# FINAL REPORT

BEST PRACTICES FOR QUALITY MANAGEMENT OF STORMWATER PIPE CONSTRUCTION

FDOT Contract Number BDK75-977-56

*Prepared for*

The Florida Department of Transportation
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## Disclaimer

# Metric Conversion Table

| SI* (MODERN METRIC) CONVERSION FACTORS | | | | |
|---|---|---|---|---|
| **APPROXIMATE CONVERSIONS TO SI UNITS** | | | | |
| Symbol | When You Know | Multiply By | To Find | Symbol |
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | | | |
| | | **MASS** | | |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| **APPROXIMATE CONVERSIONS FROM SI UNITS** | | | | |
| Symbol | When You Know | Multiply By | To Find | Symbol |
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |

*SI is the symbol for the International System of Units. Appropriate rounding shall be made to comply with Section 4 of ASTM E380.

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16. Abstract

Stormwater pipe systems are integral features of transportation construction projects. Pipe culverts direct stormwater away from roadway structures and towards designated discharge areas. The improper installation of a pipe culvert can result in costly repairs, timely delays, and/or hazardous system failure. The Florida Department of Transportation (FDOT) has firm requirements for the proper installation and final inspection of pipe culvert systems. However, there exist problems with the consistent and accurate use of laser profiling equipment, and there is no standardized testing procedure for equipment operators. With the goal of developing a certifiable exam, two preliminary exams were produced to demonstrate operator knowledge of installation and inspection procedures and operator proficiency in equipment use. The exam was required to consist of a written portion based on the latest FDOT Specification on post-installation pipe culvert inspection, as well as a field course comprising a pipe run with known defects to be located and measured. With the intent to aid in the establishment of a standardized testing procedure and training program, this project took the initial steps in validating equipment use and operator knowledge and further educating those receiving and interpreting laser profiling output data.

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# Executive Summary

Laser profiling provides an efficient and objective means of locating and identifying defects in municipal pipeline systems. A laser profiling system (comprising a mobile unit, closed circuit television camera, and laser) travels along the interior of a pipe and records all joints and observable defects. Recent difficulties in demonstrating equipment accuracy and repeatability have resulted in costly and unnecessary repairs. A means to show competency on the part of the system operator would ensure the accurate detection of defects and add validity to the stormwater pipe inspection industry.

The goal of this project was to establish testing guidelines for implementation with the Florida Department of Transportation (FDOT) to improve equipment accuracy and operator proficiency – specifically, testing for defects resulting from the improper installation of underground pipeline systems, and not limited to the selection of pipe material (e.g., concrete, plastic, or metal).

This project had the following main objectives: developing a method to validate laser profiling equipment; developing a written exam to test operator knowledge of inspection procedures; and developing a field test to certify proficiency in operating a profiling system.

Analysis of current design specification and consulting of design policy makers established the minimum acceptable standards for pipe defects and the minimum competency levels for testing operators, respectively. Equipment manufacturers were interviewed in order to ascertain the limitations of their testing devices and to understand their data generation methods. With this knowledge, a written test was developed to assess operator aptitude.

Operator skill was evaluated with a “field test course” wherein the operators must display the ability to locate and size existing defects in various buried pipes. Investigation of manufacturer case studies aided in developing the field test course. The establishment and future implementation of this certification process seeks ultimately to add validity to the stormwater pipe inspection industry.

Applicable data was obtained directly from the operators’ written and practical testing results. Supplemental data was acquired from individual surveys and included information on personality traits, educational experience, and lifestyle choices. Operator accuracy was assessed, and results were compared with pre-established percentages for equipment accuracy under nominal laboratory conditions (as provided by individual equipment manufacturers).

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# Chapter 1: Introduction

## Background

Roadways are the arteries of any modern day infrastructure system, and as such, they provide a lifeline to society's most basic needs. Public roads drive commerce, promote population growth and development, and support national defense. Ensuring that this complex network of interconnected corridors is fully functional is the key to promoting and sustaining the national livelihood.

The fundamental steps in constructing a roadway include site clearing, excavation, filling, compacting, and paving. Particular characteristics such as vertical and horizontal alignment, curve radius, stopping- and passing-sight distances, and pavement design are all specific to the job location. Environmental issues must also be addressed in roadway construction, and one such concern is stormwater drainage.

The impervious nature of most paving surfaces either prevents or inhibits water infiltration, and this can result in severe flooding. Water penetration can also degrade surface layers and, in some instances, cause asphalt stripping (Mannering and Kilareski 1998). Water erosion of a roadway's immediate surroundings can also compromise its structural integrity. In order to ensure driving safety during heavy rainfall, water must be diverted from road surfaces. Pipe culverts are laid beneath the road surface in order to direct stormwater away from roadway structures and toward designated discharge locations.

A drainage analysis ensures a culvert is optimally sized for a location's peak water runoff. Furthermore, a structural analysis ensures a culvert can withstand the traffic loads it will be subjected to. Thorough design of a culvert also requires minimal service maintenance.

Improper installation of a stormwater pipe culvert can result in costly repairs. Having to remedy a newly-placed pipe will entail clearing all infrastructure work already in place – which, depending on the progress made to that point in the production schedule, may or may not require removal of the topmost pavement surface (Hovland and Najafi 2009). Such an ordeal is not only expensive but also exceptionally time-consuming. Add to that any liquidated damages for time delay in roadway opening and costs significantly increase.

The Florida Department of Transportation (FDOT) is tasked with instituting, regulating, and maintaining the public road system for the state of Florida. Over the years, FDOT has improved upon the construction techniques associated with highway design, among which are the installation and inspection of pipe culvert systems. Firm requirements regarding the installation of pipeline systems are outlined in the specifications. All material suppliers and contractors must be listed on the approved vendors list, and all work must abide by pre-established requirements set forth by FDOT's Quality Control Program.

Stringent guidelines are also established in the current version of the FDOT specifications (2013) for the final inspection of pipe culvert systems. Among the criteria that must be examined are pipeline grade, the proper sealing of all joints, minimal pipe deflection, and freedom from cracks and other observable defects. Acceptable inspection practices are also listed in the specifications, including the use of closed circuit television (CCTV) recordings, laser profiling, and mandrel testing.

Modern technological advancements, such as laser profiling, have provided an efficient means of locating and identifying defects in pipeline systems. However, there have been issues with the consistent and accurate operation of these devices. The main problem currently encountered by FDOT is the lack of a standardized testing procedure for personnel operating laser profiling testing equipment. This project aims to develop a certifiable exam that will aid in demonstrating competency on the part of the profiling equipment operator – not only with respect to equipment utilization but also regarding knowledge of proper inspection procedures. The development of a standardized test will also probably have the effect of promoting the need for an established training program – which will further assist in preparing operators for the standardized exam.

This project also seeks to establish a method of validating the individual laser profilers used during pipe culvert inspections (which is concurrent with the FDOT's employment of an "approved vendors list"). There are several equipment manufacturers in the state of Florida, and if any one maker is selected to inspect a pipeline, they must display proper laser function and calibration. Moreover, the method of calibration must be such that the specific type of laser has no influence on the results. In other words, a calibration test must be developed in order to objectively authenticate the laser profiling equipment. This calibration test will also have to address the natural discrepancy in accuracy readings between laboratory conditions and real-world testing conditions.

FDOT has also expressed a necessity to educate those that are receiving and interpreting the laser profiling output reports. Consistency in data analysis among the different equipment manufacturers will have to be established in order to assist in understanding the inspection results.

Verifying FDOT's position concerning the use of state-of-the-art technologies is also important. It will be necessary to investigate the methods employed by other Department of Transportation (DOT) offices in post-installation pipe inspection, and compare the findings with FDOT's current practice. Understanding which states use which technologies will shed more light as to how prominent an issue culvert inspection really is.

Proper installation of pipe culvert systems is vital for the longevity of a healthy transportation industry. This project seeks to improve equipment accuracy, increase operator proficiency, and educate data analysts. The resulting goal is to accurately detect pipe culvert defects earlier in the installation process, thereby decreasing the occurrence of costly and time-consuming system failures. These minor improvements in highway construction practice can result in significant improvements to the nation's infrastructure and economy.

## Objectives

The objectives of this research project were to:

(1) generate an approval process for systems and equipment to be used for post-installation pipe inspection on FDOT projects; and
(2) generate a program to qualify those individuals who will be allowed to use the aforementioned systems and equipment to perform post-installation pipe inspections on FDOT projects.

The system and equipment approval process consisted of examining the different types of equipment used in the inspection of pipe culvert installations; assessing the validity of these methods as permitted in FDOT specifications; investigating the methods used by other state DOTs; and determining the qualities that testing methods and manufacturers must satisfy.

Operator qualification centered on the concept of a field operator certification program. A written exam would test operator knowledge of the pipe culvert inspection procedures and specializations and a field exam would test operator proficiency in using the CCTV and laser profiling system. The written portion would focus on current FDOT specification requirements while the field course would consist of various types of pipe with measured defects at known locations. Operators must demonstrate their ability to locate and measure these existing defects with approved profiling equipment of their choice.

The tasks associated with completion of the aforementioned objectives were as follows:

(1) conduct a literature search;
(2) collect data;
(3) analyze data;
(4) design and construct a field testing course;
(5) develop the technician certification program; and
(6) produce the final report.

With the understanding that the research team has limited influence on the industry-specific aspects of pipeline inspection, additional suggestions and recommendations shall be made for FDOT to pursue in future projects and Pipe Advisory Group (PAG) meetings.

While the focus of this certification program is on laser- and CCTV-based methods of inspection, the research team does not wish to alienate those DOTs that employ other methods. As such, this report may serve as an encouragement to DOTs who are not currently using these methods to potentially consider their use; and as a guide to those DOTs who want to implement an underground pipe inspection program that uses these methods.

# Chapter 2: Literature Review

## Review of Previous Research

Laser profiling was originally developed as a means to inspect the placement of liners in cured-in-place pipe systems (Hancor, Inc. 2007), and to investigate inflow conditions of existing pipe systems (Wirahadikusumah et al. 1998). Providing a smooth interior surface profile for sewage and stormwater pipe systems was key to ensuring optimal design flow. With the implementation of laser technology in pipe culvert installation inspections came a more efficient means of locating and identifying defects in reinforced concrete pipe (RCP) systems. The National Association of Sewer Service Companies (NASSCO), however, recently expressed the concern that modern profiling technologies fail to provide the required – and repeatable – level of precision (Holdener 2011).

Lack of a standardized certification process further underscores the need to add validity to stormwater pipe inspection. Although analysis of the severity of a defect and the determination of a proper course of action remains the responsibility of the engineer of record (FDOT 2010), the accurate and precise detection of these defects for municipal stormwater pipelines is crucial in preventing costly and unnecessary repairs (Bennett and Logan 2005).

Since the abovementioned disasters dealt explicitly with the transport of energy fuels, their failures fall under specific mandate of the U.S. DOT Pipeline and Hazardous Materials Safety Administration. The installation and maintenance of sewage and stormwater pipeline systems, though not governed by the same organization, is equally vital in supporting human activity and requires equal scrutiny. As such, various organizations, including the American Society of Civil Engineers Pipeline Division, have sought to promote the understanding of their technical field while concurrently advancing and refining their development.

### Culvert pipe installation inspection

FDOT outlines inspection criteria for newly installed municipal stormwater pipe per Section 430 of their Standard Specifications for Road and Bridge Construction. Prior to laying down an asphalt friction course, the specifications require measuring all joint gaps, cracks, and other such defects for all pipes 48 inches in diameter, or smaller. Proper identification and location of defects must be established; the degree of severity of all defects must be analyzed; and appropriate considerations or remediations must be made (per the engineer's judgment).

In 2004, prior to the implementation of laser scanning technology, the FDOT pipeline inspection process was comprised of a CCTV camera mounted atop a mobile system. This portable unit would travel along the pipe invert and transmit video footage to a trained operator who would locate and classify defects and joint gaps. This subjective form of visual investigation was prone to operator error, inexperience, and fatigue (Iyer and Sinha 2005). Bennett and Logan (2005) further expressed the limitations of inspecting pipelines with only a CCTV camera, wherein defects cannot be accurately measured or, in some cases, even identified.

Early image processing methods (Sinha et al. 1999, and Sinha & Fieguth 2006) had entailed the use of complex algorithms that would apply filters to the pipe images generated by the CCTV video. These complex assessments of the video images would then make adjustments for background lighting, contrast enhancement, and noise filtering; and would apply statistical filters to detect cracks.

In 1995, Australian authorities developed the Pipe Inspection Realtime Assessment Technique (PIRAT) which consisted of both laser and sonar scanners, and contained “two semi-independent systems” that collected information and objectively interpreted data (Gokhale et al. 1999). This system also included processing software that, similar to the image processing algorithms used with CCTV video, would adjust the data results to account for problems associated with the system’s movement (Kirkham et al. 2000).

The Sewer Scanner and Evaluation Technology (SSET) system that was developed in Japan, incorporated the video recording function with a gyroscope and optical scanner (Abraham and Chae 2002). Here too, the data processing involved the use of image filters but the added implementation of the gyroscope, in conjunction with the optical scanner for data geometry recognition, helped account for the motion-based problems.

<u>Use of laser profiling throughout the United States and in other countries</u>

In 2005, Pipeline and Drainage Consultants conducted a thorough investigation of existing drainage systems throughout the states of Kentucky and Ohio. The purpose of this study was to evaluate the performance of previously installed high-density polyethylene (HDPE) pipes. These inspections were performed with CCTV cameras and laser profiling equipment – and although crack detection was done primarily with video recordings, the laser profilers provided valuable information in identifying pipe distortion, including vertical and horizontal deflections. From this report came the suggestion to incorporate laser profiling into pipeline installation inspections (Pipeline and Drainage Consultants 2005).

In addition to Florida, other state DOTs that have either started requiring laser profiling or are investigating the technology for use in future installations, include California, Kansas, Michigan, Minnesota, Missouri, North Carolina, Texas, Utah, and Virginia (Abolmaali et al. 2010). As impetus grows for the use of laser profiling, there is a parallel current in the acknowledgement that an organization must provide standardization of this new technology (Holdener 2011).

Earlier studies in pipe profiling were done in the United Kingdom, Australia, and Canada. Kenter (2008) made reference that their pioneering work (as least with regards to the United Kingdom) was the result of their shallower pipe depths: because their pipelines were more susceptible to live load effects, they had sought the aid of laser profiling before it was considered in the United States. However, it is of interest to note that the United Kingdom’s Department for Transport (2009) makes no specific mention of the requirement of laser profiling inspection methods in their Manual of Contract Documents for Highway Works: the phrasing of the Testing and Cleaning sections for both Volume 1 (Specification for Highway Works, Section 509) and Volume 2 (Notes for Guidance on the Specification for Highway Works, Section 508) only describes how the substitution of CCTV inspection for traditional mandrel testing is permitted.

FDOT Specification requirements

In a series of meetings between FDOT and members of PAG and the Pipe Installation Task Group, there was an evident account of laser profiling's early involvement in the state's pipe culvert inspection process. Discussions concerning the use of deflectometers and mandrels in detecting and testing pipe deflections began on June 6, 2005, and by September 28 of the same year, the committees were already considering the potential benefits surrounding implementation of a "laser ring" inspection method. By this time (late 2005), the American Association of Highway and Transportation Officials (AASHTO) had been exposed to the laser profiling technology – by means of a conference in Kentucky – and Florida sought to use this technology with the inspection of its pipe culverts. As of the PAG's meeting on April 26, 2007, laser ring inspections had already been implemented and were being used in pipe culvert installation projects as a means to detect overall pipe deflection as well as pipe joint and crack investigation (FDOT 2007d).

The overarching theme of these meetings with PAG and the Pipe Installation Task Group, besides that of promoting the use of a new technology, was to provide a unified method of inspection to those in the pipe culvert installation business. Interspersed throughout the minutes of their meetings were talks of the development of a comprehensive Pipe Repair Matrix (FDOT 2007c) which would provide prescriptive solutions to common pipe problems. Coupled with the future goal of normalizing profiling data output (FDOT et al. 2009), a concise regimen was forming for the total process of pipe culvert inspection – from testing to analysis to remediation.

Establishing a consensus among the various laser profiling system manufacturers that provide their services in the state of Florida is also of great concern (FDOT et al. 2009). With the exception of the required information currently outlined in the FDOT Specifications, each manufacturer supplies whatever supplementary figures they deem insightful. A set of standardized procedures, input variables, data analysis generation, and output display forms would ensure an equivalent comparison between pipeline systems, if such a comparison were demanded of installation inspectors.

In 2007, FDOT Specifications included the requirement of laser scanning for final inspection of all newly installed pipe culverts. Field inspectors were to supply a CCTV video recording of all inspections as well as elevation profiles, defect reports, joint gap reports, and pipe ovality reports. Per FDOT's requirements on laser profiling equipment, an accuracy of +/- 0.5% was expected with the readings. As required per Section 449 of the FDOT Specifications, ASTM C76 – 11, and AASHTO Section 27, cracks identified as being 0.01 inch in width and at least 12 inches in length would not be accepted … bearing in mind that this 0.01 inch criteria does not signify structural failure (ACPA 1976 and 2007), and does not address the possible dismissal due to autogenous healing (Sagüés 2011) of reinforced concrete cracks. Figure 2-1 shows an image of a laser profiling system traversing along the interior of a pipeline.

