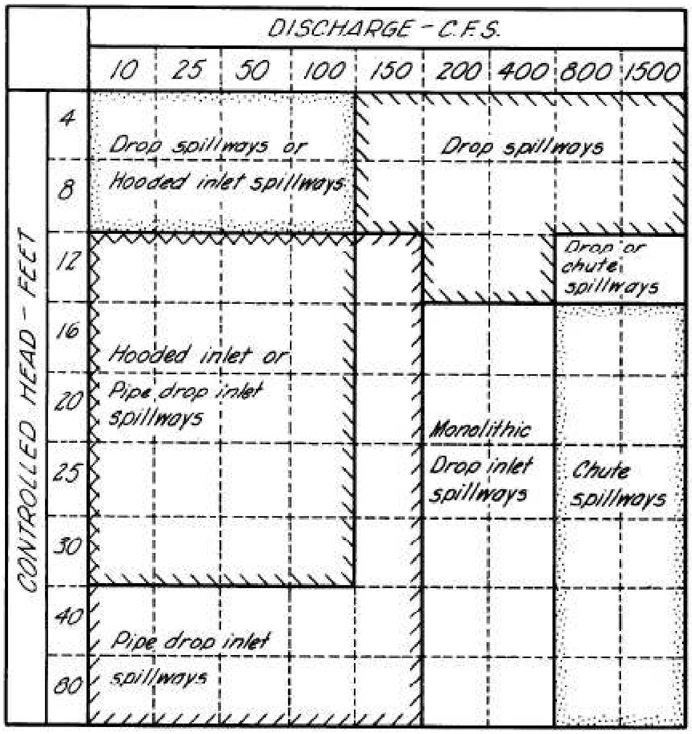
t = pipe wall thickness (in).

Appendices to NEH-Ch. 52 give section properties for corrugated pipe, such as areas and moments of inertia for different gauges.

NRCS Current Guidelines for Designing Pipes and Spillways in Structures

This section details NRCS publications that contain guidelines used in constructing these pipes and spillways.

Figure 8 (NEFH, 1984) aids in deciding what type of spillway should be used based on discharge and head. NEFH, Ch. 6, also gives capacity charts for discharge based on head and diameter specifically for corrugated metal pipe.



Note: Chart shows most economical structure as related to discharge and controlled head providing site conditions are adequate.

Figure 8 – Discharge vs. Head for determination of inlet structure

Section 11 of the National Engineering Handbook titled Drop Spillways, details information about the design of various types of drop spillways. Technical Release 3 from NRCS documents, titled “Hood Inlets for Culvert Spillways” summarizes original research preformed on hooded inlets, including dimensions and capacities.

Statement of Work

The NRCS has contacted Vortex Engineers to evaluate the problems associated with sliced and canopy entrances, determine the cause of collapse, and propose design solutions to prevent future failures. The following is a brief summary of work that has been conducted and what is planned in the future.

First a field tour in western Oklahoma of these structures was taken to help the team visualize these structures in the field. Next, at the United States Department of Agriculture, Agriculture Research Service Hydraulics Lab in Stillwater, Oklahoma, a demonstration flume that utilizes scaled Plexiglas replicas of the inlet structures was observed. The demonstration model allowed Vortex Engineers to observe flow characteristics of the pipe with different inlet structures attached (see Figure 4). Vortex Engineers performed another demonstration using red transparency film to test if failures will occur under similar conditions, but of a different material (see Figure 5). In the model, the same failures occurred with red film as those reported from the field: after a certain head was reached, the left side of the film folded inwards.

It is worth noting that though this model was helpful in demonstrating the process of how the pipe entrances failed, the model was not to scale, nor were the materials similar to that of corrugated metal pipe. Therefore, the model did not produce any measurable or useful data, but was useful in illustrating the phenomenon.

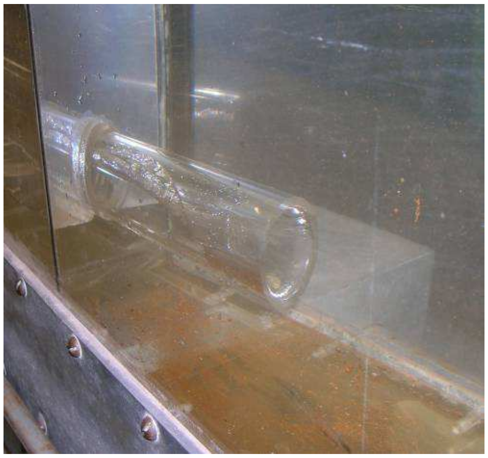


Figure 4. – Blunt inlet

Figure 5. – Red transparency film

In aid in determining where failures are occurring, Vortex has performed preliminary calculations for pressure and head analysis. These calculations will identify pressure distributions which are needed to determine forces throughout a pipe.

A scale model will be built of material similar to that of corrugated pipe, possibly plastic corrugated tubing. The scale models will aid in observing what the entrances are experiencing under different flows. Vortex Engineers also hopes to gain actual pressure and velocity measurements from the scale models.

In addition to scale modeling, computer modeling will be conducted. Vortex Engineers will model pressure and perform fluid flow analyses. After all modeling data is collected, strength analysis will be performed.

Upon completion of these tasks, Vortex can determine whether the current designs are sufficient as specified or if they need to be modified.

Initial Investigation

To aid Vortex Engineers in trying to solve the source of the collapse of the CMP drop inlet structures, the following procedures were performed. These procedures were successful in providing a better understanding of how the structure functions as well as an initial analysis of the problem.

Field Tour of Installation Sites

On October 4, 2005, Vortex Engineers toured several installed sites in western Oklahoma with Chris Stoner and Baker Eeds, engineers with the NRCS. The first failed inlet in the state occurred in Eeds' service area and he has been involved with the investigation of the failures since.

The first stop on the tour was a GSS owned by Gelene Schreck. The Schreck GSS had a 48" hooded drop inlet with 16 gauge metal thickness (see Figure 9). It was constructed in 1993, failed in 1995, and has since not been repaired. The inlet collapsed on the left side (looking downstream), which is consistent with the other documented failures. Because of the reduced flow of the inlet, a noticeable amount of erosion had occurred in the auxiliary spillway, defeating the purpose of a GSS.

Figure 9. – Schreck's failed drop inlet structure

The other three GSSs toured had not failed, though it was beneficial to see the design of the structures and how they operated. All three GSSs had had auxiliary flow in the past but had no visible detrimental effects. One GSS owned by Alexander had stiffeners installed on each side directly following construction to prevent any failures from occurring.