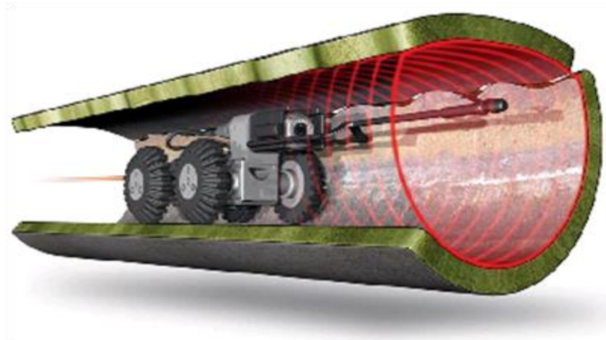


**Figure 2-1: Laser Profiler Traveling along Pipe**
*(from AET Robotics and Inspection Services)*

Per the FDOT and PAG meeting on October 7, 2008, issues with the differences between profiling equipment manufacturers were evident, and in the following year thoughts of standardization and calibration of the varying technology manufacturers arose. There was also discussion of involving NASSCO in certifying laser profiling inspections (FDOT et al. 2011).

As of this writing (2014), NASSCO only provides education and certification programs for sewer service companies in the state of Florida. Their Pipeline Assessment Certification Program provides a comprehensive and standardized means of testing those in the sewer inspection field, however, there is much headway in NASSCO's involvement of stormwater inspection certification (FDOT 2010). The similarities between installation procedures for sewage and stormwater pipeline systems warrant an in-depth assessment for the potential to either combine the two inspection services under one umbrella certification process, or to develop a separate course but govern its recertification through the same agency (FDOT 2011). Development of a standardized test, nonetheless, would also help promote acceptance by other states and would potentially foster collaboration among the different manufacturers of laser profiling equipment.

Profilometry

A profile is the projected image of a surface's roughness, and a profilometer (or profilograph) is a device that generates this visual representation by means of either a contact- or non-contact method. First developed by Elson Spangler and William Kelly at the General Motors Research Laboratory (Sayers and Karamihas 1998), the earliest uses of profilometry include the 1960s study by AASHTO on the roughness of road pavements and the vibration effects of vehicles (Transportation Research Board (TRB) 2007). The major advances from this project were the use of a device that had an internal "inertial component" that would create a moving reference point, and allow for more advanced methods of mobile profile measurement.

The basic measurements with which a profiler interprets its information are a reference elevation, a height (in relation to the reference elevation), and a distance (Sayers and Karamihas 1998). Prior to the establishment of the "inertial component", these three components would have been evaluated statically, with an established reference point. In measuring with a mobile system, an accelerometer would account for the vertical displacement between measurements (as calculated algorithmically), and the distance (longitudinal displacement) would be accounted for by means of a speedometer.

The mobile method of profile generation made possible the extensive studies to correlate road characteristics with an International Roughness Index, influencing the future of road pavement design and assessment (TRB 2007). Additional advances were made in the fields of road rut evaluation and curvature and slope design.

As a precursor to laser profiling, mandrels provided a much more primitive method for verifying ovality and locating deflections along a pipeline. A mandrel is a round apparatus that is driven through the interior of a pipe in order to verify that the pipe meets the minimum size requirements and contains no major obstructions to flow (RedZone 2011). The mandrel is slightly smaller than the required internal diameter of the pipe, and this difference in size corresponds to a proportional percent variance that is acceptable in the pipe size. If a mandrel does not successfully pass through the inner workings of a pipeline, the inspection is unsuccessful. A picture of a mandrel by itself, and in operation, is shown in Figure 2-3.

**Figure 2-2: Image of Pipe Mandrel by Itself and within a Pipeline**
*(from the Ontario Concrete Pipe Association)*

Aside from surface roughness, a modern laser profile can identify such features as pipe ovality, and horizontal and vertical deflection. The ovality of a pipe is determined as the difference between the maximum diameter and a mean diameter, expressed as a percentage (RedZone 2011). The vertical and horizontal deflections of the pipe are presented with respect to the differences in the "graphical diameter analysis report" (FDOT Specifications 2010).

Video micrometers are employed alongside the profilometer to determine the approximate dimensions of the discovered crack. A video micrometer is a video-based measurement device that is typically internal to the laser profiling system and allows for the images observed on the CCTV to be accurately dimensioned. This method provides for crack width and length estimates that are more detailed than scaled readings. Crack detection involves a detailed location of the defect along the pipe's longitudinal axis and along its circumference, and must detail the width and length (if exceeding the dimensions for a minimum-sized crack).

Laser profiling technology

Laser profiling is a non-contact and non-destructive form of testing used to acquire the interior profile of a pipe. A laser is made up of three main elements: an active material, an energy source, and a pair of mirrors (Shan and Toth 2009). The active material is comprised of select atoms whose electrons can be excited. The energy source can come in the form of heat, light, or electricity, and it is what provides the energy necessary to excite the electrons of the active material, which in turn release photons. The two mirrors (one completely reflective and one semi-reflective) are used to further propagate electron excitation and to direct laser light through the aperture. Figure 2-4 provides an illustration of the basic components of a laser.

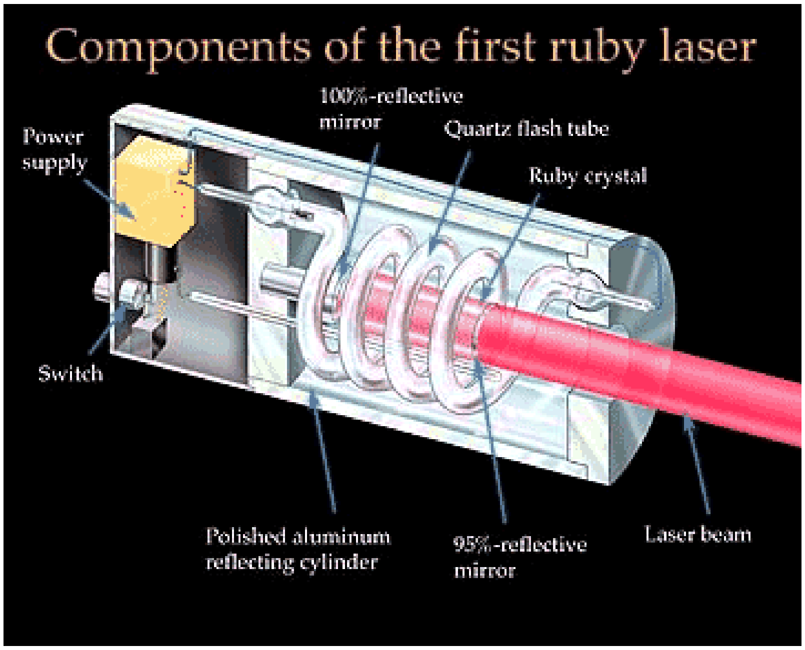



**Figure 2-3: Laser Components**
*(from Lawrence Livermore National Laboratory)*

With respect to the laser profiling systems, the process can be performed in one of three ways: by laser ring, by point cloud, or by rotating laser. As the name implies, the laser ring method entails projecting a laser ring along the interior of the pipe culvert, just ahead of the CCTV camera. As the mechanism travels along the pipe invert, a laser ring is projected perpendicular to the longitudinal axis and any defects in the overall shape of the pipe are recorded both visually and digitally. A picture of a laser ring projected onto the interior wall of a pipe is shown in Figure 2-5 – note the inverted curve of the ring at the top of the pipe.

**Figure 2-4: Laser Ring Profiler**
*(from Maverick Inspection Ltd.)*

The second laser profiling method involves projecting multiple pulses at once and back-calculating the distances of their respective reflected object based on the “time of flight” of the individual pulses (WEF et al. 2009). Figure 2-6 shows an image produced by a point cloud laser profiler. For either method – ring or point cloud – the profiling system manufacturer provides the software and/or services necessary to convert the information into usable data which may then be analyzed appropriately.

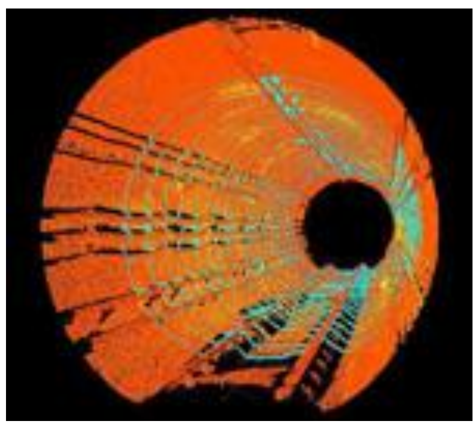


**Figure 2-5: Point Cloud Laser Profiler**
*(from Engineering Surveys Limited)*

The third laser profiling method consists of parallel laser diodes mounted atop a camera head. While the unit travels down the length of the pipe, the lasers are aimed towards the pipe surface, remaining perpendicular to the wall, and the laser mount rotates at a predetermined speed producing a spiral image recording pipe deflections, diameters, and deformations. Since the laser diodes are integrated into the camera unit, no user calibration is necessary prior to pipe inspection.

<u>Physics behind laser accuracy</u>

The practical accuracy of most laser profiling systems was questioned by Holdener (2011) when stating that the majority of manufacturer literature boasts an accuracy of 0.03 inches under ideal laboratory conditions. Comparing that with the 0.01 inch requirement in the field can put into question the validity of most profiling systems currently used in Florida. Environmental factors can also adversely affect a field inspection (Hancor, Inc. 2007).

While not specifically listing profiling equipment manufacturers either in their Qualified Products List or the Quality Assurance Program, FDOT does have specific requirements mandating the calibration of all laser profiling equipment. According to the Office of Construction Laser Profiling Calibration Criteria, accuracy must be shown to be 0.5% (or better), and repeatability must be shown to be 0.12% (or better) for both software and equipment. This verification must be made by a third party (FDOT 2007b).

Most literature presented by laser profiling manufacturing companies shows adequate accuracy and repeatability in the lab. For example, RS Technical Services presents a +/- 0.25% accuracy and 99.9% repeatability (Griffin 2008). Yet there still remains the question of how the aforementioned criteria, which are tested under ideal controlled conditions, can be accepted or applied to uncontrollable field conditions. Environmental conditions can present a degree of variability which is hard to reproduce in the lab (Holdener 2011; Motahari and Forteza, date unknown). The likelihood of accurate repeatability, given the natural and human aspects that influence inspection procedures in the field, is also questionable (Holdener 2011).

Taking a more in-depth examination of the physics behind the equipment, consider, then, the resolution of the detection lasers for this application. Resolution can be defined as the minimal distance that can lie between two points and still have those points register as distinct, individual points (Cullity and Stock 2001). The ultimate resolution is defined by the physics of the laser, or any form of electromagnetic radiation detection, which is a function of the probe's wavelength. For the purposes of this research, however, this is irrelevant, as the laser's wavelength will be on the order of hundreds of nanometers (where 100 nm $\approx 3.9\text{x}10^{-6}$ inches). What is more important to this project is the actual resolution, which can be defined as the minimal distance between two distinct points at a given distance from the probe source. This more usable definition takes into account several variables: the electronics; the method of detection; the conditions of the environment in which it will be deployed; and the position of the detecting unit as probe angle. Any one of these variances can have a drastic effect on resolution (Bush and Cox 1984).

The type of pipe to be examined should also be taken into account as different materials can absorb, reflect, or refract the probe laser in different ways, altering the perceived resolution (Hummel 2001). Even the roughness of the surface of the pipes can have an effect on laser reflection. The resolution will determine the minimal size crack that can be detected at a given distance under nominal conditions (Chu and Butler 1998). This information should be available from the manufacturers' literature in the form of a "Distance versus Resolution" graph, or even as an equation. Figure 2-7 presents an overly simplified depiction of how an object's detection is related to the size of the wavelength.

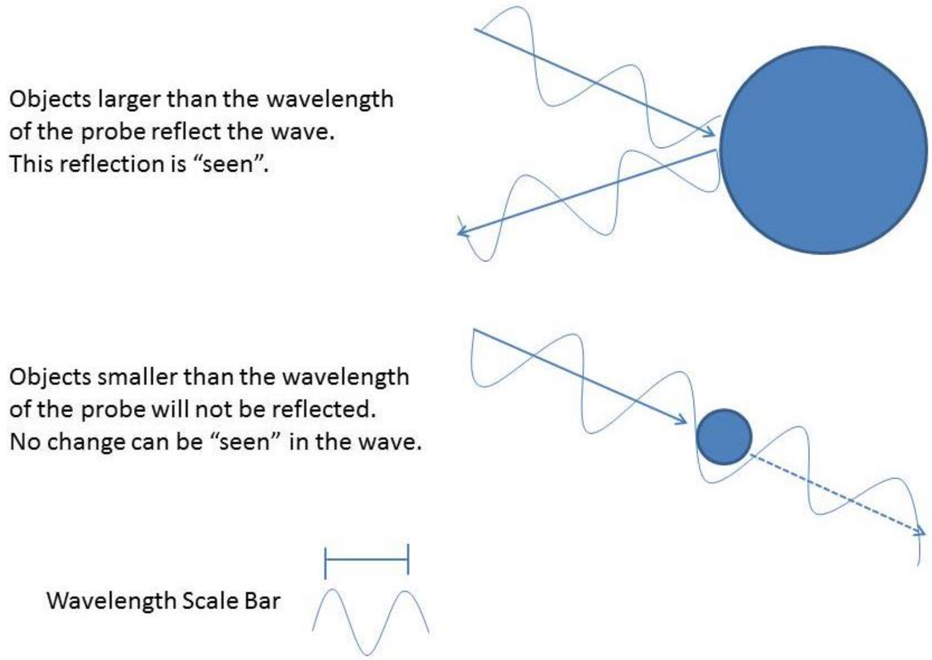



**Figure 2-6: Object Detection in Relation to Wavelength**

Information presented about the assumed conditions and angle of detection should be provided, as this information will help determine how applicable the given data is to the project. Knowing the angle of detection may require more investigation depending of the diameter of the pipe being examined and the location of the probe source inside the cross section of the pipe (i.e., centered versus non-centered).

Even given all the required information from the manufacturer, independent testing and confirmation of the resolutions for a wide set of conditions should be performed and the data obtained used to gauge the accuracy of the manufacturers' claims. Finally, the causality of the limits of the resolution should be well known and understood (Chu and Butler 1998).

Having a complete knowledge of how the probe physically detects the cracks, and the limitations of the given method – including resolution – will enable the operators to correctly assess the data collected from the detection devices being utilized. The same is true of understanding how the software interprets the data before displaying the results in a useful format for the operators. The understanding of data processing and results generation methods are often overlooked to the detriment of the data interpretation (Richerson 1992) and, thus, to the overall goal of the project: to identify the location and size of cracks in a given section of pipe.

Equipment limitations

Although laser profiling technology has been readily embraced and steadily growing as an inspection method of sewage and stormwater pipe system defects (Sutton 2009), it is not devoid of issues. Although objective in its presentation of data, improper configuration and poor initial positioning of the equipment can result in inaccurate data (Dettmer et al. 2005). When investigating a specific profiling system, Motahari and Forteza (date unknown) highlighted the need to ensure dewatered and debris-free conditions – not a likely scenario when performing outdoor field inspections.

Buonadonna et al. (2011) summarized the most recurring problems with laser profiling: the laser will only collect information above a waterline (as the laser light will be refracted); the laser cannot distinguish between material density (i.e. corrosion and spalling may falsely be considered debris); and it is very difficult to align the laser "cross-section" with the pipe center. These instances of faulty data can result in distorted images that appear "cloudy" (due to wave refraction) or do not have corresponding data points in select areas. Figure 2-8 shows the lack of data points below a visual obstruction.) In the cases where a third-party is charged with analyzing the laser profiling data, one may discount these "cloudy" images as perceived areas of debris (or water) and declare the datum an outlier. Since one cannot know whether a potential crack lies beneath this area, a potential defect may unintentionally be neglected. (It must be noted that these instances of misinterpreted data can also be associated with Operator Limitations, which shall now be discussed in greater detail.)

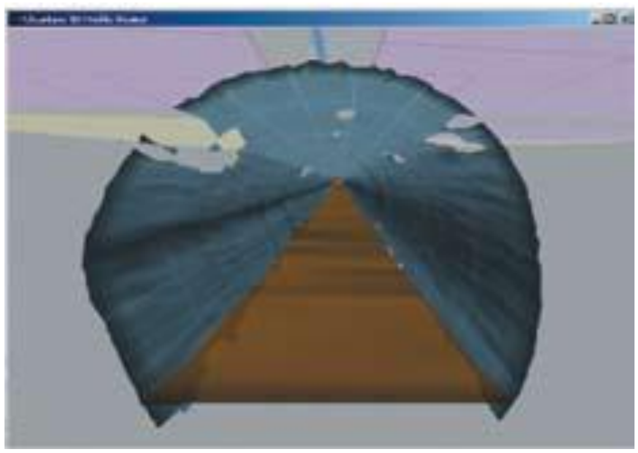


**Figure 2-7: Illustration of Non-registered Points below Waterline**
*(from CUES Laser Profiling System Brochure)*

Operator limitations

In a recent discussion with FDOT (2011), both laser profiling manufacturers and those in the video inspection industry were quick to point out the need to improve the operator's knowledge and implementation of existing specification guidelines. For example, many have observed the wanton neglect of the maximum system speed (30 feet/minute) for running a laser profiling inspection. In some cases, the laser profiling systems being used do not display the unit's speed on the video screen, and the operators are quick to exploit this feature. Although it has been requested that all system manufacturers provide this feature on their video displays, an immediate solution includes the random inspection of operator performance. For example, recording the beginning and ending times for a particular pipeline run will supply an average of the actual testing speed. Regardless, when an inspection is performed too fast, the resulting images on the CCTV video recording will appear blurred and will not provide sufficient help if an image must later be referenced with a corresponding laser profile.

Other instances of inspector failure include the omission of joint gap reports for all connections along a pipeline run. Particular operators will only supply gap reports for those instances in which the requirements are not met. Although a subsequent joint gap may fall within the appropriate parameters, remediations for an adjoining joint gap may affect the connection of the previous joint gap. Therefore, it is vital to have all the information available (FDOT et al. 2011).

In reiterating the need to observe and control the maximum inspection run speeds, it must be stated that there is a direct correlation between inspection run speed and the data analysis capacity for any given laser profiling equipment. Looking specifically at the equipment literature for the CUES Laser Profiler System (CUES, Inc. 2011), their pipe ovality routine processes at a maximum speed of 30 times/second. When considering the average pipe culvert segment length of 8 feet and assuming a "worst case scenario" inspection speed of 30 ft/minute, completing a run for a single segment of pipe will take approximately 16 seconds:

time = distance / velocity
time = (8 ft) / (30 ft/minute) = (0.267 minutes) * (60 seconds/minute)
time = 16 seconds

At that maximum speed, ovality analysis will process 480 times:

number of analyses = time * 30 times/second
number of analyses = 16 seconds * 30 times/second
number of analyses = 480 times

This results in approximately 60 analyses per linear foot of pipe:

number of analyses / linear foot of pipe = 480 times / 8 linear feet
number of analyses / linear foot of pipe = 60 analyses/linear foot

Looking at roughly five analyses per linear inch of pipe seems a reasonable sampling for pipe ovality evaluation; however, individual manufacturers' equipment processing speeds and individual operator inspection speeds must be verified and a standardized minimum number of analyses should be established on the inspection specifications in order to ensure the proper number of observations per pipeline run.

Another key issue mentioned in the Laser Profiling and Video Inspection Industry Meeting (2011) was the lack of proper specimen cleaning/clearing prior to inspection – particularly in the instance of pipe dewatering. As difficult and time-consuming a task as this poses, without thoroughly clearing a pipe, the resulting data will either skew deformation results or will require additional investigation (for example, having to spend more time cross-referencing the data with the video images) (Motahari and Forteza, date unknown).

The issue of project scheduling also comes into play as several operators have noted that their inspection runs would oftentimes be squeezed in between other installation operations. If a questionable reading were to present itself during inspection, an operator would have to take the time to further analyze the situation, taking time away from the already-delayed schedule. Note however, that this instance is only true for cases where the laser profiling inspection is done in real-time. For the instances where the inspection is performed and data processing is done by a third-party, problems that need remediation may require expensive excavation as other procedures will have continued with their installation. To address this issue, FDOT is investigating implementing partial inspections of pipeline systems (FDOT et al. 2011).

Besides operator error, there also lies the potential for fault in analyzing the data obtained by the laser profiling system. Manufacturers will either supply proprietary software and training or they will provide access to an analysis center (Griffin 2008). In the case where the clients are performing their own investigation, insufficient training or inadequate knowledge of the software can result in erroneous results. It was mentioned by the participants of the Laser Profiling and Video Inspection Industry Meeting that one particular laser profiling system manufacturer only supplies a PowerPoint presentation with instructional steps to follow in learning the corresponding hardware and software.

When employing a third-party processing system of data analysis, there exists an unfortunate "black box analysis" where inspectors are familiar with the inputs and outputs, but are oblivious to the computational dealings of the observations (FDOT et al. 2011). It is vital to have a skilled field operator that can fully comprehend the limitations of the equipment, can recognize and remedy any common problems, and can understand the analytical procedures involved in evaluating the resulting information.

<u>Video micrometer technology</u>

The most common misconception in post-installation pipe inspection is that the laser profiler measures pipe cracks and joint gaps (Conow 2011). For a profiler to measure a joint gap requires a high scan density, as in the case of point cloud lasers. The majority of laser profiler manufacturers use video micrometers to measure crack and gap sizes.

A video micrometer, typically attached or built into a laser profiling setup, consists of two parallel lasers. These lasers are spaced apart at a known distance, and they function as a reference point when measuring the required defect. Proper measurement of a pipe defect necessitates proper alignment of the CCTV mechanism. Using the image as a guide, an operator must maneuver the recording device so that the image and respective laser beams are perpendicular to the longitudinal axis of the pipe. When an image of the defect and the two laser points is properly captured on the screen, a ratio can be established between the screen image pixilation and the known reference distance between the two lasers. With this corresponding value, the profiling software can then calculate the corresponding defect measurement.

It is imperative that the two lasers form a $90^{o}$ angle with the pipe to ensure there is no skewing of the laser lines. If the lasers are not exactly perpendicular to the defect surface, the corresponding defect measurement will be incorrect. Accounting for this likelihood of operator error, some video micrometer manufacturers offer an H-beam laser. As the name implies, the image produced by an H-beam laser resembles the letter H. The purpose of this particular shape is to verify on video if the laser is truly perpendicular to the defect – as a slight angle difference will cause an obvious visible distortion of the H-beam. Looking at Figures 2-9 and 2-10, one can compare the images of a two-point laser system with that of an H-beam laser system.

**Figure 2-8: Measurement of a Joint Gap with a Video-Micrometer – Using Two Laser Beams**
*(from C-Tec Presentation)*

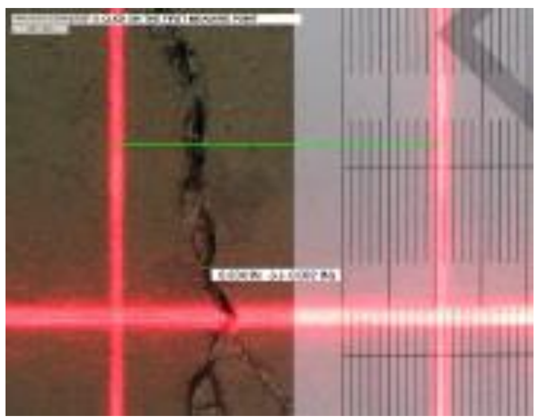


**Figure 2-9: Measurement of a Crack with a Video-Micrometer – Using an H-Laser Pattern**
*(from C-Tec Presentation)*

**Summary of State-of-the-Art**

Of the various inspection methods denoted within state DOT specifications for pipe culvert installation, their complexities range from simple tool-based methods to more complex and technologically advanced methods. The four most commonly used methods of pipe inspection among state DOT facilities (also in order of increasing complexity) are mandrel testing, CCTV recording, laser profiling, and video micrometer testing. Focusing mainly on laser profiling and CCTV-based methods of inspection, the research team does not discredit or discourage the use of increasingly advanced methods. Such focus is the result of DOTs placing an increasing demand on such technologies – relying on the validity of the output.

<u>Laser profiling equipment manufacturers</u>

The predominant manufacturing companies and software providers for laser profiling equipment in the state of Florida are listed immediately below:

*CUES, Inc.*

CUES, Inc. is a pipeline inspection equipment manufacturer based in Orlando, Florida. They provide inspection and rehabilitation services for stormwater and sanitary sewer systems by means of CCTV, laser, and sonar equipment (Cues, Inc. 2011). The CUES LaserProfiler, in combination with their CUES CCTV survey system, provides defect detection in pipes between 6 and 72 inches in diameter. The system functions by projecting a laser ring perpendicular to the longitudinal axis of the pipe, and ahead of the mounted video camera. CUES, Inc. provides software to analyze the data obtained from the inspection runs. The video and profiling information are compiled to generate a digital profile which is subsequently analyzed to find such effects as pipe ovality. Line graphs can also be produced to show the cross-sectional amplitude in relation to inspection traverse length.

*RedZone Robotics, Inc.*

RedZone Robotics, Inc. is based in Pittsburgh, Pennsylvania, and supplies pipeline inspection equipment for systems that are either newly installed or already in service. Their system employs a point cloud method of profile generation for pipes equal to and larger than 36 inches in diameter. This LIDAR (light detection and ranging) system functions at a rate of 90 measurements per second, and generates a three-dimensional representation of the pipeline (Kevin Lipkin, personal communication, September 29, 2011). Their software processes the data to obtain ovality reports in addition to alignment and bend geometry reports. Internal dimensions can also be evaluated to find possible corrosion sites. As of this writing RedZone had acquired CleanFlow Systems and, as a result, their smaller-diameter inspection systems use CleanFlow's laser ring method of detection.

*ARIES*

ARIES is based in Waukesha, Wisconsin, and they provide inspection and rehabilitation equipment for such underground systems as stormwater, sanitary sewer, gas and utility. The ARIES Coolvision profiling system uses a CCTV and laser ring projection system for pipes between 8 and 48 inches in diameter (ARIES 2011). The system also advertises a "fixed optical triangulation system" which they claim improves accuracy as compared to other systems with attachable laser probes and separate laser/camera components. Data analysis is performed by C-Tec which is based in Montreal, Canada, and the reports include pipe deflection and ovality.

*RapidView / IBAK*

RapidView supplies pipeline inspection and rehabilitation equipment from their distribution center in Rochester, Indiana. The actual product is manufactured by CleanFlow Systems and their base is in Auckland, New Zealand (Matt Sutton, personal communication, September 28, 2011). The profiling equipment employs a CCTV and laser ring projection system for pipes between 6 and 60 inches in diameter. Their Precision Vision software provides data analysis, and ovality and cross-sectional reports. Additional software packages provide for corrosion analysis and defect quantifying.

*Rausch Electronics USA, LLC (REUSA)*

REUSA is based in Chambersburg, PA, and they provide inspection, testing, and rehabilitation equipment for sanitary sewer, stormwater, and utility pipelines. The Rausch profiling system employs rotating laser technology mounted on a CCTV unit for pipes between 6 and 72 inches. Their software generates 2- and 3-dimensional graphs without the use of third party analysis.

# Chapter 3: Methodology

## Experimental Design

A synthesis of the industry was necessary to establish Florida's standing in the use of laser profiling equipment for the inspection of post-installation pipe culverts. Moreover, an evaluation of the current practice in pipe culvert inspection was deemed essential in gauging the overall industry culture. As illustrated in Figure 3-1, input from all levels of the pipe inspection industry were essential in establishing key project activities. Regulating agencies, existing certifying organizations, pipe manufacturers and inspection contractors alike would provide the data in which to frame the basis for the written exam, field test course and baseline.

(It should be noted that while the establishment of a baseline would seem to be a subcategory – and equivalent to an "answer key" – to the pipe field test course, the process of comparing data output from the competing equipment manufacturers is a widely expressed petition on the part of both regulating agencies and contractors.)

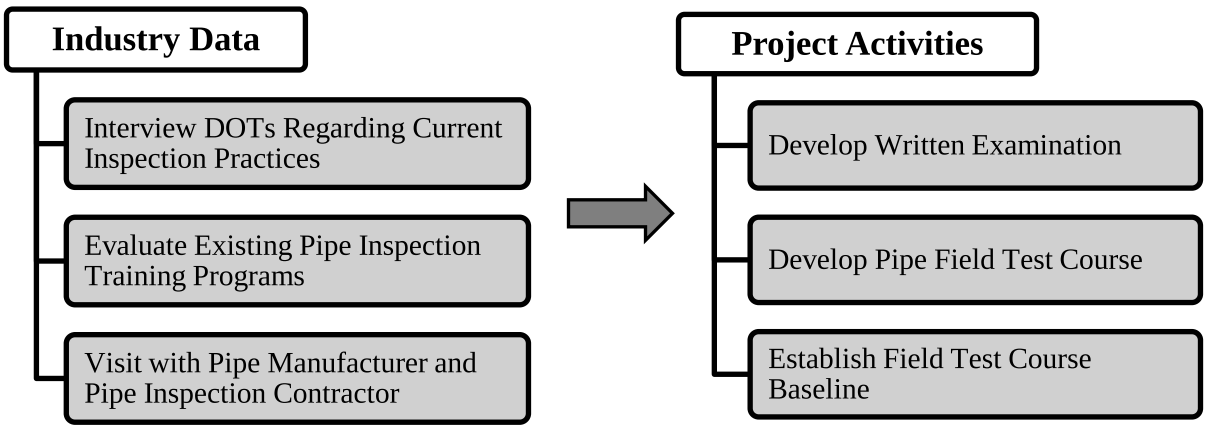



**Figure 3-1: Influence of Industry Data on Project Activities**

## Data Acquisition

In gathering industry data, the following tasks were conducted:

- Interviewing of DOTs to investigate the requirement of inspection, current inspection methods used, and explicit specification requirements.
- Evaluation of existing pipe inspection training programs to determine relevance to current FDOT post-installation inspection requirements, and to assess the possibility of a joint effort between the industries.
- Visitation of pipe manufacturers and inspection contractors to observe common practices and obtain valued input.

DOT interviews

Interviews were conducted over the telephone with DOT officials from State Construction Offices (or equivalent) and individual members of the AASHTO Subcommittee on Construction Management. The response rate of the interviews was 100% (52 of 52 agencies, including Puerto Rico and Washington, D.C.).

The primary interview consisted mostly of closed-ended survey questions that required Yes/No responses. Questions focused on whether the state required inspection of newly installed pipe culvert systems; if they required separate initial and/or final inspections; and the different types of methods they permitted and/or required for inspection.

Existing pipe inspection training programs

Per the recommendations of several participants in the 2011 PAG meeting, the research team decided to investigate the existing Pipeline Assessment & Certification Program (PACP) offered by the National Association of Sewer Service Companies (NASSCO). NASSCO offers a two-day course as a means to instruct those in the underground utility rehabilitation industry in properly documenting pipe defects.

The research team both hosted one of the two-day courses and participated in the certification program. This provided the opportunity to get feedback from other participants in the course, by the course instructor, and from personal opinion after having completed the course.

Manufacturer and contractor visits

In-state pipe manufacturers and pipe inspection contractors provided opportunities for personal site visits. Both manufacturers and contractors were privy to the research project and were encouraged to provide input regarding their personal experiences with the equipment; individual opinions on the specifications, and expressed views on current industry practice were also solicited. The manufacturers and contractors contributed great quantities of this kind of information.

## Procedures

The following tasks were conducted:

- Development of the written exam entailed generating questions based on FDOT specifications for the laying and inspection of post-installed pipe culverts and from supplementary resources on equipment calibration criteria.
- Construction of the field test course entailed selecting a site; designing the layout of the pipe runs; obtaining materials and equipment; setting up the course; designing and constructing a frame for shade; and introducing defects.
- Establishment of the baseline entailed bringing in volunteer contractors to run the field test course and provide output reports that would serve as a "key" for future inspections and as initial comparisons between data output results.

Written exam

Two separate 40-question exams were developed. The number of questions was arbitrarily set at 40 as a sufficient amount to demonstrate operator knowledge. The style of testing was multiple-choice and included topic-specific questions, sentence completion, and True/False statements. Topics were taken from the latest version (2013) of Section 430 of the FDOT Specifications, which pertains to Pipe Culvert installation and inspection. Additional questions were derived from the FDOT Calibration Criteria.

A bank of 80 questions was developed from these sources and from there two individual exams were created – both exams having an even distribution of material. The development of two exams (instead of just one) would permit the testing agent to either alternate between tests for each testing cycle, or to deter dishonest conduct. Further details of the procedures the test development are withheld from this report to preserve the integrity of the written exam.

**Exams and answer keys were intentionally withheld from inclusion in this report. Please direct any questions regarding the written exam to the Central Construction Office.**

Field test course

The research team met with key individuals from the FDOT State Materials Office (SMO) to establish an ideal location for the pipeline field test course. After discussing potential sites available to the research team, it was decided that setting up on the southernmost part of the SMO site was most convenient for accessibility. Figure 3-2 shows the designated area set aside by the SMO for the development of the field test course – located far enough away from existing testing facilities to prevent disturbance and still within access to the road for material delivery.


**Figure 3-2: SMO Site Map for Pipeline Field Test Course**

The type of pipes to be investigated had previously been determined at the 2011 PAG meeting. Per common use in Florida, the research team was to test corrugated metal (CMP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), and reinforced concrete pipe (RCP). All pipes have an inner diameter of 36 inches. This size was selected to permit entrance into the pipe for the repositioning of internal defects, and to allow testers and observers to investigate and verify defects, if necessary.

The ideal layout for the field test course (and the layout suggested by the research team and FDOT Project Manager) would have consisted of four runs of 200-foot pipe with each run consisting solely of one type of pipe material (e.g., one 200 foot run of CMP; one 200-foot run of PVC pipe; etc.). Due to size restrictions at the SMO site and monetary constraints for the acquisition of pipe material, the suggested layout was scaled down to four runs of approximately 40-foot pipe (with the exception of PVC which is manufactured in 22-foot segments, comprising a total run length of 44 feet), with each run consisting of one type of pipe material (e.g., one 40-foot run of CMP; one 40-foot run of PVC pipe; etc.). Table 3-1 shows the different types of pipe used and specific details of the material.