Baker Eeds shared valuable information that helped Vortex understand the problem more fully. Mr. Eeds felt that the difference between the inlet and outlet water heads was a big factor in the failure of the pipe. He stated that structures with submerged outlets were less likely to fail due to the smaller difference between the two water heads.

Demonstration Flume

For preliminary investigation, Vortex went to the ARS Hydraulics Lab in Stillwater, Oklahoma to make observations on pipe flow using a demonstration flume (see Figure 10).

Figure 10. – Demonstration Flume

The flume is a Plexiglas construction that models pipe flow that uses detachable replicas of various pipe inlets; such as canopy, sliced, and blunt. See Figure 11 for an example of a canopy inlet. Vortex was able to observe water flow characteristics and how they differed through the various inlets.

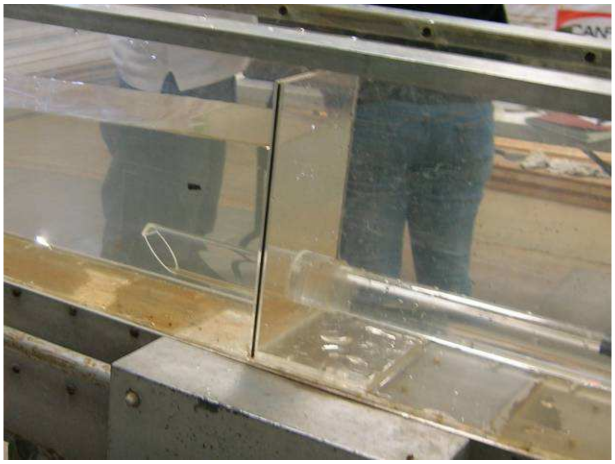


Figure 11 – Canopy pipe inlet replica

The demonstration flume also is capable of adjusting pipe slope and water head.

Following the observation of flow in the pipe models, the team marked each of the three inlet replicas with lines every 0.2 inches along the perimeter of the inlet with a permanent pen (see Figure 12). After drawing the lines on the inlet models, the team began taking pressure measurements at each increment marked around the inlet.

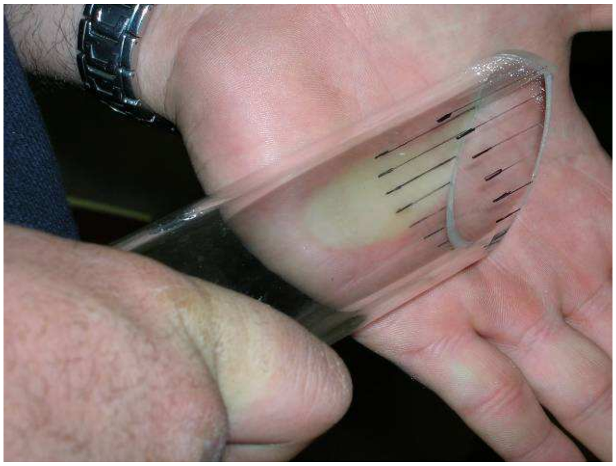


Figure 12 – Pressure measurement layout

To obtain these pressure measurements Vortex Engineers used a simple manometer constructed of a small clear plastic tube open on one end and an air pump needle attached to the opposite end. Each pressure measurement was calculated by how much the water level in the manometer changed in relation to the water level at the inlet. Measurements were taken as the needle was moved each 0.2 inch increment around the circumference of the pipe. This process was preformed twice for each inlet model.

In Figures 13-15 these distributions are graphically displayed. The x-axis represents the circumference of the inlet where the center is located at the lower x = 0.0 cm, and negative x represents the left side of the pipe and positive x, the right side. The most left and right boundaries of the pipe occur approximately at -0.8 cm and 0.8 cm respectively. The values at each increment show the pressure changes in terms of centimeters of water within the pipe as a function of location. All pressures are negative because the water level of each measurement dropped below the reference water level. The reference water level was taken at the surface of the impounded head on the inlet. The graphs and their discussion follow.

The pressure data for the canopy inlet is in Figure 13.

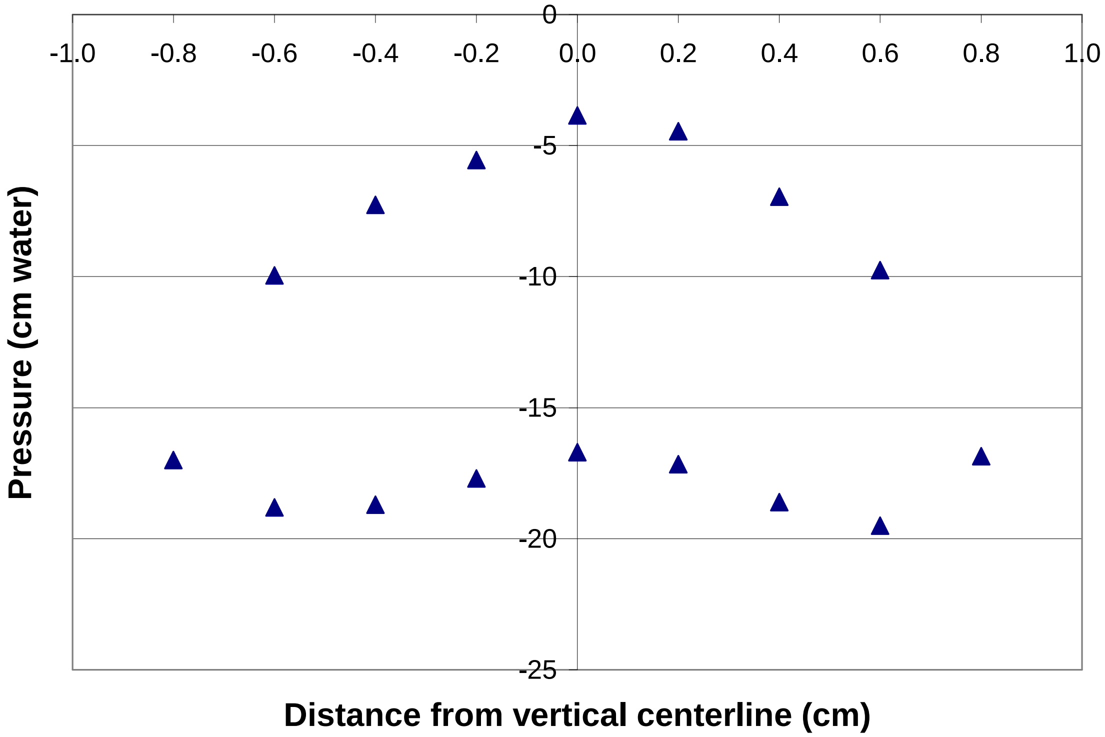


Figure 13 – Pressure distribution around circumference of canopy inlet

The lowest negative pressures of -18.8 cm occurs between -0.4 and -0.6 cm and -19.5 cm on the left side at -0.6 cm. There is quite a bit of pressure distribution along the inside of the pipe, which leads Vortex Engineers to believe this could lead to unstable conditions.

The sliced inlet data is very similar to that of the canopy inlet. Refer to Figure 14.

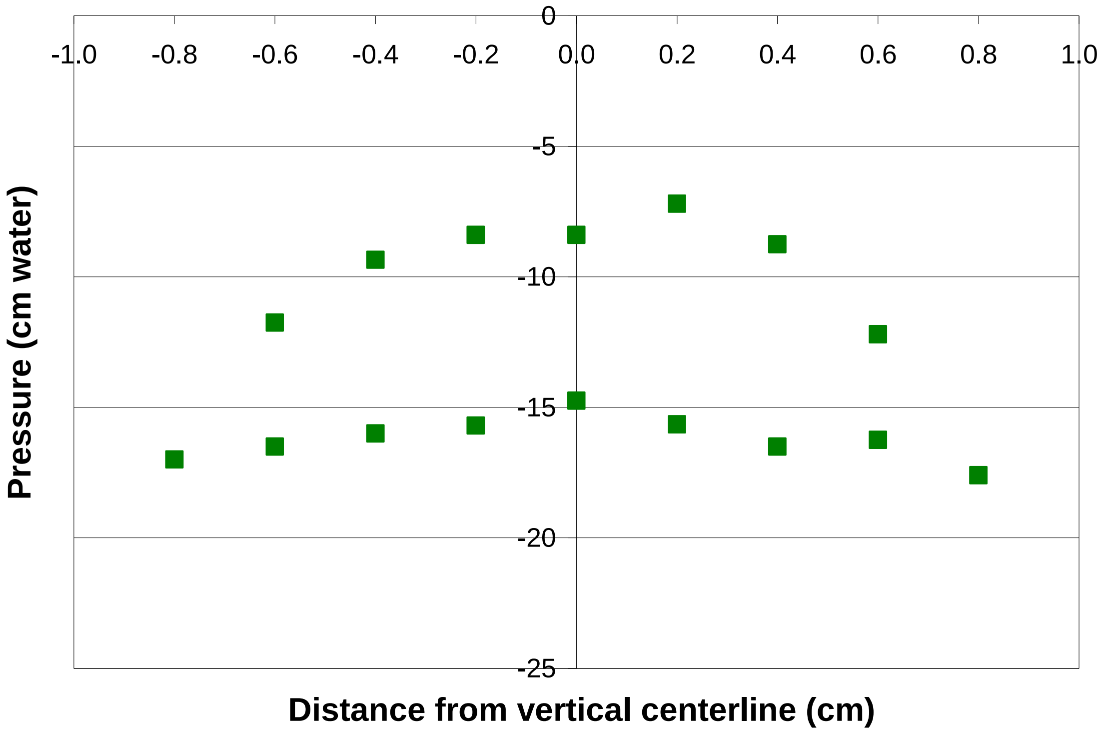


Figure 14 – Pressure distribution around circumference of sliced inlet

The sliced inlet displays pressure that is slightly higher on the right side of the inlet. There is also less variation in the extremes of about 10.4 cm of water with the sliced inlet when compared to a difference of 15.7 cm with the canopy inlet.

The blunt inlet differed greatly from the other two inlets in its pressure distribution. Refer to Figure 15.

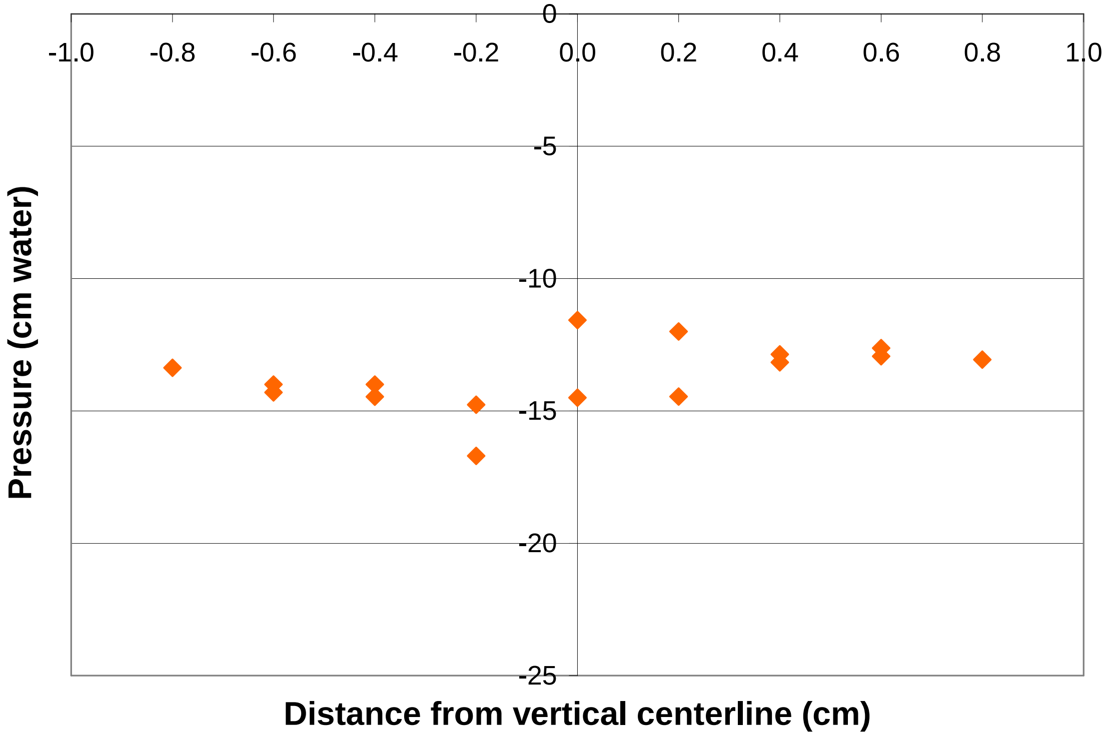


Figure 15 – Pressure distribution around circumference of blunt inlet

The pressure on the left side of the inlet had a greater negative pressure than on the right side. There is much less variation of pressure within the blunt entrance as well, of about only 1.6 cm. The head necessary to create full pipe flow was higher than the other two. It was also noticed that during the demonstration, the blunt inlet created water vortices at the front portion of the inlet (see Figure 16).