**Table 3-1: Pipe Material Listing and Suppliers**

| Inner Diameter | Material | Description | Installation | Segment Length | Supplier |
|---|---|---|---|---|---|
| 36 inch | Polyvinyl Chloride (PVC) | A2000 PVC Pipe | 2 segments; 1 o-ring gasket per length; bell and spigot ends | 22 feet | Contech Engineered Solutions |
| 36 inch | Metal-Corrugated (CMP) | Aluminized Steel Ultra-Flow (Spiral Rib, SRASP) | 2 segments; 1 band with adjustable metal collar | 20 feet | Contech Engineered Solutions |
| 36 inch | High-density Polyethylene (HDPE) | FDOT Class II HDPE | 2 segments; 1 o-ring gasket per length; bell and spigot ends | 20 feet | HD Supply and Advanced Drainage Systems, Inc. |
| 36 inch | Reinforced Concrete Pipe (RCP) | FDOT Approved RCP | 5 segments; 1 o-ring gasket per length; bell and spigot ends | 8 feet | Rinker Materials |

The ideal setup for the field test course (and the setup suggested by the research team and FDOT Project Manager) would also have consisted of burying the pipe underground to simulate actual field conditions. Due to site restrictions at the SMO site, the suggested setup was modified to rest aboveground. Aboveground installation, however, had its advantages. First, it allowed the research team to easily setup and relocate mobile pipe defects throughout the length of the pipe course. Second, it allowed for easy entry into the pipe when an inspection unit needed to be manually moved, or for other reasons. Third, it was less expensive, and fourth, it was much easier than expected to connect the different types of pipe, using the commercial dissimilar pipe couplers. However, the setup had the one major drawback that it was not totally realistic and was subject to temperature swings that would not be a factor when the pipe was buried.

Once delivered onsite, pipe segments were positioned into place with the use of a 4-ton capacity forklift. Individual pipe segments rested on 4-foot pieces of 4"x4" lumber, with chocks to keep them in place. Figures 3-3 to 3-9 illustrate the positioning of pipe material.

**Figure 3-3: Delivery of PVC and CMP**

**Figure 3-4: Lumber Supports and Chocks**

**Figure 3-5: Forklift Loading PVC Pipe**

**Figure 3-6: Forklift Moving PVC Pipe**

**Figure 3-7: Forklift Loading CMP**

**Figure 3-8: Positioned PVC and CMP**

**Figure 3-9: Positioned PVC, CMP, and HDPE Pipes**

Once positioned, the pipe segments were connected per pipe supplier assembly instructions. HDPE and PVC pipes required the installation of o-ring gaskets and proper greasing. Segments were then manually aligned and driven together using the 4-ton forklift. Metal pipe segments required installation of a rubber band and adjustable metal collar.

While care was taken in the overall assembly process, the research team permitted the inclusion of faulty connections including the following: large joint gaps, misaligned pipe segments; intrusion of debris; and damage to pipe material.

Prior to delivery of the RCP segments, suppliers introduced crack defects on four of the five segments by means of a three-edge bearing test device (Figure 3-10). The pipe segments were loaded until the development of hairline fractures was observed, and in some cases until failure occurred. This ensured a distribution of both "negligible" and "more substantial" cracks (Figures 3-11 and 3-12), illustrating situations that were both common-place and extreme for pipe culvert installation inspection.

**Figure 3-10: Introduction of Cracks on RCP by Means of Three-Edge Bearing Test Device**

**Figure 3-11: Hairline Crack on RCP**

**Figure 3-12: Larger Crack on RCP**

Visits to the SMO by those in the pipe inspection industry prompted changes to the layout of the field test course. By nature of the inspection process and by design of the inspection equipment, the first and final few feet of a pipe run are usually inspected visually. Because the inspection equipment must sit at the edge of a pipe, and because the inspection equipment increases in length the larger the pipe diameter, the recording/measuring device cannot record/measure the initial portion of the pipe above which the equipment sits (a distance spanning from the outermost edge of the pipe to the "front" of the recording/measuring device). As such, depending on the pipe diameter and the size of the inspection equipment, 2 to 4 feet of each end of a pipe run (totaling 4 to 8 feet per pipe segment) will not be inspected by the system. Bearing this in mind, the shorter a pipe run, the greater percentage of pipe that is not sufficiently inspected.

Because of this problem, the preliminary layout of four individual runs was changed a single 164-foot continuous run composed of varying pipe material. Relocation of the entire course, however, was now limited by the inability to move the installed concrete pipe run. Instead, the remaining three pipe runs (PVC, HDPE, and CMP) were relocated to either side of the RCP (Figure 3-13). In moving the pipe segments it was discovered that the terrain to the east of the RCP was at a lower elevation. Sandbags were used to raise individual pipe segments in order to provide a continuous line (Figure 3-14).

**Figure 3-13: Relocating Pipe Segments**

**Figure 3-14: Elevated Pipe Course Run**

The easternmost end of the pipe run was designated as the unofficial start of the course, and there was sufficient space for a contractor to drive their equipment vehicles up close to the course. Traversing westward from the unofficial start of the course, the pipe material order was as follows: HDPE, PVC, RCP, and CMP. Connections between the HDPE and PVC pipe were relatively flush – the bell and spigot ends for the dissimilar pipe fitted together well. Proper connections could not be established between the PVC (spigot end) and RCP (bell end) or RCP (spigot end) and CMP runs. For these two junctions, FDOT recommended the use of Mar Mac Dissimilar Pipe Couplers. The couplers are designed to prevent system infiltration and are composed of rubberized mastic laminated to a reinforcing mesh, incorporated with high-strength ratcheting steel straps to keep the device in place.

Figures 3-15 and 3-16 show the use of dissimilar pipe coupling material to seal the joints for the PVC-to-RCP and CMP-to-RCP runs. It should be noted that the use of these couplers for the specific dissimilar pipe junctions is not recommended by the coupling material supplier. Because of the extreme difference in outside pipe diameters, these couplers would probably not be used in proper pipe culvert installations.

**Figure 3-15: Dissimilar Pipe Coupler at PVC-to-RCP Junction**

**Figure 3-16: Dissimilar Pipe Coupler at RCP-to-CMP Junction**

The course was covered by tarp for two reasons: (1) to prevent the influence of thermal expansion on pipe defects, potentially influencing operator crack measurements; and (2) to conceal the location of pipe defects, potentially influencing operator defect locations.

Inability to relocate the RCP also hindered construction of the tarp structure; the continuous run was in close proximity to an existing buried drainage pipe. Support posts would have to be carefully located and in some cases could not be fully inserted into the ground for fear of damaging the existing drainage pipe. Figures 3-17 to 3-21 illustrate the approximated distances between the pipe run and the drainage pipe that were taken into consideration when designing the tarp cover.


**Figure 3-17: Distance to Existing Drainage Pipe (West End)**

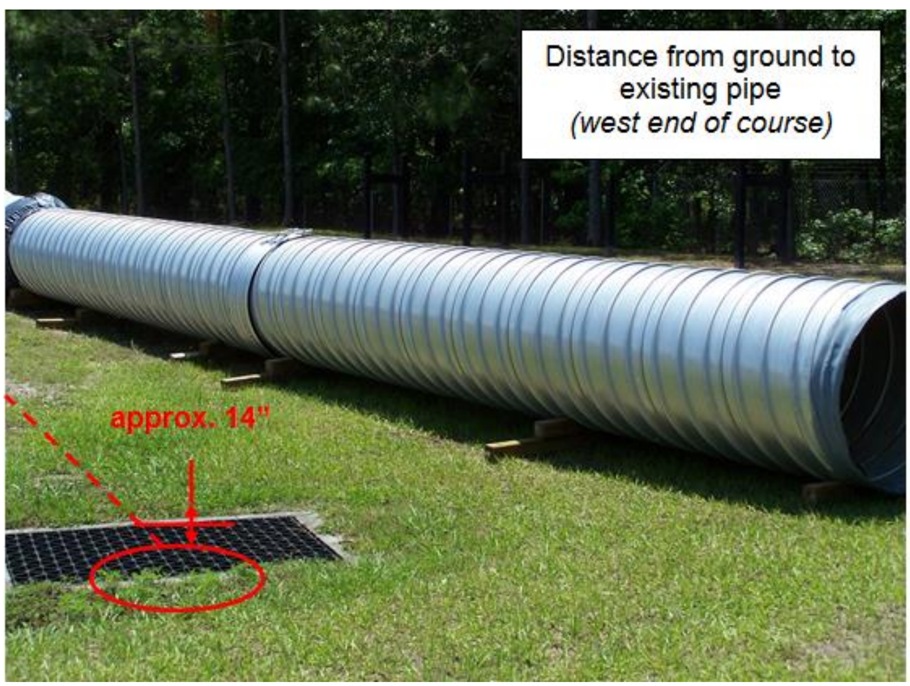



**Figure 3-18: Depth to Existing Drainage Pipe (West End)**

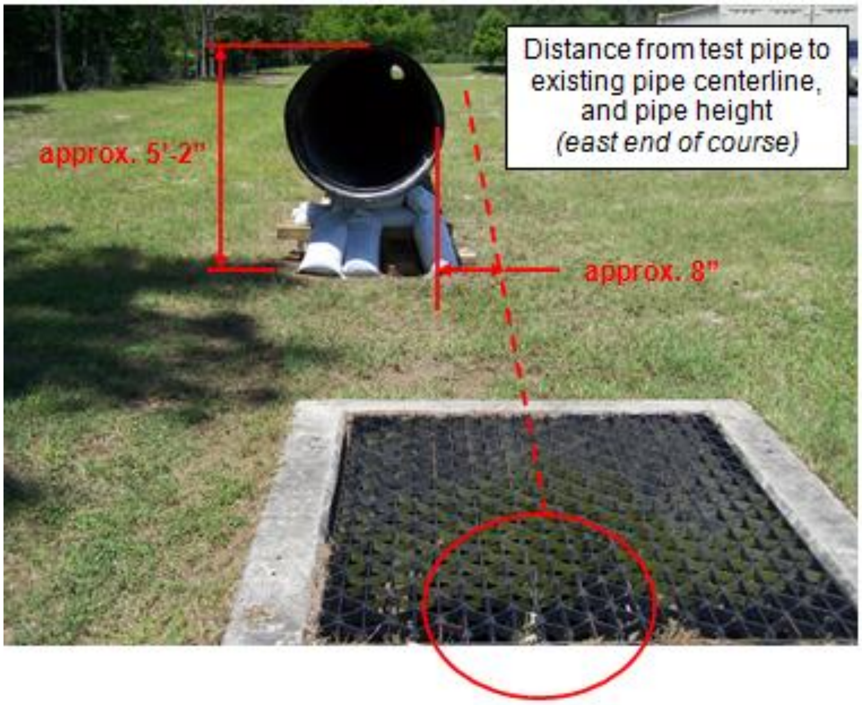



**Figure 3-19: Distance to Existing Drainage Pipe (East End)**

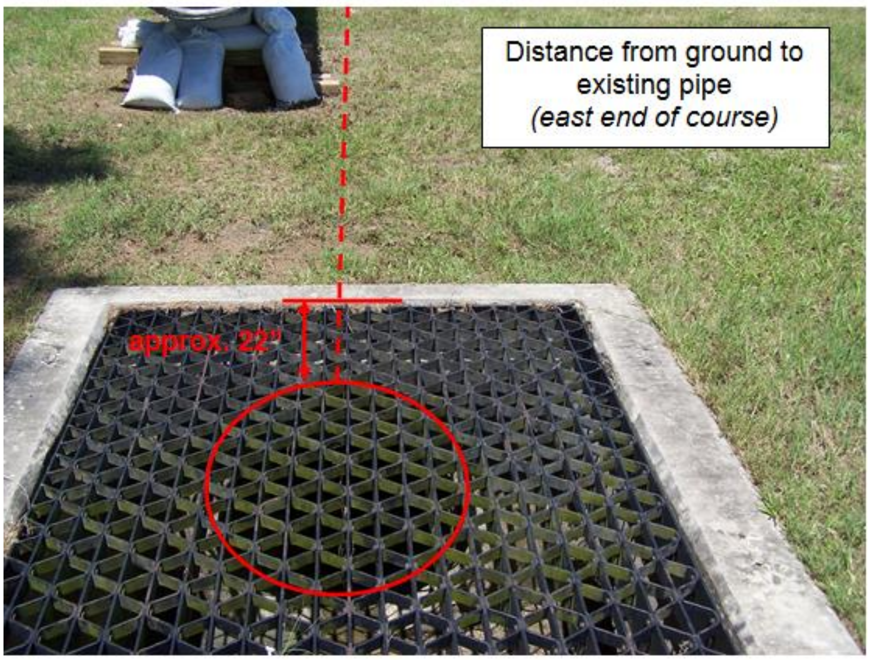



**Figure 3-20: Depth to Existing Drainage Pipe (East End)**


**Figure 3-21: Additional Distances to Existing Drainage Line**

Final dimensions for the tarp framing structure were approximately 6 feet wide by 170 feet long, with maximum and minimum heights of about 5 feet and 7 feet, respectively. Room was provided for easy access alongside the pipe.

The four corners of the framing structure were located; post locations were staked out; four corner and two mid-point posts were set up; and a line was strung up between the posts. The remainder of the post holes were dug, posts erected, and framing was set up.

Posts that were located directly above, or within close proximity to, the existing drainage pipe were not buried completely underground but instead were supported by cinder blocks filled with concrete. All other posts were buried at a maximum depth of 3 feet. Figures 3-22 to 3-31 illustrate the construction process of the framing structure.

**Figure 3-22: Corner Posts (East End)**

**Figure 3-23: Corner Posts (West End)**

**Figure 3-24: Stringing Line**

**Figure 3-25: Drilling Post Holes**

**Figure 3-26: Support Posts**

**Figure 3-27: Post Alignment**

**Figure 3-28: Framing Installation**

**Figure 3-29: Posts with Cinderblocks**

**Figure 3-30: Diagonal Cross-Bracing**

**Figure 3-31: Completed Structure with Tarp**

Besides the defects introduced during the assembly process, ovality issues were introduced once the entire course run and framing structure were completed. Deflection vices were created from 4x4 lumber pieces, threaded rods, galvanized hex nuts and washers as shown in Figure 3-32. The devices were tightened in order to produce observable defects within the interior of the pipe.

**Figure 3-32: Deflection Vice on PVC Pipe**

A pipe deflectometer was used to verify the presence and severity of pipe ovality as a result of the deflection vices. The deflectometer fits inside the pipe and is guided through with the use of attachable extension rods. The deflectometer can be adjusted to fit within different pipe sizes, and as such, spring-loaded mechanisms on the end arms of the device will rest flush with the inner walls of the pipe. As the deflectometer travels the length of the pipe, any variations in the inner diameter of the pipe (exclusively in either the X- or Y-direction) will be displayed by the presence of reflective dots on the faceplate, and the number of dots revealed correlates to the percentage of pipe ovality exceeding the 5% allowed per FDOT specifications – each reflective dot denotes a decrease in the pipe inner diameter by approximately ¼ inch. Figures 3-33 to 3-35 illustrate the process by which the device was used to confirm deflection in the pipe.

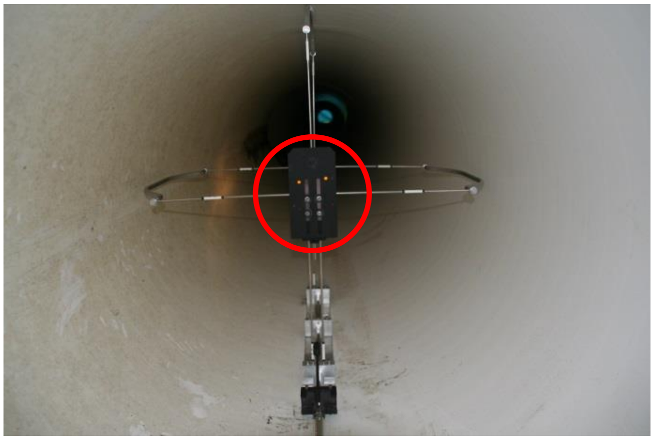


Figure 3-33: Location before the Deflection Vice

Comments:
To ensure the device was "snug" within the confines of the pipe, the end arms were extended to fit a larger sized pipe, thus explaining the presence of two orange reflective dots (circled) at the onset of the test.

These two dots were regarded as a "baseline" and the intent was to observe changes in the number of reflective dots.

Figure 3-34: Location at the Deflection Vice

Comments:
At the location of the deflection vice there is an observable increase in the number of reflective dots.

Two additional dots were seen for a total of four reflective dots (circled).