Figure 16 – Demonstration model for blunt inlet

This phenomenon could possibly be the cause of the pressure differences on each side of the inlet.

The pressure measurements using this method are not considered to be hard and accurate data, and will not be treated as such by the design team. However, these data do give Vortex Engineers an idea of what the different inlets are experiencing as far as pressure is concerned. It also allows Vortex to get an idea of what forces could be resulting from these pressures.

Preliminary Calculations

Initial fluid flow and pressure analysis calculations were an important part of the initial investigation. The team wanted to mathematically determine the pressure gradient that existed throughout the pipe using several fluid mechanics equations.

First, the flow rate through a pipe needs to be calculated by either the pipe flow or weir flow equation. At a given head, flow is calculated by both equations and the minimum of the two determines the flow rate. For weir flow:

$$Q_w = \sqrt{g} C H^{3/2} \quad (12)$$

where:

g = gravity (32.2 ft/s^2)

C = the circumference of a circle (ft)

H = head (ft), measured from the invert of the riser.

The equation of pipe flow is:

$$Q_P = \frac{A(2gH')^{1/2}}{(1 + k_c + k_b + k_c L)^{1/2}} \quad (13)$$

where:

A = area of the pipe (ft^2),

H' = head (ft) measured from the top of the water surface to a point $0.6D$ above the outlet of the barrel

L = length of the pipe (ft)

k_e = entrance loss coefficient

k_b = bend loss coefficient

k_c = loss coefficient due to friction of the pipe.

All k values are dimensionless.

To determine the total head losses throughout the pipe the Darcy-Weisbach equation was used:

$$h_l = \left(\frac{fL}{D} + \sum K \right) \frac{V^2}{2g} \quad (14)$$

where:

f = friction factor

D = internal diameter (ft)

ΣK = sum of minor losses

V = velocity (ft/s).

After calculating the head losses, the internal pressures along the pipe were calculated by the following equation:

$$P = h_l \gamma \quad (15)$$

where:

P = pressure (lb/ft^2)

h_l = head loss (ft)

γ = specific weight of water (62.4 lb/ft^3).

Once the pressures were calculated throughout the length of pipe the hydraulic grade line was determined.

$$HGL = h_l + z + CLP \quad (16)$$

where:

z = elevation along the pipe and

CLP = centerline dimension of the pipe.

Along with calculating the HGL, the Energy Grade Line (EGL) of the pipe system was calculated as well by:

$$EGL = HGL + \frac{V^2}{2g} \quad (17)$$

Figure 17 shows a graph containing the calculations described above.

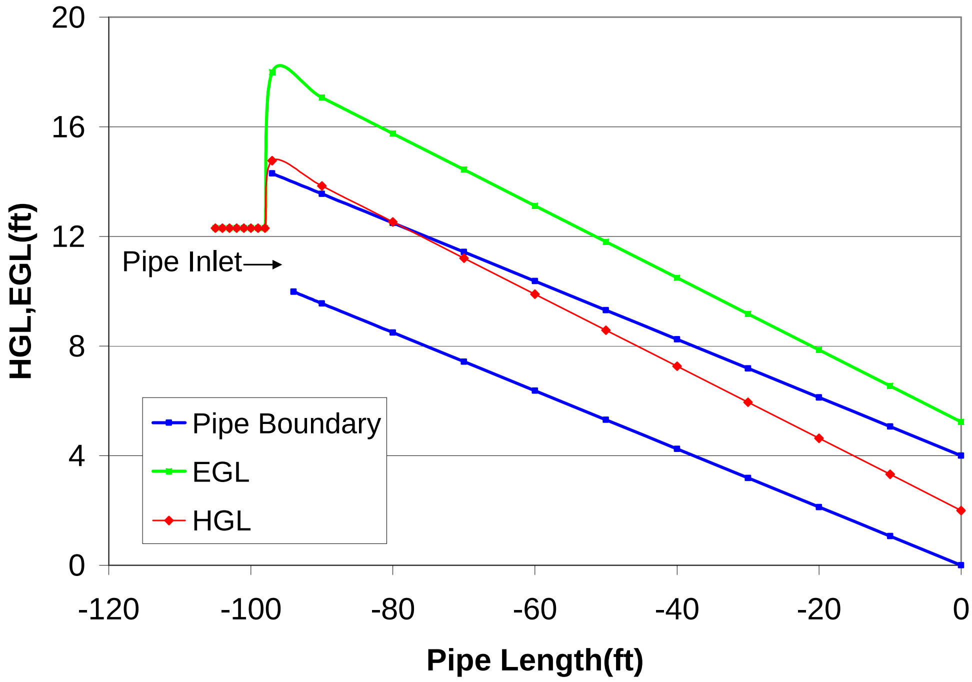


Figure 17 – Pressure distribution throughout pipe

The data used in these calculations was taken from a drop inlet structure specification that had recently failed in western Oklahoma.

Proposed Budget

The cost for our project will come mainly from the scale model components. The intention of Vortex Engineers is to redesign an existing flume located at the USDA-ARS lab in Stillwater, OK, shown in Figure 18.

Figure 18 – Picture of flume to be redesigned for testing

In reusing this model versus building a new one, a lot of money will be saved. Other materials that may be needed are listed and broken down in Table 1.

Materials for Scale Modeling	**Cost ($)**	**Description**
Corrugated Plastic Tubing	**$20.00**	3” diameter 10’ long
Waterproof Adhesive	**$3.00**	10.2 oz.
Miscellaneous Materials (for inlet construction)	**$15.00**	Plastic pieces, tape

Table 1 – Budget Analysis

Devices from the ARS Hydraulics Lab or the BAE Department may also be needed to conduct experiments on the scale model, which we hope to use or loan. Further budget analysis is not possible at this point in time, as the dimensions and costs to redesign the existing flume have yet to be determined. When the team begins scale modeling, there is a possibility of using corrugated metal pipe to model the inlet structure; costs of this material and the inlet construction will be determined if needed.

Conclusion

This semester Vortex Engineers have focused on finding the cause of the pipe inlet failures. Investigation is ongoing into the forces the pipe experiences during various flow conditions. In the spring semester Vortex plans to perform tests using scale models to determine why these pipes are failing and what type of reinforcement might be needed. Future tasks that need to be completed can be found in Appendix A. Vortex will then use this data to recommend new design solutions for the inlet structures if applicable, as well as provide a cost analysis of the options.

References

American Iron and Steel Institute 1994. Handbook of Steel Drainage & Highway Construction Products. Washington D.C.: AISI.

Blasidell, F. Hydraulics of closed conduit spillways: Part I. Technical Paper No. 12, Series B. St. Anthony Falls Hydraulic Laborotory. United Stated Department of Agriculture. 1952.

Haan, T., B. Barfield, J. Hayes, *Design Hydrology and Sedimentology for Small Catchments.* Academic Press, San Diego, CA. 1994.

Kitoh, Osami. 1991. “Experimental study of turbulent swirling flow in a straight pipe”. *Journal of Fluid Mechanics.* (225):445-479.

Spangler, M.G. December 24,1941. The Structural Design of Pipe Culverts. Bulletin 153. Ames, Iowa: Iowa State College of Agriculture and Mechanic Arts.

Stoner, C. December 15, 2000. Memo: Research Needs –Canopy Inlet Drop Structures to Johnny Green, State Conservation Engineer, NRCS. USDA – NRCS.

USDA-NRCS. 1984. National Engineering Field Handbook, Ch. 6: Structures. USDA Natural Resources Conservation Service.

USDA-NRCS. 1968. National Engineering Handbook, Section 11: Drop Spillways. USDA Natural Resources Conservation Service.

USDA-NRCS. 2005. National Engineering Handbook, Ch. 52: Structural Design of Flexible Conduits. USDA Natural Resources Conservation Service.

USDA-NRCS. 1956. Technical Release 3: Hood Inlets for Culvert Spillways. USDA Natural Resources Conservation Service.

Appendices

A. Task List

B. Gantt Chart

C. NRCS Standards and Specifications
    1. Grade Stabilization Structure Conservation Practice Standard
    2. Pond Conservation Practice Standard
    3. Engineering Field Handbook, Chapter 6 – Structures
    4. OK-Dwg-205 – Canopy Drop Inlet
    5. OK-Dwg-203 – Hooded Drop Inlet

D. Patent – Internally Reinforced Extruded Plastic Pipe

Task List

1) Preliminary Manometer tube pressure testing on several variations of inlet structures.
    a. Canopy inlet
    b. Hooded inlet
    c. Blunt inlet
2) Perform basic fluid mechanic calculations on pressure and head analysis of pipe structures.
    a. Friction loss
    b. Inlet loss due to contraction
3) Preliminary computer modeling with the use of FemLab.
    a. Pressure analysis
4) Gather materials needed for scale modeling.
    a. Determine sizes of pipe needed
    b. Find vendor
    c. Purchase pipe
5) Create several scale models using different inlet designs and corrugations in determining the integrity of current designs.
    a. Canopy inlet
    b. Hooded inlet
    c. 2 2/3" x ½" corrugations
    d. 3" x 1" corrugations
6) Obtain hard data on pressures and forces that are seen by the pipe using the ARS Hydraulics Lab.
    a. Head
    b. Suction
    c. Velocity profile
7) Develop possible designs for reinforcement of different inlet structures.
8) Build new models to determine if design concepts are effective.
9) Develop an overall cost analysis for the project.
10) Create presentation and write detailed report about our findings and proposed solution(s).

Drop Inlet Failures

Vortex
Engineers

Brian Dillard Rachel Oller Ryan Stricklin Mary Womack

Client

- Natural Resources Conservation Service
  - Federal agency that provides assistance to private landowners.
  - Helps improve and protect the soil, water, and natural resources of the land.

Introduction

- During a storm event, runoff volumes are high over agricultural land.

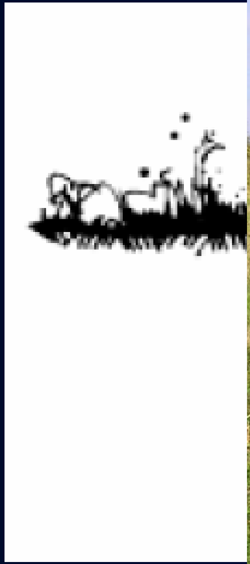
- This results in an increase of:
  - Surface runoff
  - Rill and gully erosion
  - Peak discharge rate

http://www.soils.agri.umn.edu/academics/classes/soil2125/img/10riller.jpg

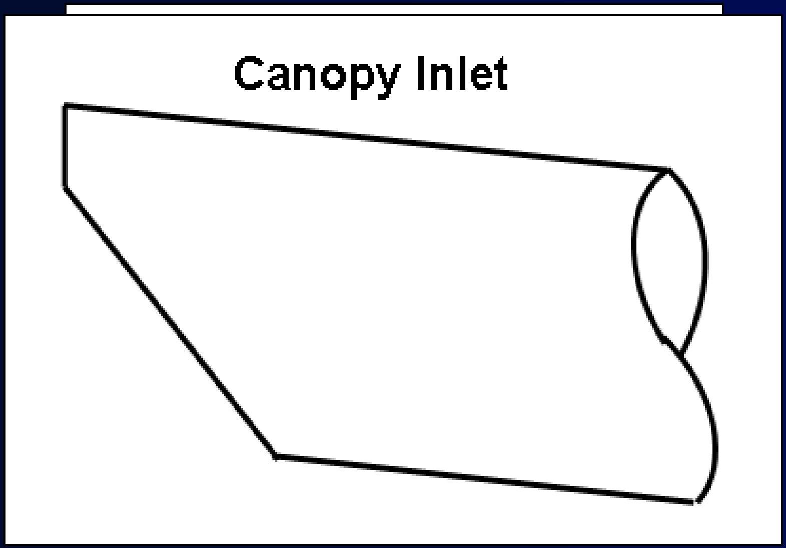
Grade Stabilization Structures

- GSSs stabilize grades by moving runoff through artificial or natural channels.
- GSSs are effective in:
    - Controlling runoff volumes
    - Preventing advancement of gullies
    - Stabilizing land forms