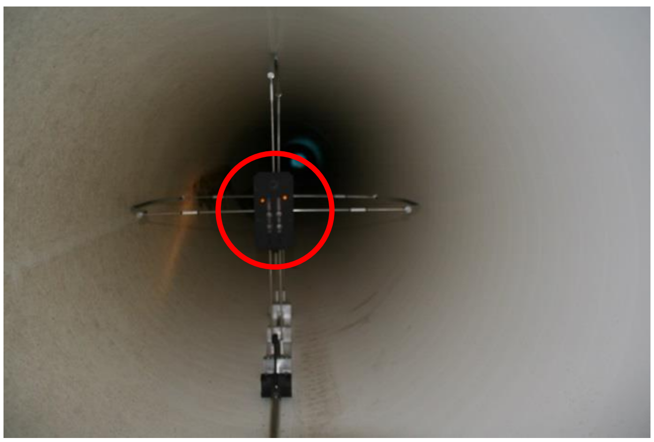


Figure 3-35: Location after the Deflection Vice

Comments:
Moving past the deflection vice there in an observable decrease in the number of reflective dots.

The additional reflective dots are no longer observed. The faceplate returned to its "baseline" of two dots (circled).

The net increase in reflective dots at the location of the deflection vice confirms a total deflection ranging between ¼ to ½ inch, with each dot at the site of the defect representing approximately ¼ inch change in inner pipe diameter.

Baseline establishment

Contractors invited to perform baseline tests had all previously done work for FDOT, and were thus familiar with their specification requirements. They were selected based on their equipment manufacturer – ensuring a representative sample of the different systems available in the state. The visiting contractors were instructed to inspect the pipe run exactly as they would any other job, provided input on the field test course and produced output data for comparisons and baseline establishment. Table 3-2 lists the contractors and their equipment manufacturer.

**Table 3-2: Pipe Inspection Contractor Visits and Equipment Use**

| Contractor | Equipment Manufacturer | Laser Type | Processing Software |
|---|---|---|---|
| American In-Line Inspection, Inc. | C-Tec (laser profiler)<br>Aries (cameras) | Ring-based | CleanFlow |
| B&D Enterprises | Rausch | Spiral-based | POSM |
| Granite Technologies | CUES | Ring-based | Granite XP |

# Chapter 4: Findings

## Presentation of Findings

Industry data

Looking at the responses from the DOTs, participants in inspection training programs, manufacturers and contractors, gives a glimpse into how the entire industry responds to inspection certification.

*DOT Interviews*

Upon immediate observation (Figures 4-1 to 4-4), several state agencies lacked explicit pipe installation inspection procedures in their specifications. These agencies reported that inspection of material and installation techniques were generally implied and thus did not require specific inclusion in the standards. In most cases, detailed inspection requirements were incorporated into other aspects of a state's provisions for highway construction (i.e., DOT construction checklists). Table 4-1 shows that 18 of 52 agencies mention inspection methods for pipe installation in their specifications. Of these, 16 have specifications on CCTV, eight on laser profiling and five on video micrometers.

**Table 4-1: Inspection Methods for Pipe Culvert Installations**

| | **States** | |
|---|---|---|
| **Inspection Method** | Number | Percentage |
| Mandrel Testing | 18 | 35% |
| CCTV | 16 | 31% |
| Laser Profiling | 8 | 16% |
| Video Micrometer | 5 | 10% |

States that did mention inspection techniques within their specifications trended towards technologies with the least complexity: mandrel testing being the most prevalent and simplest of methods; and video micrometers being the least prevalent and most complex. Newer, more technical inspection methods generally require more skill on the part of the operator. This increased demand on operator skill (and, subsequently, increased contracting costs) may discourage state agencies from implementing newer technologies.

Among the states that mentioned inspection techniques within their specifications, the various combinations of technologies are noted in Table 4-2. These combinations of technologies were categorized as those that included laser profiling or those that did not include laser profiling. State agencies that used laser profiling also used CCTV. Also, a greater number of states allowed both mandrel testing and laser profiling (6 states) than allowed both laser profiling and video micrometer (3 states). States that did not include laser profiling either explicitly used mandrel testing or CCTV, or a combination of those two. And in a few instances (2 states), all methods were permitted except for laser profiling.

| State | AL | AK | AZ | AR | CA | CO | DE | FL | ID | IL |
|---|---|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Y (by owner agency) | Y | Y - while installed / before they're covered | Y - for galvinizing and prequal. on culvert; soil & compaction | Y | Y | Y | N | N - procedures / Y - construction manual |
| Do your specifications require initial inspections? | Y *(laid in presence of engineer / only covered when approved) | Y - mat'l cert. | Y - initial and in progress, depending on pipe | Y | Y - culvert tested | Y - for mat'l suppliers | Y - and semifinal | Material prequalification | N | Y - in progress inspection |
| Do your specifications require final inspections? | Y *(laid in presence of engineer / only covered when approved) | Y | Y (inspect from excavation to backfill/subgrade) | N - not specifically required | Y | Y | Y - final is when maintenance and quality comes in | Y | N | Y - required / not as comprehensive |
| Inspection methods used: | | | | | | | | | | |
| Mandrel testing? | Y | N | N | N | Y | Y | Y | Y | N | N |
| Closed circuit television (or CCTV)? | N (unless in contract) | N | N | N | Y - circumstances | Certain areas | Y | Y | N | N - not on stormsewer (rarely) |
| Laser profiling? | N (unless in contract) | N | N | N | N | N | Y | Y | N | N |
| Video micrometer (for crack measurement)? | N | N | N | N | N | N | N | Y | N | N |
| *Other not mentioned?* | | inspect grade and profile (standard survey) | Standard survey and auto leveling at inverts and as needed | Visual inspection | | | Mirror testing (full light at one end) | | visual installation for culvert | Transit, level, total station of inverts and catch basin or manholes (std. survey) |

**Figure 4-1: Preliminary Interview – Requirement of Inspection and Methods (part 1)**

| State | IA | KS | LA | ME | MD | MA | MI | MS | MO | NE |
|---|---|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Y | Y - plastic - mandrel - changing to laser all plastic | Y* - not explicitly written in specs, but it is policy | Y | Y | Y | Y | Y - post installation | Y |
| Do your specifications require initial inspections? | | Y - while installing | Y | ? - test random samples | Y - prior material inspection | Y - precast at the plant, and as it goes in the ground | Y - density | Y | Y - inspection of pipe at plant | Y |
| Do your specifications require final inspections? | | N - but area-dependent | N - just making sure clean | Y - someone there the whole time | | Y - punchlist w/final walkthrough | Y | Some - certain sizes (ie. smaller = video / bigger = walk through) | Y | Y |
| Inspection methods used: | | | | | | | | | | |
| Mandrel testing? | N | N | Y | Y | N | Y | Y | Y | Y - with video | N |
| Closed circuit television (or CCTV)? | N | N - not required, but if needed | N - considering | N | N (for conduit or sewer) | Y - sometimes when needed, but not routine | Y (not on all inspections) - included in some contracts | Y | Y | Y |
| Laser profiling? | N | N | N - considering | N | N | Y - sometimes when needed, but not routine | N | N | Y - in specs, but not doing much with it yet | Y |
| Video micrometer (for crack measurement)? | N | N | N - considering | N | | N | N | Y | N | N |
| *Other not mentioned?* | - | - | | GPS or laser | | | | | | Visual inspection |

**Figure 4-2: Preliminary Interview – Requirement of Inspection and Methods (part 2)**

| State | NV | NH | NM | NY | NC | ND | OH | OK | SC | SD |
|---|---|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | N - (method spec versus performance method spec.) | Y | Y | Y | Y | Y - during installation | | N | Y | Y |
| Do your specifications require initial inspections? | N - not per specifications | N* - continuous inspection (not in specs, but part of project closeout) | Y | Inspection during installation | Current policy: inspect first portion | N | | Inspection during installation | Y | Y |
| Do your specifications require final inspections? | Y | N* - continuous inspection (not in specs, but part of project closeout) | Y | N/A | (see above) | N | | N | N/A | Y - inspections are done during installation and on completion |
| Inspection methods used: | | | | | | | | | | |
| Mandrel testing? | N | Y | N | Y | allowed | | Y | N | Y | Y |
| Closed circuit television (or CCTV)? | N | Y | Y - if not normal | Y | Y | | | Y | Y | Y |
| Laser profiling? | N | N | N | Some, no specifications, but contractors are beginning to adopt newer technologies | Y | | | N | Y | N |
| Video micrometer (for crack measurement)? | N | N | N | Y | Y | | | N | N | N |
| *Other not mentioned?* | | | | Magnetic testing for metal pipe coatings | | | | | | |

**Figure 4-3: Preliminary Interview – Requirement of Inspection and Methods (part 3)**

| State | TN | TX | UT | WA | WV | WI | WY |
|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Only during the installation | Y | Y | N/A | Y | Y |
| Do your specifications require initial inspections? | Y | N | Y | Inspection during installation | N/A | Y (implied) | Inspection during installation |
| Do your specifications require final inspections? | Y - pipes inspected during installation and once it is complete | N - pipe visually inspected during installation | | - | N/A | Y | N/A |
| Inspection methods used: | | | | | | | |
| Mandrel testing? | Y | N | Y | No done on culverts | N/A | Y | Allowed, typically only on sewers |
| Closed circuit television (or CCTV)? | Y | N | Y | N | N/A | N | N |
| Laser profiling? | Y | N | | N | N/A | N | N |
| Video micrometer (for crack measurement)? | Y | N | | N | N/A | N | N |
| *Other not mentioned?* | Mandrel testing is the base method used, anything more advanced is allowed for the inspections | | Visual inspection | | | Installation inspection (bedding placement, back filling) | |

**Figure 4-4: Preliminary Interview – Requirement of Inspection and Methods (part 4)**

**Table 4-2: Combinations of Technologies with Respect to the Use of Laser Profiling**

| Category | Technology Combination | Number of States |
|---|---|---|
| Combinations Including Laser Profiling | Mandrel, CCTV, Laser Profiling | 4 |
| | Mandrel, CCTV, Laser Profiling, Video Micrometer | 2 |
| | CCTV, Laser Profiling | 1 |
| | CCTV, Laser Profiling, Video Micrometer | 1 |
| Combinations Omitting Laser Profiling | Mandrel | 6 |
| | CCTV | 2 |
| | Mandrel, CCTV | 4 |
| | Mandrel, CCTV, Video Micrometer | 2 |

Advanced inspection methods also demand more from the highway construction owner. The need to research, test, and review techniques makes state agency endorsement more problematic. As improvements develop over time, there is the added strain of staying current with software and equipment updates. However, even with a small number of laser profiling manufacturers nationwide, there is significant overlap in software use between these companies. This familiarity in system software allows for the collaboration between states and can ease acceptance in highway construction agencies. And with an increase in popularity, more agencies will include laser profiling in their specifications, improving the technology, and decreasing costs in the subcontracting of these services.

*Existing Pipe Inspection Training Programs*

The curriculum of the NASSCO Pipeline Assessment & Certification Program is structured around the PACP Reference Manual, familiarizing students with the inspection form, illustrating the limits of the inspection equipment, and educating them on how to accurately locate and identify both structural and operational pipe defects. Emphasis was placed on understanding and completing the inspection form as this is the basis by which a project engineer assesses an existing pipeline. Table 4-3 highlights some major details from the NASSCO PACP training course.

**Table 4-3: Review of NASSCO PACP Training Course**

| | |
|---|---|
| **Dates:** | Friday, March 2, 2012 through Sunday, March 04, 2012 |
| **Location:** | Indianapolis, Indiana |
| **Instructor:** | Marilyn Shepard |
| **Pros**<br>• Course provides a broad-level overview of inspection procedures<br>• Content on defect identification is descriptive<br>• Inspection exercise (wherein the class views a sample video and documents pipe defects as if the footage were real-time) was extremely effective in demonstrating the proper documentation process<br>• Group atmosphere (specifically included the research team, subcontractors, engineers, and inspection operators) facilitated an exchange of ideas | |

**Table 4-3: Review of NASSCO PACP Training Course (cont.)**

| **Cons** |
|---|
| • Training program does not instruct operators in the procedures particular to their state's DOT pipe installation specifications<br>• Focus is on sanitary sewer systems either currently or no longer in service. Although similar in nature to stormwater systems, the illustrated defects are highly unlikely for newly installed stormwater pipe systems<br>• Literature material is geared towards those with field experience. Familiarity with the vocabulary is helpful, and insight to the installation and inspection processes is essential<br>• CCTV is the main inspection method discussed. Little mention of the use of laser profilers |

*Visits with Pipe Manufacturer and Pipe Inspection Contractor*

Pipe manufacturers and inspection contractors alike have expressed support for the certification of post-installation pipe inspectors. Both share interest in the certification process: pipe manufacturers with providing satisfactory pipe; pipe inspectors in providing a valued service to contractors and, ultimately, owners.

Pipe manufacturers have expressed repeated concern with the claims made by equipment manufacturers regarding the accuracy of their measurements: it appears current inspection equipment is not equipped to measure the size of crack required by the specifications.

There also exists scrutiny with the type of laser used by equipment manufacturers and the ability to detect defects. It has been questioned whether spiral laser-based equipment will detect the same defects at one speed of travel as with a slightly different speed in the same pipeline.

These concerns are mirrored by pipe inspection contractors. They have seen inconsistencies between contractors regarding pipeline inspections. A "failed" pipeline may be re-tested with a competing brand of equipment and subsequently pass.

Project activities

*Written Exam*

FDOT shall oversee the certification process. As of the conclusion of this research project the exam has not been administered. As such, there are no findings to report regarding the success of the test or its credibility among those in the post-installation pipe inspection industry.

*Field Test Course*

As of the conclusion of this research project, the field test course has only been employed for the production of a baseline and has not been used as part of any certification process.

As such, there are no findings to report regarding the success of the test or its credibility among those in the post-installation pipe inspection industry.

*Baseline*

Pipe inspection contractors performed test runs on the field test course for three main reasons: (1) to investigate the laser profiling equipment used by the varying manufacturers; (2) to assess the overall course setup (and recommend any changes); and (3) to provide output data reports for direct comparison.

Looking at the output reports and video recordings for the three inspection contractors there are notable differences and similarities. Videos for all three contractors were fairly similar. Initial title screens presented project-specific information (Figures 4-5 to 4-7), and all presented footage of the instrument traveling down the pipe with a display of the current distance.


**Figure 4-5: American In-Line Title Screen**


**Figure 4-6: B&D Enterprises Title Screen**


**Figure 4-7: Granite Technologies Title Screen**

Contractor output begins to vary with the data reports. Although FDOT's specifications specifically identify what information is necessary, the specific reports provided vary, the style of formatting differs between reports, and the information presented differs. Tables 4-4 and 4-5 provide a comparison of the types of reports and graphs, respectively, provided by the three contractors. Equivalent (or comparable) reports/graphs are listed next to each other for ease of contrast.

**Table 4-4: Comparison of Profiler Data Output Reports**

| American In-Line (CleanFlow Software) | B&D Enterprises (POSM Software) | Granite (Granite XP Software) |
|---|---|---|
| | **Project Information Page**<br>Information relating to pipe length, material, shape, diam./width, cleaning conditions, grade, etc. | |
| **Inspection Report** | **Pipe Layout Report** | **Main Insp. w/Pipe-Run Graph** |
| Graphical representation of pipe with “issues” at corresponding locations (including project information) | Graphical representation of pipe with “issues” at corresponding locations | Graphical representation of pipe with “issues” at corresponding locations (including project information) |
| Position, codes, and observations, including:<br>- material changes noted<br>- crack type, position, and if within 8 inches (Y/N) | Position, codes, remarks, and color coding with respect to severity | Position, remarks, and category |
| | **Fault Observation Report**<br>Detailed listing of all observed issues (includes joint measurements, ovality issues, and defects)<br>Distance, fault observation, time, picture, and information including:<br>- defects (type, position, severity, size, structural weight)<br>- joints (severity, size)<br>- general observations | |
| | **NASSCO CCTV Defect Code Information**<br>Detailed chart with video references to pipe defects<br>Distance, video reference, code, values, and locations | |

**Table 4-5: Comparison of Profiler Data Output Graphs**

| American In-Line (CleanFlow Software) | B&D Enterprises (POSM Software) | Granite (Granite XP Software) |
|---|---|---|
| **Flat Summary Report**<br>Shows a “flat” representation of the ovality of the pipe’s internal diameter<br>Pipe distance to clock-position ovality (color coded with respect to severity) | | **Flat Summary Report**<br>Shows a “flat” representation of the ovality of the pipe’s internal diameter<br>Pipe distance to clock-position ovality (color coded with respect to severity) |
| **Ovality Summary Report**<br>Shows percent deflection per ASTM F 1216<br>Pipe distance to percent deflection (percentage)<br>Upper and lower limits are set and graph shows if/where the bounds are exceeded | **Horizontal Deviation**<br>Shows percent deviation of internal horizontal diameter<br>Pipe distance to percentage above/below deviation<br>Upper and lower limits are set and graph shows if/where the bounds are exceeded<br>**Vertical Deviation**<br>Shows percent deviation of internal vertical diameter<br>Pipe distance to percentage above/below deviation<br>Upper and lower limits are set and graph shows if/where the bounds are exceeded | **Ovality Summary Report**<br>Shows percent deflection per ASTM F 1216<br>Pipe distance to percent deflection (percentage)<br>Upper and lower limits are set and graph shows if/where the bounds are exceeded |
| **XY Diameter Summary**<br>Shows percent deviation of internal horizontal and vertical diameters<br>Pipe distance to percentage above/below (color coded with respect to direction) | **Average Pipe Diameter**<br>Shows average internal diameter of pipe<br>Pipe distance to pipe size (inches) | |
| | **Pipe Profile**<br>Shows profile grade along the pipe length<br>Pipe distance to height (feet) | |

Among the three contractors, a general inspection layout report is provided illustrating the defects and observations relative to pipe length location (identified as the Inspection Report for American In-Line, the Pipe Layout Report for B&D Enterprises, and the Main Inspection with Pipe-Run Graph for Granite). While B&D Enterprises provides a separate report (the Project Information Page) stating all general project details and descriptions, American In-Line and Granite include these specifics within their layout reports. However, B&D’s Fault Output Report provides an additional – and more graphic – catalog of all recorded issues and observations, and their NASSCO CCTV Defect Code Information page provides a descriptive catalog of issues that more closely corresponds with the wastewater industry's standards for defect classification.