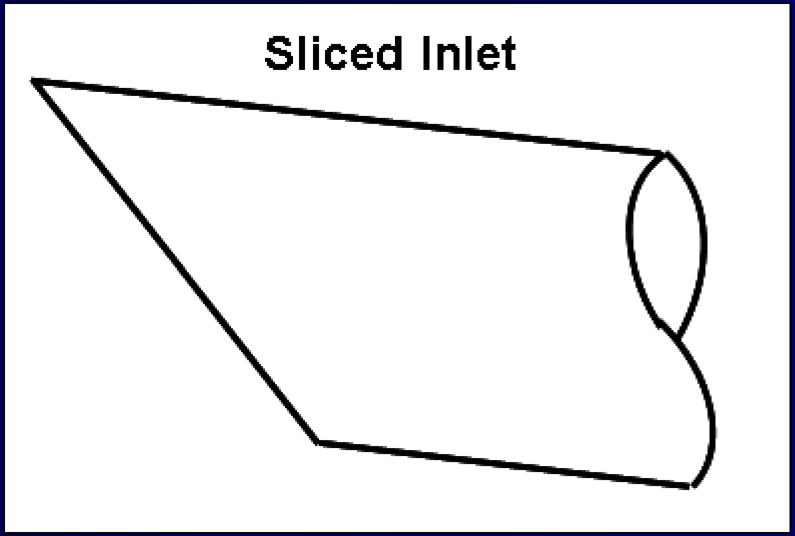
Grade Stabilization Structures



Profiles of Inlet Structures



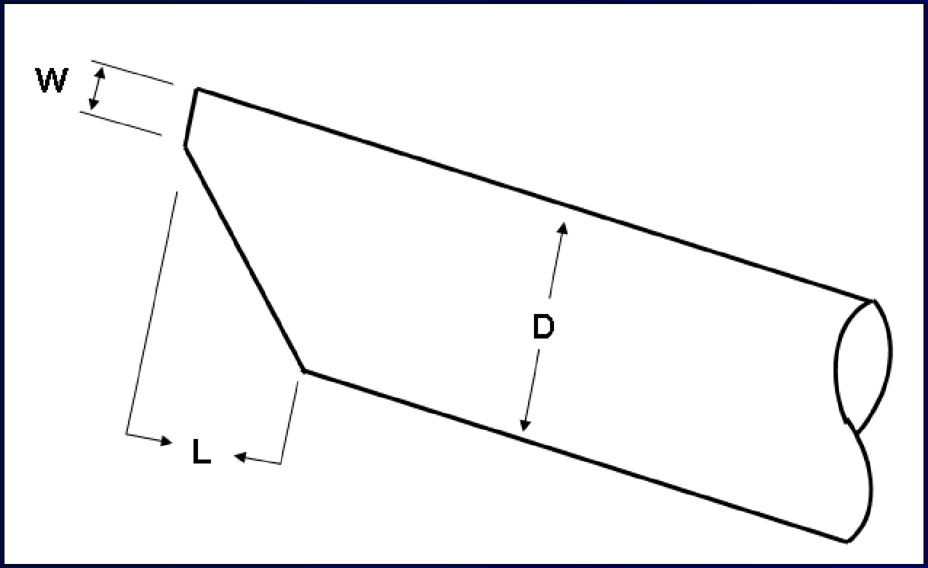
- Canopy provided more strength
- Requires high heads for full pipe flow
- Ineffective for GSSs
- Even less vortex formation than sliced



- Initial design in 1950s
- Low heads produce full pipe flow
- Less vortex formation than blunt

Current Design Specifications

- NRCS spec. for canopy inlet dimensions.
  - slope less than 15%:
    W=0.2D; L=0.75D
  - slope greater than 15%:
    W=0.3D; L=1.25D



Canopy and Sliced Inlets

- Effective in moving large volumes of water at low heads
- Widely used in Oklahoma for GSSs
- As sizes increased, failures began occurring

Failure Definition

- Inlet folds inward, creating a blockage of flow.
- Always occurring on the left side
- Typically 48” diameter or greater; 16 gauge thickness.

Current Repair Options

Methods currently in use:

- Angle-iron on rim
- Angle-iron top of inlet
- Anti-vortex baffles
- Convert sliced inlets to canopy inlets

NRCS Desired Results

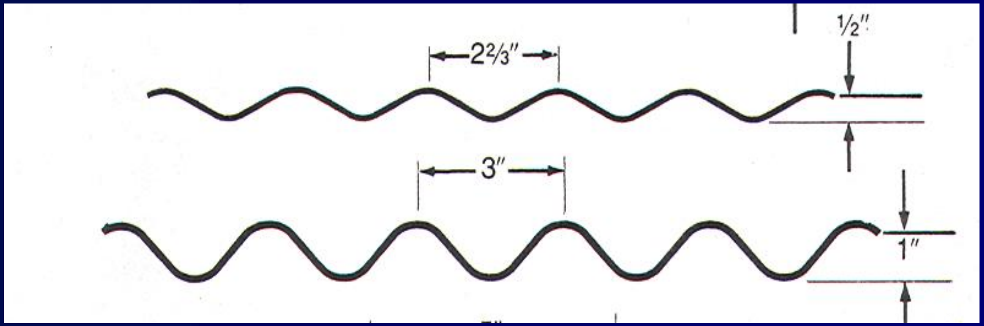
- Identify causes of inlet failures
- Determine pipe sizes, corrugations, and gauges that need increased strength
- Develop new design standards

NRCS Desired Results

- The NRCS also requests:
  - alternative methods for strengthening
  - cost comparison of retrofit options

Why Corrugated Metal Pipe?