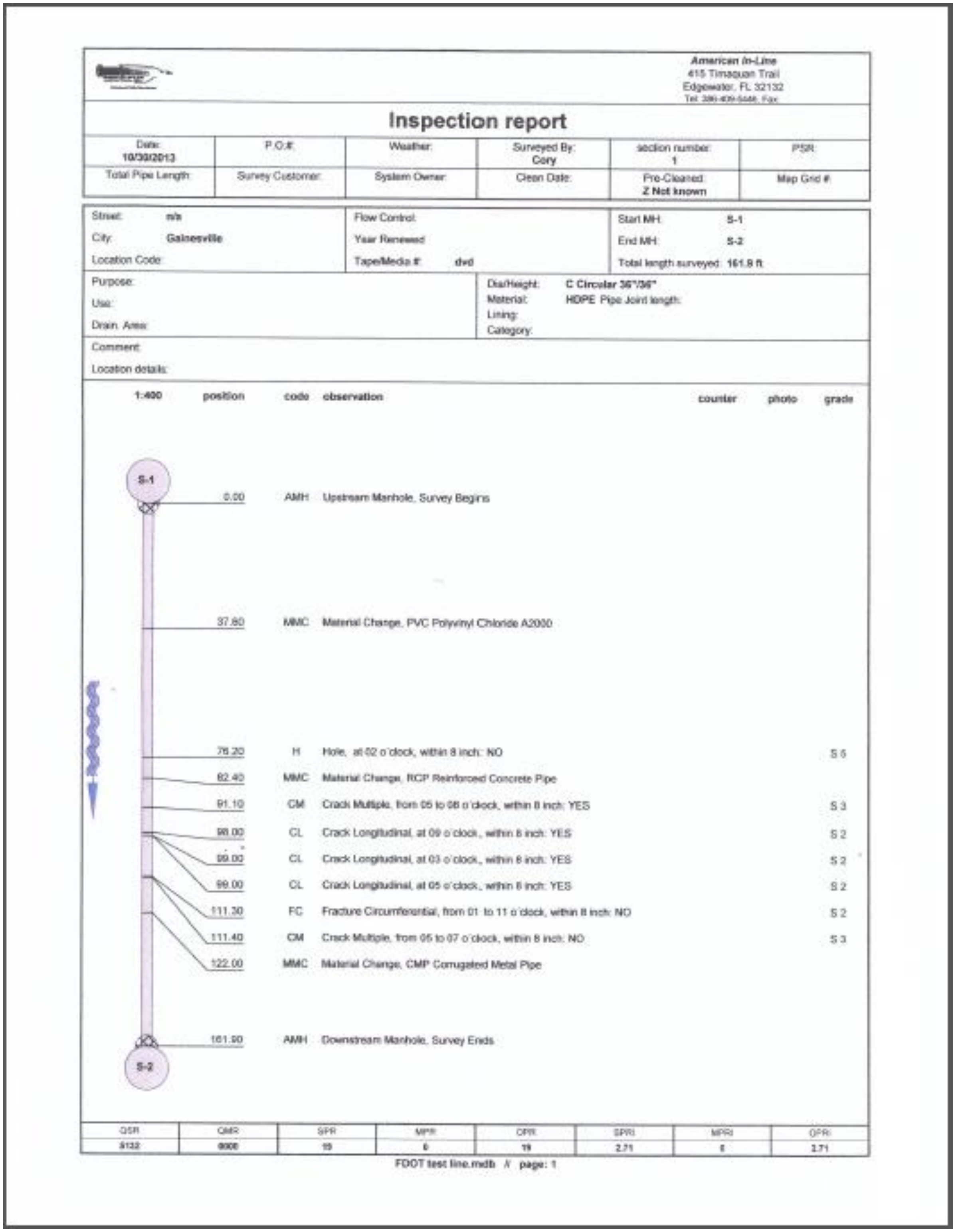
Comparing data output graphs is a more challenging task. While American In-Line (with CleanFlow software) and Granite (with Granite XP software) both produce similar output, they are not exact equivalents with their B&D Enterprise-counterparts (using POSM software). For example, the Ovality Summary Reports (for both American In-Line and Granite) can be grouped into the same category as B&D's Average Pipe Diameter; however, the data presented cannot easily be translated between graphs. The same goes for the XY Diameter Summary and Horizontal/Vertical Deviations. Comparing data between the contractors will require an interpretation or conversion between values.

This conversion issue also poses a problem when trying to compare data with regards to the type of laser being used. B&D uses Rausch technology, which corresponds with a spiral-type laser. American In-Line and Granite both use ring-type lasers. Because the data graphs for the two types of laser systems cannot be directly correlated, attempting to evaluate how the systems themselves compare is even more challenging.

Although all three contractors were asked to prepare and submit the graphs that would be required of them for a standard FDOT job, they all provided different types and varying quantities of data. American In-Line submitted a Flat Summary Report, Ovality Summary Report and XY Diameter Summary. B&D Enterprises submitted the Average Pipe Diameter, Horizontal and Vertical Deviations, and a Pipe Profile. Granite submitted a Flat Summary Report, and Ovality Summary Report. An industry-wide standardization of the graphs required and the data presented can easily remedy this situation.

Figures 4-8, 4-9, 4-10 show the general inspection reports with pipe layout images for each of the three contractors. All of these reports show a lengthwise representation of the pipeline with all noted defects delineated at their appropriate locations. It should be noted that not all of the output reports show values for joint gaps, crack lengths, or crack thicknesses. American In-Line reports, for example, shows "Yes/No" comments regarding if the observations were within specific dimensions. Granite reports show ratings for both joint separations and cracks. Without prior knowledge of either the pre-established minimums or rating systems, unfamiliar analysts may misinterpret readings. And if measurement verification is deemed necessary, the time-consuming process of cross-referencing output reports with video recordings may be a daunting task.

Of the three contractors, B&D Enterprise's reports provide values for joint gaps and cracks. Their Pipe Layout Report and Fault Observation Report display dimensions that are readily visible and discernable to the analyst.



American In-Line
415 Timaquan Trail
Edgewater, FL 32132
Tel: 386-409-5448, Fax:

## Inspection report

| Date: 10/30/2013 | P.O.#: | Weather: | Surveyed By: Cory | section number: 1 | PSR: |
|---|---|---|---|---|---|
| Total Pipe Length: | Survey Customer: | System Owner: | Clean Date: | Pre-Cleaned: Z Not known | Map Grid #: |

Street: n/a
City: Gainesville
Location Code:
Flow Control:
Year Renewed:
Tape/Media #: dvd
Start MH: S-1
End MH: S-2
Total length surveyed: 161.8 ft
Purpose:
Use:
Drain. Area:
Dia/Height: C Circular 36"/36"
Material: HDPE Pipe Joint length:
Lining:
Category:
Comment:
Location details:

| 1:400 | position | code | observation | counter | photo | grade |
|---|---|---|---|---|---|---|
| S-1 | 0.00 | AMH | Upstream Manhole, Survey Begins | | | |
| | 37.80 | MMC | Material Change, PVC Polyvinyl Chloride A2000 | | | |
| | 76.20 | H | Hole, at 02 o'clock, within 8 inch: NO | | | S 5 |
| | 82.40 | MMC | Material Change, RCP Reinforced Concrete Pipe | | | |
| | 91.10 | CM | Crack Multiple, from 05 to 08 o'clock, within 8 inch: YES | | | S 3 |
| | 98.00 | CL | Crack Longitudinal, at 09 o'clock., within 8 inch: YES | | | S 2 |
| | 99.00 | CL | Crack Longitudinal, at 03 o'clock., within 8 inch: YES | | | S 2 |
| | 99.00 | CL | Crack Longitudinal, at 05 o'clock., within 8 inch: YES | | | S 2 |
| | 111.30 | FC | Fracture Circumferential, from 01 to 11 o'clock, within 8 inch: NO | | | S 2 |
| | 111.40 | CM | Crack Multiple, from 05 to 07 o'clock, within 8 inch: NO | | | S 3 |
| | 122.00 | MMC | Material Change, CMP Corrugated Metal Pipe | | | |
| S-2 | 161.90 | AMH | Downstream Manhole, Survey Ends | | | |

| QSR | QMR | SPR | MPR | OPR | SPRI | MPRI | OPRI |
|---|---|---|---|---|---|---|---|
| 5132 | 0000 | 19 | 0 | 19 | 2.71 | 0 | 2.71 |

FDOT test line.mdb / page: 1

**Figure 4-8: Inspection Report for American In-Line**

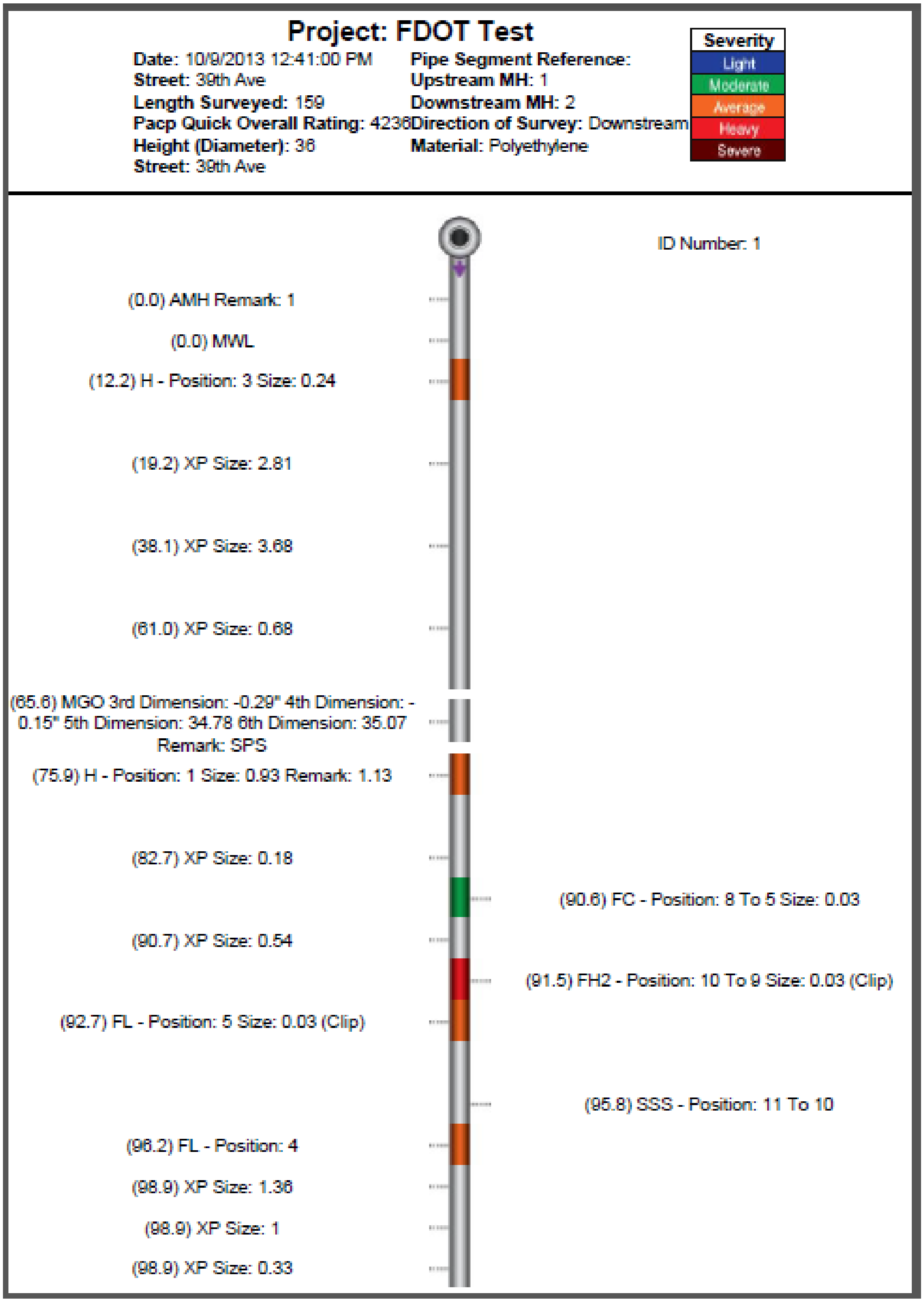



**Figure 4-9: Inspection Report for B&D Enterprises**

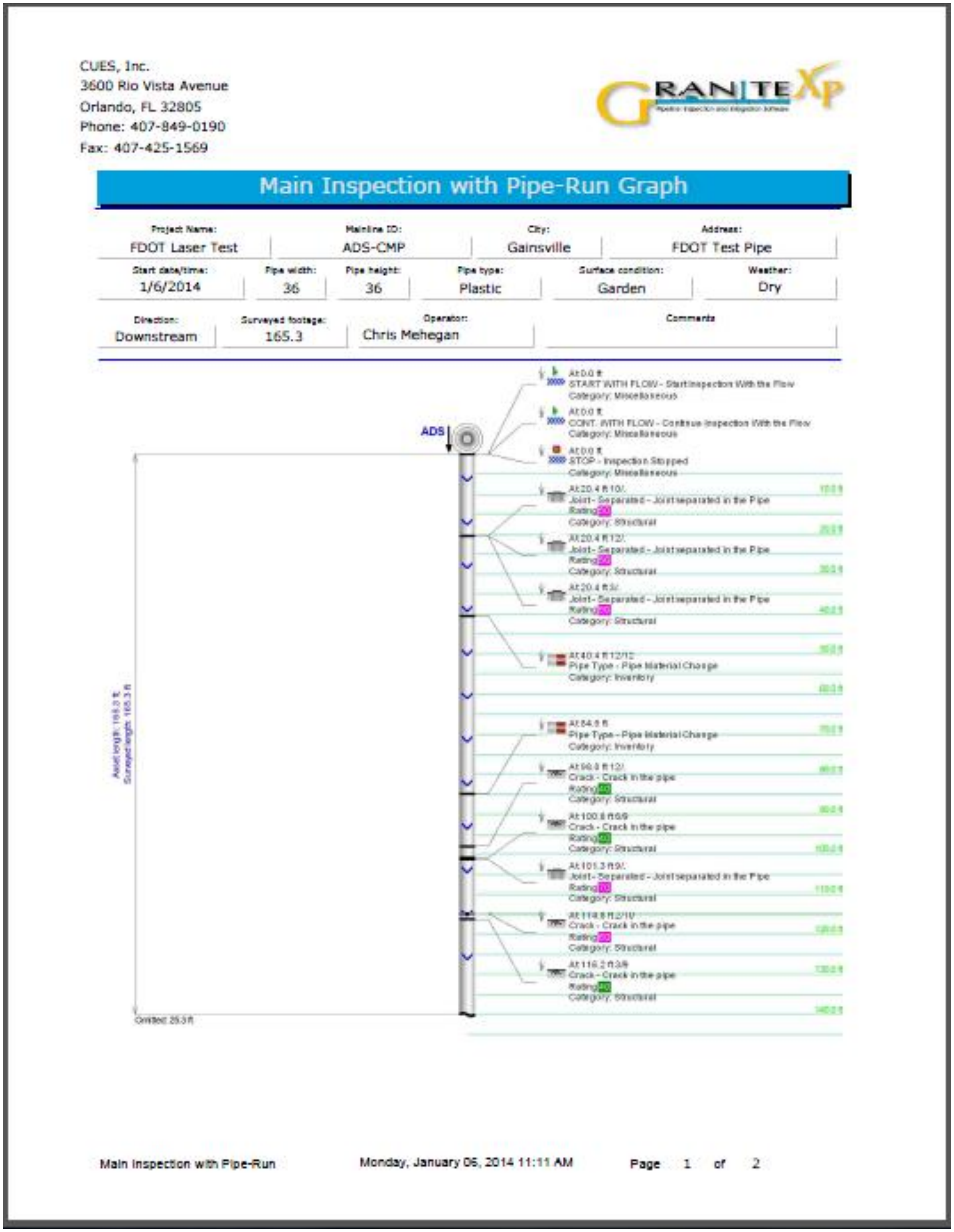
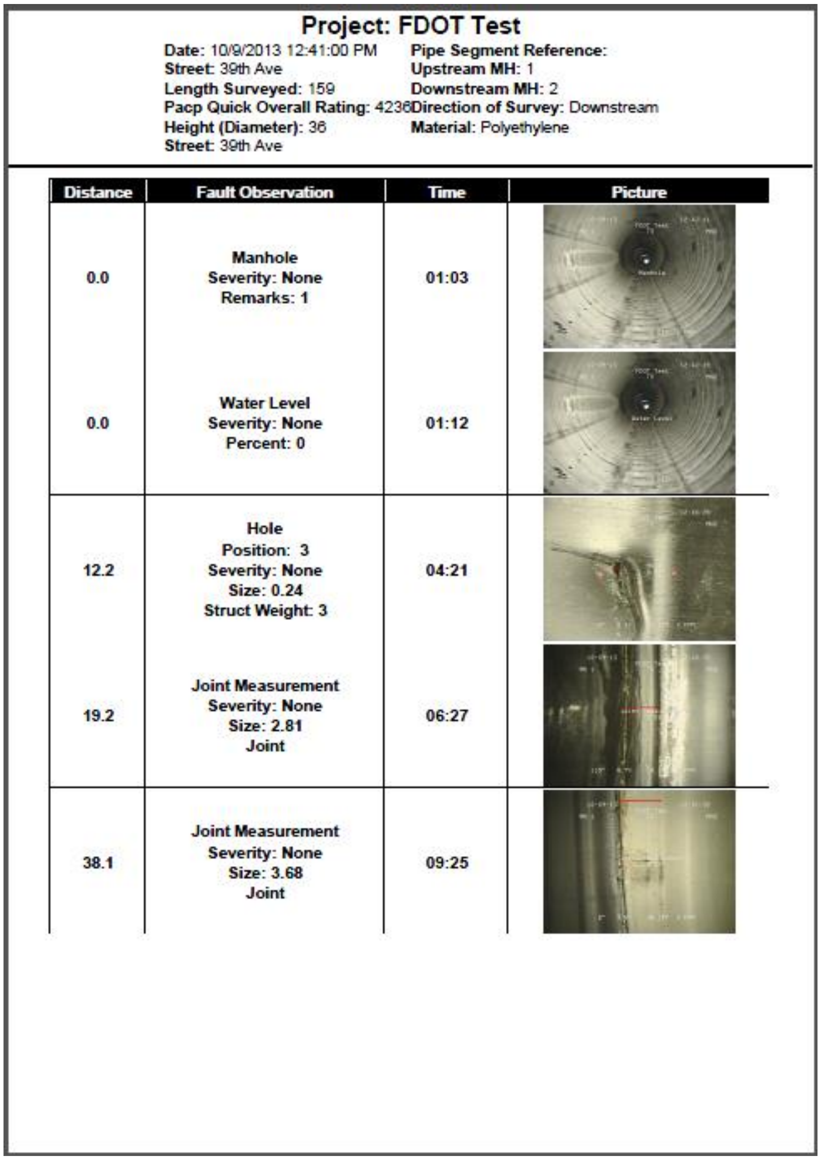