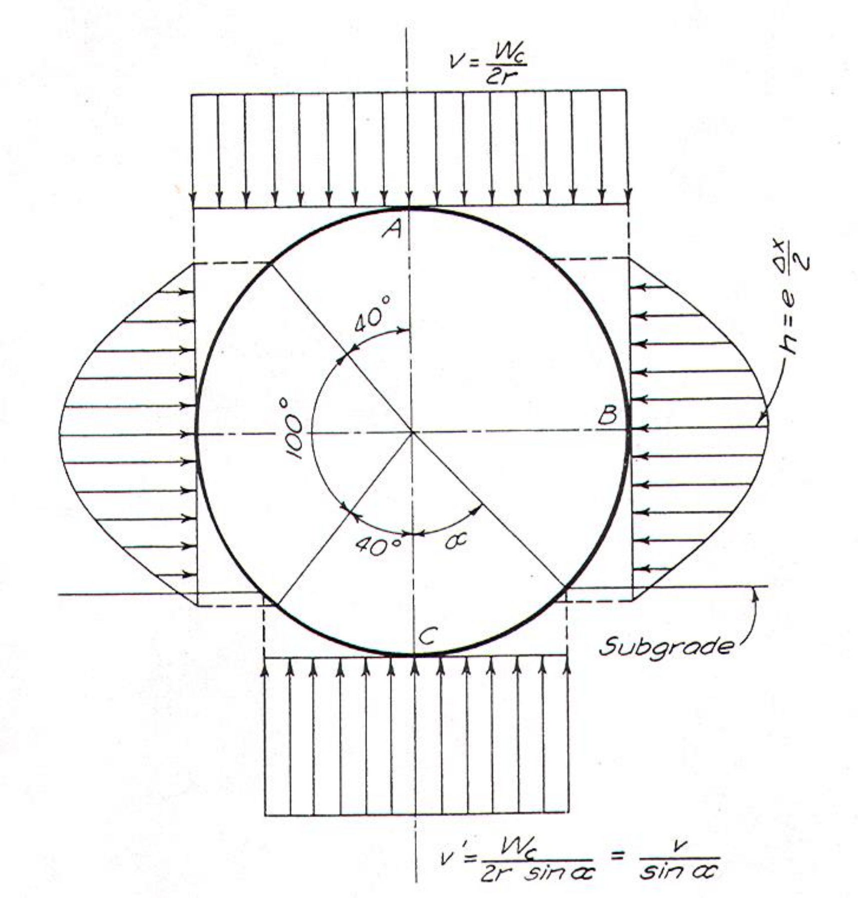
- Corrugation increases the stiffness of steel plates and improves strength.
- Lightweight and durable.
- The application determines corrugation size and type.



Structural Analysis of CMP

- The ability of CMP to support a load is derived from:
  - Dead Loads- embankment or trench backfill, stationary superimposed surface loads, uniform or concentrated.
  - Live Loads- Moving loads, including impacts (AISI, 1994).

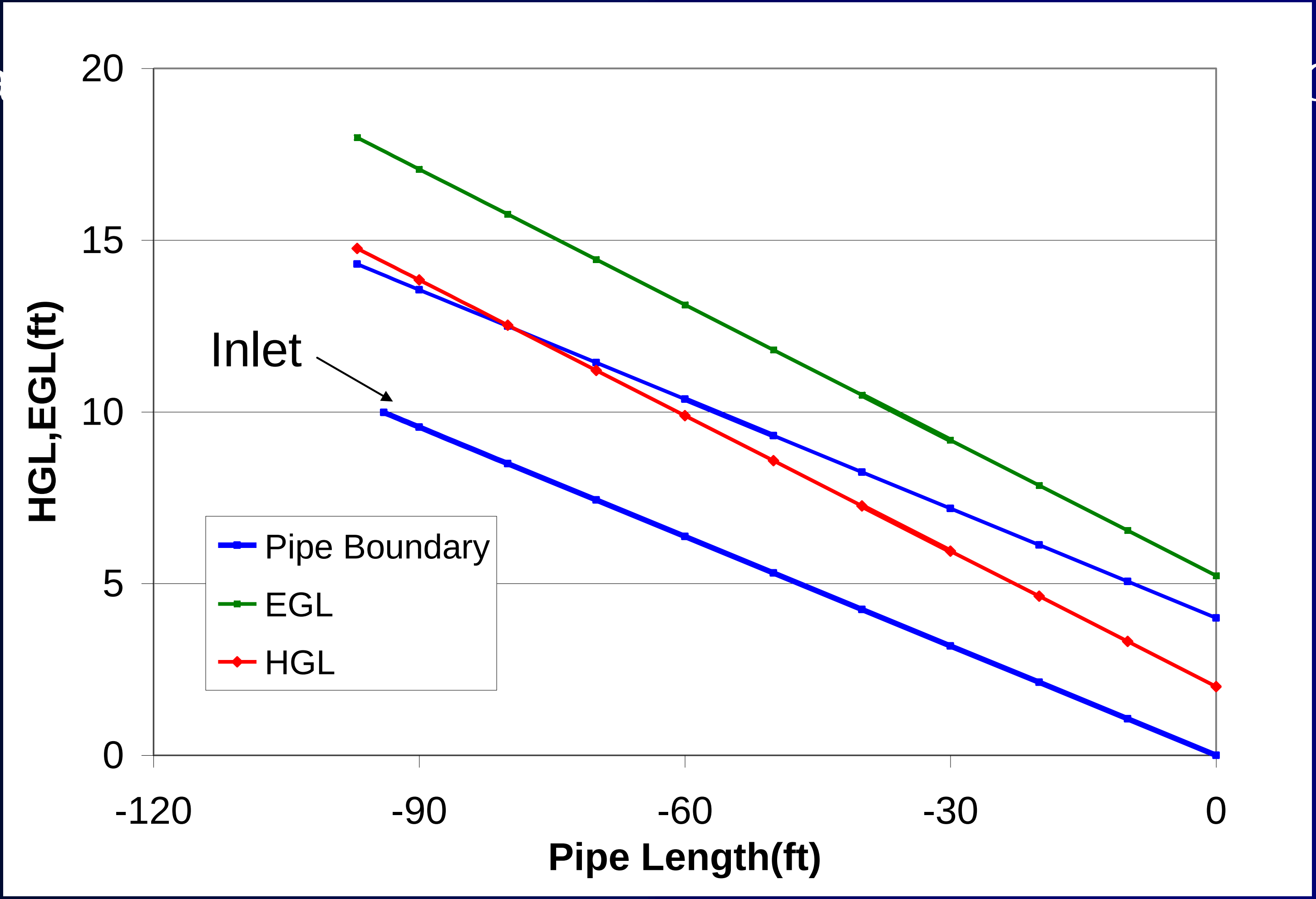
Load Distributions



- Loads are distributed uniformly over top and bottom of pipe.
- Loads caused by passive pressures of the earth are said to be greater toward the center of the pipe.

Preliminary Calculations

- Ca GL).



Initial Investigation

- Field Tour of Installation Sites
  - Toured several installation sites in western Oklahoma
  - Viewed failed and reinforced inlet structures

Initial Investigation

- Demonstration Flume
  - Located at the USDA ARS Hydraulics Lab in Stillwater, Ok.
  - Made observations of pipe flow characteristics through pipe inlets.

Demonstration Models

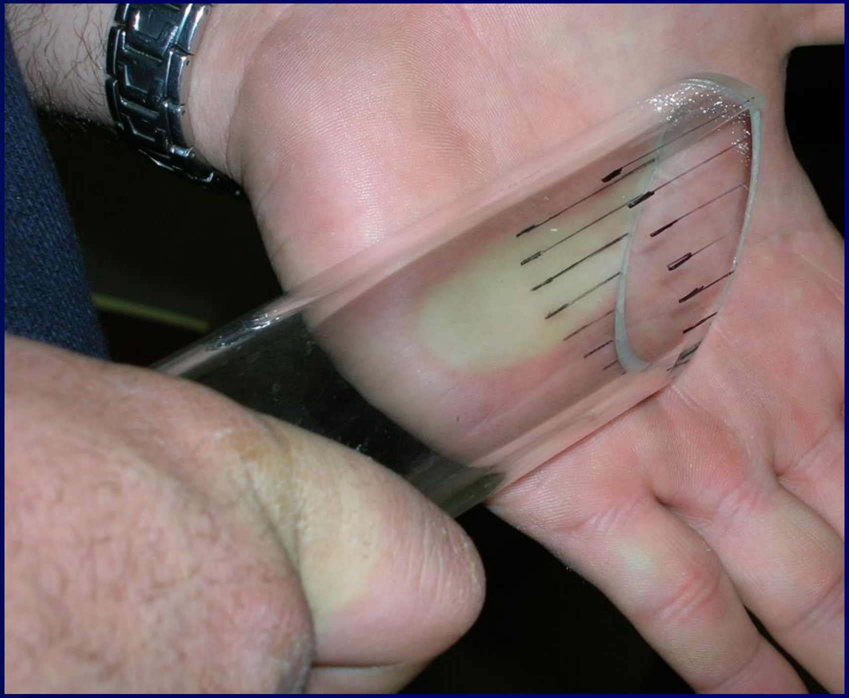
- Plexiglas inlet models include:
  - Blunt
  - Sliced
  - Canopy
  - Red film

Red Film Observation

- Modeled same failures as seen in the field
- Exhibited similar characteristics

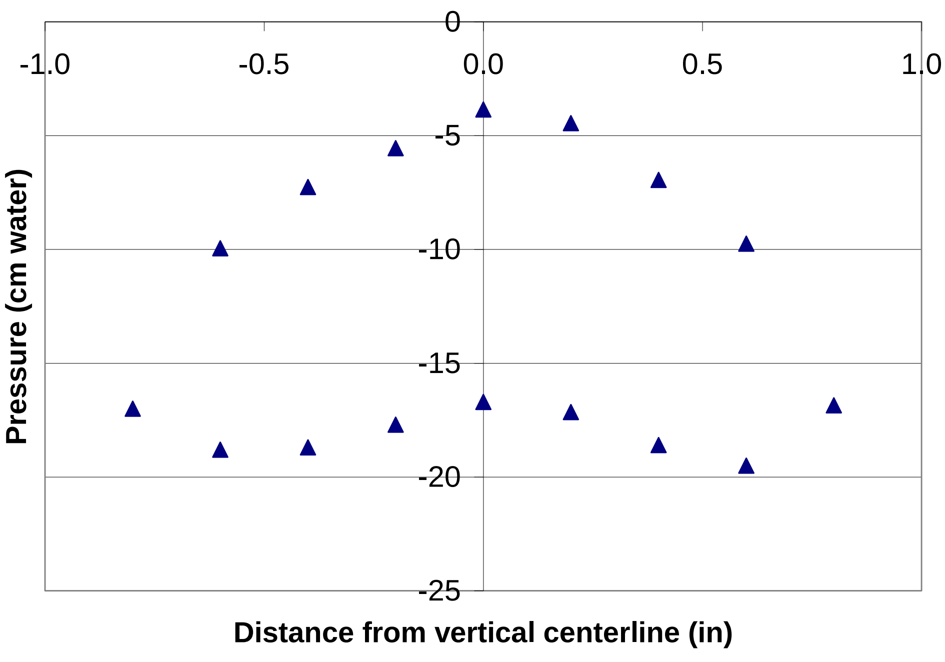
Manometer Test

- Manometer constructed of flexible clear plastic tubing and an air pump needle.
- Pressure measurements taken at increments around circumference.
- Pressure measured by changes in water level.

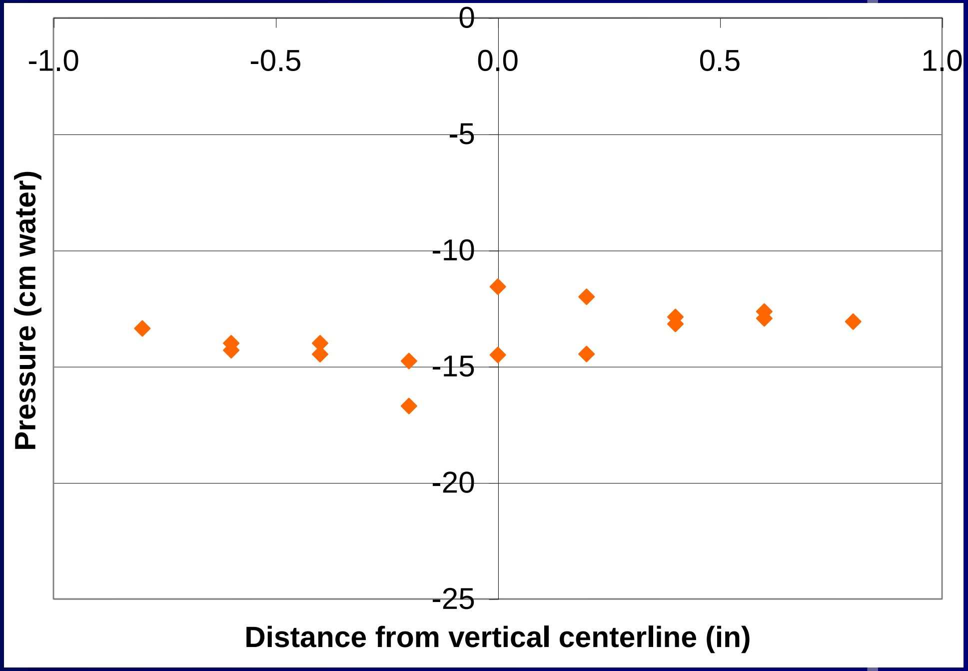


Manometer Test Results

Canopy Inlet Model
Pressure Distribution



Blunt Inlet Model
Pressure Distribution



Future Investigation

- Physical modeling
  - Redesign flume
  - Plastic corrugated tubing
  - 3” – 6” diameters

- Numerical modeling

Conclusion

- Investigation is ongoing into the forces that the pipe is experiencing
- Further testing of inlet structures with physical models
- Determine reinforcement methods that need to be implemented

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