**Figure 4-10: Inspection Report for Granite**

Comparing the inspection report with B&D Enterprises' Fault Observation Report (Figure 4-11), the presence of individual defect photos and specific observation information provides the user with information for all occurrences that were previously listed in the inspection report. While more illustrative, for longer pipe runs, sorting through a multitude of pages and images may become cumbersome. Rausch (and POSM) provide their reports in a format more in line with NASSCO's detailed defect coding.



**Project: FDOT Test**

Date: 10/9/2013 12:41:00 PM
Street: 39th Ave
Length Surveyed: 159
Pacp Quick Overall Rating: 4236
Height (Diameter): 36
Street: 39th Ave

Pipe Segment Reference:
Upstream MH: 1
Downstream MH: 2
Direction of Survey: Downstream
Material: Polyethylene

| Distance | Fault Observation | Time | Picture |
|---|---|---|---|
| 0.0 | Manhole<br>Severity: None<br>Remarks: 1 | 01:03 | |
| 0.0 | Water Level<br>Severity: None<br>Percent: 0 | 01:12 | |
| 12.2 | Hole<br>Position: 3<br>Severity: None<br>Size: 0.24<br>Struct Weight: 3 | 04:21 | |
| 19.2 | Joint Measurement<br>Severity: None<br>Size: 2.81<br>Joint | 06:27 | |
| 38.1 | Joint Measurement<br>Severity: None<br>Size: 3.68<br>Joint | 09:25 | |

**Figure 4-11: B&D Enterprise Fault Observation Report**

Comparing the content between reports was also revealing. Figure 4-12 shows ovality reports for both American In-Line and Granite Technologies and although the two graphs appear similar (and both use ring-based laser profiling systems) there are a few differences between the graphs. Both graphs appear to show the greatest variance in ovality for the last segment of pipe measured (HDPE). However, there is a notable difference in the magnitude of the values. American In-Line shows the data, on average, falling below the 5% line; however, Granite shows the data, on average, surpassing the 5% line. Since the two graphs present identical scales for the y-axis, there is a possibility that other settings have influenced the output. Profiler settings or software analysis information could have potentially skewed the results, but without knowing what values were established prior to data processing for the two graphs, we cannot properly assess the reason for the disparity.  Attempts to confirm the actual deflection by means of the SMO's pipe deflectometer device were unsuccessful.  On two separate occasions, the deflectometer registered pipe deflections exceeding 10%, but when confirmed profiler measurements were taken, the readings came in at under 5%.  Faulty design of the deflectometer was suggested but unconfirmed.

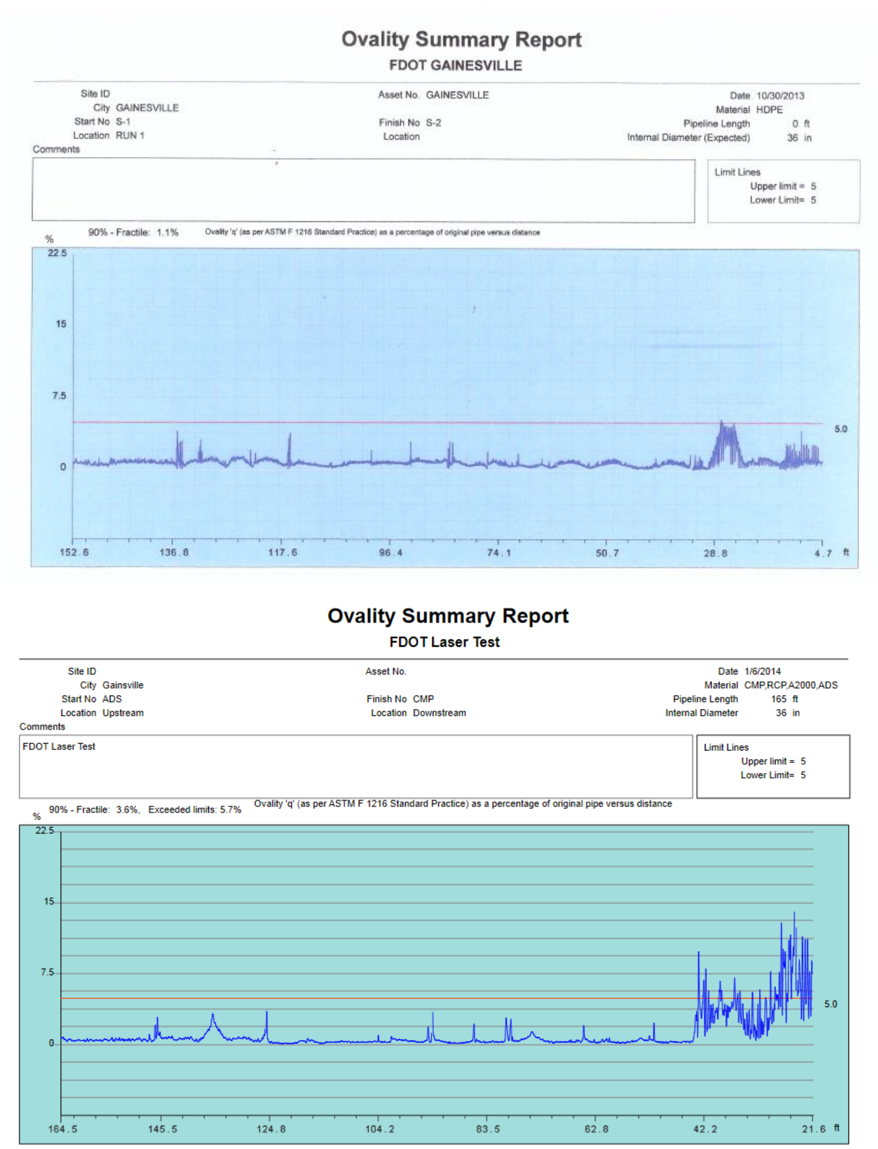



**Figure 4-12: Comparison of Ovality Reports**
**between American In-Line** *(top)* **and Granite Technologies** *(bottom)*

Attempting to compare horizontal and vertical deviations Figure 4-13 to the ovality reports in Figure 4-12 illustrates the need for standardization between laser-based system output graphs.  While the deviation values are not quite equivalent to pipe ovality, general trends follow that the HDPE pipe for both reports (on the right for the ovality graphs and on the left for the deviations) show extreme fluctuations.

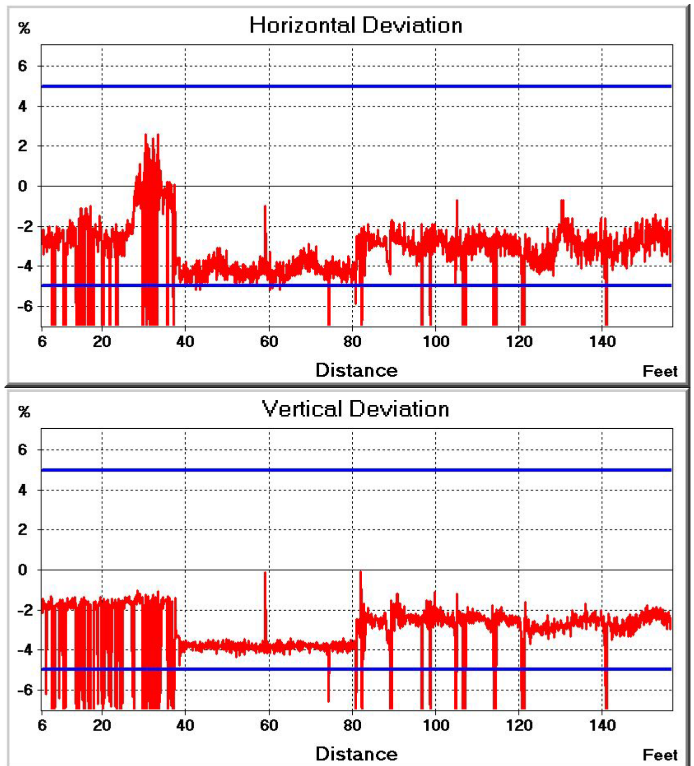



**Figure 4-13: Observation of Horizontal and Vertical Deviations by B&D Enterprises**

While the final baseline could not be established, the visiting contractors provided immediate feedback on the field test course and provided preliminary reports for the research team to familiarize themselves with the output data and compare measurements (if possible).

Once the reports (and systems) are properly compared to one another, a proper baseline can be attained. Key factors include the determination of a baseline report: if from one contractor (regardless of system) the selection process would have to be justified (i.e., if in state, why selected; if from the DOT, and not a contracting agent; or if from out of state); if from two contractors (from each laser-type); or if from multiple contractors (from each system manufacturer) a compiled output report from multiple contractors, systems, and laser-types, in which case the data selection process would have to be justified (i.e., if different values are presented, is the average taken or the mode).

# Chapter 5: Summary

## Commentary on Findings

Looking at the data from the DOT interviews regarding use of inspection technology for pipeline inspection, for states with specific mention of inspection techniques, use appears to be greater for methods having the least technological complexity:

- mandrel testing was the most prevalent
- video micrometer testing was the least utilized

It can be argued that the newer, more technical methods require the most skill from the operators and are thus less desirable due to the need for more training. Also, the complexity of more technical methods may not be fully understood by the industry:

- constant advancements lead to constant revisions in software and equipment, potentially precluding state DOTs from implementing these newer methods
- the need to research, test and review inspection techniques may require more time than suitable for state endorsement

## Observed Limitations

Specific issues stood out in this project as significant limitations. Table 5-1 identifies those limitations. Table 5-2 (in the Final Recommendations section) attempts to provide viable solutions to the limitations expressed below.

**Table 5-1: Observed Limitations for Industry Data**

| **Industry Data** | |
|---|---|
| Existing Pipe Inspection Training Program | (*referring specifically to NASSCO PACP*):<br>• Training program looks only at existing sewer lines, and while the defects here may be more severe than for post-installed pipe culverts, the comparison is obvious<br>• Training program does not include inspection by means of laser profiling (strictly CCTV) |
| Pipe Manufacturer and Pipe Inspection Contractor Visits | • Expressed concern with operators having varied results for pipe runs<br>(e.g., inspecting contractor may determine a pipeline to fail → competing inspector will re-test with different equipment and determine the pipeline to pass)<br>• Expressed concern with operators inspecting long runs in a surprisingly short amount of time (i.e., suspicions at testing above maximum travel speed) |

**Table 5-2: Observed Limitations for Project Activities**

| Project Activities | |
|---|---|
| Written Exam | • Exam has not been properly tested as a suitable assessment of contractor knowledge<br>• Lack of analysis regarding passing rates and industry acceptability |
| Field Test Course | • Pipe run setup does not reflect real world conditions: above-ground, short run distances, dissimilar pipe connections<br>• Lack of analysis regarding passing rates and industry acceptability |
| Baseline | • (*regarding crack defects …*) Defects too numerous and difficult to distinguish for measurement comparisons<br>• (*regarding joints …*) Gaps not measured in the same manner<br>• Data output graphs vary by laser-type manufacturer (i.e., ring-based output are different from spiral-based output)<br>• Potential conflict with asking contractors to aid in establishing a baseline for an exam they may have to take |

**Final Recommendations**

The research team identified practical solutions to the project limitations expressed above. Table 5-2 identifies the suggested recommendations.

**Table 5-3: Final Recommendations for Industry Data**

| Industry Data | |
|---|---|
| Existing Pipe Inspection Training Program | (*referring specifically to NASSCO PACP* ):<br>• The correlation between stormwater and sewer system pipelines warrants sincere consideration in the use of this program as a means of certification<br>• Investigate the methods by which NASSCO currently certifies software associated with the inspection of pipelines (i.e., find a possible correlation with the intended purpose of operator qualification)<br>• Examine Inspector Training & Certification Program (ITCP) to observe where emphasis is being placed – on equipment knowledge, inspection accuracy, or data evaluation |
| Pipe Manufacturer and Pipe Inspection Contractor Visits | • Investigate use of competing companies when retesting “failed” pipelines:<br>- suggest that the same company has to re-test failed pipe<br>- suggest the rearrangement of contract relationships (i.e., use of CEI for the owner instead of inspecting for the pipe layers).<br>• Approach equipment manufacturers to add a real-time speedometer display (i.e., show velocity and identify if equipment is exceeding maximum requirement) |

**Figure 5-4: Final Recommendations for Project Activities**

| **Project Activities** | |
|---|---|
| Written Exam | • Investigate suitability of exam as an assessment of contractor knowledge<br>• Assess operator performance by analyzing test and test results |
| Field Test Course | • Remedy non-ideal conditions: bury pipe, have longer runs, maintain the same material per run<br>• Assess operator performance by analyzing test and test results. Make changes as needed. |
| Baseline | • (*regarding crack defects …*) Label defects and establish precise measurements for these defects for future, accurate comparisons with operator measurements<br>• (*regarding joint gaps …*) Require similar method of measurement (i.e., either all measure the point of greatest separation, or all measure at 3-6-9 positions)<br>• Approach equipment manufacturers to produce standardized data output graphs<br>• Obtain outside support when establishing the baseline (e.g., inspectors from another state, or an FDOT official proficient in the use of the equipment) |

Overall, the current field test course arrangement may serve as a preliminary trial to verify operator instrument familiarity. Limitations previously identified (while non-ideal for a certifiable exam) were beneficial in this precursory project. The above-ground setup allowed for the visual inspection of defects. The short run length permitted quick turn-around for the test runs. Dissimilar pipe connections provided a way for contractors to demonstrate the different testing requirements for different pipe materials; and the large diameter pipe enabled easy access and defect repositioning. A future, certifiable field course should be constructed to address real-world conditions – conditions the operator is assumed to experience in normal day-to-day activity.

Further research is suggested in comparing the ability of laser profilers to detect identical sets of defects. There is much debate regarding the competing makes of laser profiling equipment – specifically with regards to the types of lasers being used. With the suggestion that spiral laser-based equipment may miss defects if traveling faster than the established maximum speed, it is in the pipeline industry's best interest to assess the merits of such thinking. Test runs should be performed analyzing varying speeds of travel, and output reports should be compared in identifying known defects.

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## Appendix A: Primary Interview Instrument for DOT Agency

**Call Information:**
Date: ________________________
Time: ________________________
DOT state: __________________
Phone number:__________________

**Personal Questions:**
Name: ________________________________________________
Position/title in the DOT:__________________________________
Years of experience in current position:______________________

**Preliminary Questions: Answer (Y/N)**
Do your roadway construction specifications require inspection for culvert pipe installations?
Do your specifications require initial inspections?
Do your specifications require final inspections?
Do you perform any of the following inspection methods listed below?

Mandrel tests
Closed circuit television tests (or CCTV)
Laser profiling
Video micrometer (for crack measurement)
Other not mentioned

## Appendix B: Kentucky Transportation Cabinet Pipe Inspection Method

***Kentucky Method 64-114-12***
Revised 04/01/12

Supersedes 64-114-11

**Dated 08/16/11**

CAMERA/VIDEO INSPECTION OF PIPE WITH ALTERNATE METHODS OF DEFLECTION MEASUREMENT

1. SCOPE: This method provides procedures for camera inspection of pipe and three methods of determining deflection: laser, mandrel testing, and physical measurements.

2. EQUIPMENT: All equipment must be certified by the Kentucky Transportation Center (KTC) prior to its use on a project and recertified annually. Prequalified Contractors must ensure that the equipment meets the following specifications prior to equipment being certified for use on KYTC projects.

   2.1. Camera Inspection Equipment: Provide a pipeline inspection camera having the following features:

   1) Configured properly in the pipe both vertically and horizontally, and having the ability to pan and tilt to a 90 degree angle with the axis of the pipe and rotate 360 degrees.
   2) Low barrel distortion camera.
   3) Color image with a minimum standard resolution of 720 x 480 pixels.
   4) Equipped with sufficient lighting to provide a clear image of the full circumference of the pipe.
   5) Capable of recording the station, milepost, distance along the invert of the pipe, or other indicators of location superimposed on the video.
   6) Capable of moving through entire length of pipe.
   7) Capable of measuring cracks greater than 0.1” and joint separations greater than 0.5”.
   8) Software capable of generating a report that shows each fault along with its location from the inspection entrance and a still frame image of the fault.

   2.2. Laser deflection measuring device: For use on Corrugated Metal Pipe, High Density Polyethylene Pipe, and Polyvinyl Chloride Pipe up to 48 inches in diameter, provide a laser deflection measuring device capable of measuring the maximum deflection to an accuracy of 0.5% or better and a repeatability of 0.12% or better.

2.3. Mandrel: For use on Corrugated Metal Pipe, High Density Polyethylene Pipe, and Polyvinyl Chloride Pipe, use a mandrel device with an odd number of legs (9 minimum) having a length not less than the outside diameter of the mandrel. The diameter of the mandrel at any point shall not be less than the diameter specified in Section 3.6. Mandrels can be a fixed size or a variable size. The diameter of the mandrel, whether it is fixed or variable size, must be verified with a proving ring or other method as per the manufacturer's guidelines.

2.4. Physical Measuring Tools: Use contact or non-contact distance instruments.

2.4.1. Measurement of pipe diameter: This may include tape extensometers, standard folding wooden carpenters tape with a 6-inch slide or a standard retractable metal carpenters tape. The measuring device should be readable to the nearest 1/16-inch.

2.4.2. Measurement of crack width in RCP: Measure crack width using a crack comparator, micrometer or a feeler gage capable of measuring 0.01 inch. Record the measurements and include them in the written inspection performance report including: location of crack, length, width, and greatest width of each crack exceeding 0.01 inch.

3. PROCEDURE:

3.1. Ensure pipe is clear of water, debris or obstructions. Complete the video inspection and any necessary measurement prior to placing the final surface over any pipe. When paving will not be delayed, take measurements 30 days or more after the completion of earthwork to within 1 foot of the finished subgrade. Notify the Engineer a minimum of 24 hours in advance of inspection and notify the Engineer immediately if distresses or locations of improper installation are logged.

3.2. Pipeline Video Inspection for Defects and Distresses:

3.2.1. Begin at the outlet end and proceed through to the inlet at a speed less than or equal to 30 ft/minute. Remove blockages that will prohibit a continuous operation.

3.2.2. Document locations of all observed defects and distresses including cracking, reinforcing steel showing, sags, joint offsets, joint separations, deflections, improper joints/connections, blockages, leaks, rips, tears, buckling, deviation from line and grade, and other anomalies not consistent with a properly installed pipe.

3.2.3. During the video inspection provide a continuous 360 degree pan of every pipe joint.

3.2.4. Identify and measure all cracks greater than 0.1” and joint separations greater than 0.5”.

3.2.5. Video Inspections are conducted from junction to junction which defines a pipe run. A junction is defined as a headwall, drop box inlet, curb box inlet, manhole, buried junction, or other structure that disturbs the continuity of the pipe. Multiple pipe inspections may be conducted from a single set up location, but each pipe run must be on a separate video file and all locations are to be referenced from nearest junction relative to that pipe run.

3.2.6. Record and submit all data as per Section 4.1.

3.3. Pipeline Laser Inspection for Deflection:

3.3.1. Calibrate the laser deflection measuring device according the manufacturers specifications. Provide all calibration data and applicable manufacturers recommendations for calibration and use to the Engineer.

3.3.2. Measure the deflection occurring at the point of the projected laser and at a minimum interval of 0.1 feet along the pipe.

3.3.3. All deflection measurements are to be based off of the AASHTO Nominal Diameters. Refer to Section 3.6.

3.3.4. Inspect at a speed that will provide proper data acquisition to effectively measure the maximum deflection. The inspection speed shall be less than or equal to 30 ft/minute.

3.3.5. Laser inspections are to be conducted in the same manner as Section 3.2.5.

3.3.6. Record and submit all data as per Section 4.2.

3.4. Mandrel Testing: Mandrel testing will be used for deflection testing if the video measurements are called into question or if limitations in the laser deflection measuring device are exceeded. Physical measurements as described in Section 3.5 may also be used in lieu of the laser or mandrel methods.

3.4.1. Use proving ring or other method recommended by the mandrel manufacturer to verify mandrel diameter prior to inspection. Provide verification documentation for each size mandrel to the Engineer.

3.4.2. All deflection measurements are to be based off of the AASHTO Nominal Diameters. Refer to Section 3.6.

3.4.3. Begin by using a mandrel set to the 5.0% deflection limit. Place the mandrel in the inlet end of the pipe and pull through to the outlet end. If resistance is met prior to completing the entire run, record the maximum distance achieved from the inlet side, then remove the mandrel and continue the inspection from the outlet end of the pipe toward the inlet end. Record the maximum distance achieved from the outlet side.

3.4.4. If no resistance is met at 5.0% then the inspection is complete. If resistance occurred at 5.0% then repeat 3.4.1 and 3.4.2 with the mandrel set to the 10.0% deflection limit. If the deflection of entire pipe run cannot be verified with the mandrel then immediately notify the Engineer.

3.4.5. Record and submit all data as per Section 4.3.

3.4.6. Care must be taken when using a mandrel in all pipe material types and lining/coating scenarios. Pipe damaged during the mandrel inspection will be video inspected to determine the extent of the damage. If the damaged pipe was video inspected prior to mandrel inspection then a new video inspection is warranted and supersedes the first video inspection. Immediately notify the Engineer of any damages incurred during the mandrel inspection and submit a revised video inspection report.

3.5. Physical Measurements: Alternate method for deflection testing when there is available access or the pipe is greater than 48 inches in diameter.

3.5.1. Use a contact or non-contact distance instrument as per Section 2.4.1. A leveling device is recommended for establishing or verifying vertical and horizontal control.

3.5.2. Physical measurements may be taken after installation and compared to the AASHTO Nominal Diameter of the pipe as per Section 3.6. When this method is used, determine the smallest interior diameter of the pipe as measured through the center point of the pipe (D2). Take the D2 measurements at the most deflected portion of the pipe run in question and at intervals no greater than ten (10) feet through the run. Calculate the deflection as follows:

% Deflection = [(AASHTO Nominal Diameter - D2) / AASHTO Nominal Diameter] 100%

Note: The Engineer may require that preset monitoring points be established in the culvert prior to backfilling. For these points the pre-installation measured diameter (D1) is measured and recorded. Deflection may then be calculated from the following formula:

% Deflection = [(D1 – D2) /D1] (100%)

3.5.3. Record and submit all data as per Section 4.2.

3.6. AASHTO Nominal Diameters and Maximum Deflection Limits: These deflection limits are the maximum allowable deflection on any axis within the pipe and not just in the XY plane.

| Base Pipe Diameter | AASHTO Nominal Diameter | Max. Deflection Limit | | |
|---|---|---|---|---|
| | | 5.0% | 7.5% | 10.0% |
| (inches) | (inches) | (inches) | | |
| 15 | 14.76 | 14.02 | 13.65 | 13.28 |
| 18 | 17.72 | 16.25 | 16.39 | 15.95 |
| 24 | 23.62 | 22.49 | 21.85 | 21.26 |
| 30 | 29.53 | 28.05 | 27.32 | 26.58 |
| 36 | 35.43 | 33.66 | 32.77 | 31.89 |
| 48 | 47.24 | 44.88 | 43.70 | 42.52 |
| 54 | 53.15 | 50.49 | 49.16 | 47.84 |
| 60 | 59.06 | 56.11 | 54.63 | 53.15 |

4. REPORTING: Submit all recorded information to the Engineer on standard forms along with the complete video inspection on DVD in digital format. The forms included in this method shall be used for reporting the inspection information. Ensure all video pipe runs on the DVD have the station, milepost, distance into the drain or other indicators

of location superimposed on the video. Submit two copies of the paper inspection report forms (one copy to the Section Engineer and one copy to Central Office Division of Construction), a copy of the DVD and one electronic copy of the report. All inspection reports shall be completed on the attached forms and shall be clearly named and organized in the electronic copy.

4.1. Pipeline Video Inspection Report: The Pipeline Video Inspection Report shall include the “Pipe Video Inspection Summary Report” form, the “Individual Pipe Video Inspection Report” form(s), and the report(s) generated by the inspection software for each pipe run.

4.1.1. Individual Pipe Video Inspection Report form: Complete Project Information, Inspector Information, and Pipe Information. Under Inspection Information record each defect/distress and joint along with its distance from the inspection entrance in feet and in sequence. Attach a copy of the report generated from the inspection software and reference the page number associated with the still image of the joint, distress/defect along with any additional information.

4.1.2. Pipe Video Inspection Summary Report form: This page is to be used as the cover sheet for the completed video inspection report. Complete Project Information, Inspector Information, and Pipe Information.

4.2. Pipeline Deflection Inspection Report: The Pipeline Deflection Inspection Report shall include the “Pipe Deflection Inspection Summary Report” form, the “Individual Pipe Deflection Inspection Report” form(s), and the report(s) generated by the inspection software for each pipe run. If using physical measurements, as per Section 3.5, then include a copy of all calculations.

4.2.1. Individual Pipe Deflection Inspection Report form: Complete Project Information, and Inspector Information. Under Inspection Information record each joint location along with the beginning and ending locations where the deflection exceeds 5.0%, 7.5%, and 10.0%. Attach a copy of any supportive information generated from the inspection software and reference the page number where more detailed deflection information may be conveyed.

4.2.2. Pipe Deflection Inspection Summary Report form: This page is to be used as the cover sheet for the completed deflection inspection report. Complete Project Information, Inspector Information, and Pipe Information.

Kentucky Transportation Cabinet
Division of Construction, 3rd Floor
200 Mero Street

Frankfort, Kentucky 40622

APPROVED ______________________________

DIRECTOR
DIVISION OF MATERIALS

DATE 04/01/12

## Appendix C: DOT Data Spreadsheet

**PRIMARY TELEPHONE INTERVIEW: Establishing the Use of Laser Profiling in Pipe Culvert Installation Inspections**

| State | AL | AK | AZ | AR | CA | CO | DE | FL |
|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Y (by owner agency) | Y | Y - while installed / before they're covered | Y - for galvinizing and prequal. on culvert; soil & compaction | Y | Y | Y |
| Do your specifications require initial inspections? | Y *(laid in presence of engineer / only covered when approved) | Y - mat'l cert. | Y - initial and in progress, depending on pipe | Y | Y - culvert tested | Y - for mat'l suppliers | Y - and semifinal | Material prequalification |
| Do your specifications require final inspections? | Y *(laid in presence of engineer / only covered when approved) | Y | Y (inspect from excavation to backfill/subgrade) | N - not specifically required | Y | Y | Y - final is when maintenance and quality comes in | Y |
| Inspection methods used: | | | | | | | | |
| Mandrel testing? | Y | N | N | N | Y | Y | Y | Y |
| Closed circuit television (or CCTV)? | N (unless in contract) | N | N | N | Y - circumstances | Certain areas | Y | Y |
| Laser profiling? | N (unless in contract) | N | N | N | N | N | Y | Y |
| Video micrometer (for crack measurement)? | N | N | N | N | N | N | N | Y |
| *Other not mentioned?* | | inspect grade and profile (standard survey) | Standard survey and auto leveling at inverts and as needed | Visual inspection | | | Mirror testing (full light at one end) | |

| State | ID | IL | IA | KS | LA | ME | MD | MA |
|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications <u>require</u> the inspection of culvert pipe installations? | N | N - procedures / Y - construction manual | Y | Y | Y - plastic - mandrel - changing to laser all plastic | Y* - not explicitly written in specs, but it is policy | Y | Y |
| Do your specifications require <u>initial</u> inspections? | N | Y - in progress inspection | | Y - while installing | Y | ? - test random samples | Y - prior material inspection | Y - precast at the plant, and as it goes in the ground |
| Do your specifications require <u>final</u> inspections? | N | Y - required / not as comprehensive | | N - but area-dependent | N - just making sure clean | Y - someone there the whole time | | Y - punchlist w/final walkthrough |
| Inspection methods used: | | | | | | | | |
| Mandrel testing? | N | N | N | N | Y | Y | N | Y |
| Closed circuit television (or CCTV)? | N | N - not on stormsewer (rarely) | N | N - not required, but if needed | N - considering | N | N (for conduit or sewer) | Y - sometimes when needed, but not routine |
| Laser profiling? | N | N | N | N | N - considering | N | N | Y - sometimes when needed, but not routine |
| Video micrometer (for crack measurement)? | N | N | N | N | N - considering | N | | N |
| *Other not mentioned?* | visual installation for culvert | Transit, level, total station of inverts and catch basin or manholes (std. survey) | - | - | | GPS or laser | | |

| State | MI | MS | MO | NE | NV | NH | NM | NY |
|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications <u>require</u> the inspection of culvert pipe installations? | Y | Y | Y - post installation | Y | N - (method spec versus performance method spec.) | Y | Y | Y |
| Do your specifications require <u>initial</u> inspections? | Y - density | Y | Y - inspection of pipe at plant | Y | N - not per specifications | N* - continuous inspection (not in specs, but part of project closeout) | Y | Inspection during installation |
| Do your specifications require <u>final</u> inspections? | Y | Some - certain sizes (ie. smaller = video / bigger = walk through) | Y | Y | Y | N* - continuous inspection (not in specs, but part of project closeout) | Y | N/A |
| Inspection methods used: | | | | | | | | |
| Mandrel testing? | Y | Y | Y - with video | N | N | Y | N | Y |
| Closed circuit television (or CCTV)? | Y (not on all inspections) - included in some contracts | Y | Y | Y | N | Y | Y - if not normal | Y |
| Laser profiling? | N | N | Y - in specs, but not doing much with it yet | Y | N | N | N | Some, no specifications, but contractors are beginning to adopt newer technologies |
| Video micrometer (for crack measurement)? | N | Y | N | N | N | N | N | Y |
| *Other not mentioned?* | | | | Visual inspection | | | | Magnetic testing for metal pipe coatings |

| State | NC | ND | OH | OK | SC | SD | TN | TX |
|---|---|---|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Y - during installation | | N | Y | Y | Y | Only during the installation |
| Do your specifications require initial inspections? | Current policy: inspect first portion | N | | Inspection during installation | Y | Y | Y | N |
| Do your specifications require final inspections? | (see above) | N | | N | N/A | Y - inspections are done during installation and on completion | Y - pipes inspected during installation and once it is complete | N - pipe visually inspected during installation |
| Inspection methods used: | | | | | | | | |
| Mandrel testing? | allowed | | Y | N | Y | Y | Y | N |
| Closed circuit television (or CCTV)? | Y | | | Y | Y | Y | Y | N |
| Laser profiling? | Y | | | N | Y | N | Y | N |
| Video micrometer (for crack measurement)? | Y | | | N | N | N | Y | N |
| *Other not mentioned?* | | | | | | | Mandrel testing is the base method used, anything more advanced is allowed for the inspections | |

| State | UT | WA | WV | WI | WY |
|---|---|---|---|---|---|
| Do your roadway construction specifications require the inspection of culvert pipe installations? | Y | Y | N/A | Y | Y |
| Do your specifications require initial inspections? | Y | Inspection during installation | N/A | Y (implied) | Inspection during installation |
| Do your specifications require final inspections? | | - | N/A | Y | N/A |
| Inspection methods used: | | | | | |
| Mandrel testing? | Y | No done on culverts | N/A | Y | Allowed, typically only on sewers |
| Closed circuit television (or CCTV)? | Y | N | N/A | N | N |
| Laser profiling? | | N | N/A | N | N |
| Video micrometer (for crack measurement)? | | N | N/A | N | N |
| *Other not mentioned?* | Visual inspection | | | Installation inspection (bedding placement, back filling) | |