

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

Final Report RC-1569

Prepared by:

Hristo Peev, PE – URS Corporation
Michael Guter, PE – URS Corporation
John Fleckenstein, PG – Spartan Construction, Inc.
Scott Belz, PE – URS Corporation
Stephen Abbate, PE – URS Corporation

URS Corporation
3950 Sparks Drive SE
Grand Rapids, MI 49546
PHONE: 616-574-8500
FAX: 616-574-8542

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16. Abstract In 1994 the Michigan Department of Transportation (MDOT) initiated a sewer and culvert condition research conducted at various locations throughout Southeast and Southwest Michigan to review the performance of concrete, plastic and metal pipe that varied in diameter from 12 inches to 24 inches. The present research, conducted in 2011, re-evaluated the current condition of pipe included in the 1994 study and expanded the study scope by adding new sewer pipe locations and 36 inch diameter pipe. The inspection in 2011 added laser profiling and micrometer measuring to the traditional CCTV and mandrel inspection methods used in 1994. The inspection and video results from 1994 were compared to the inspection and video results from 2011. The research evaluated the test pipe performance and made recommendations about pipe installation methods, use of mandrel testing versus laser profiling and application of laser micrometer measurement of pipe anomalies. The research evaluated several laser profiling and CCTV devices and their operation in sewers and culverts. Recommendations were made for updating the current MDOT laser profiling specification and implementing laser profiling in MDOT's practice.			
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DISCLAIMER

The contents of this report reflect the views of the author/principal investigator and the research team who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Michigan Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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Therese Kline, PE - Michigan Department of Transportation

Michael Townley, PE - Michigan Department of Transportation

Kevin Blankenship - Spartan Construction, Inc.

James Stankiewicz, PE - URS Corporation

James Kuntz, PE - URS Corporation

Douglas Parmerlee, PE – URS Corporation

Nathan Verseput, PE – URS Corporation

William Kasberg - URS Corporation

Eric Westra – URS Corporation

Technical editing was performed by Barry Chung, Phd, PE, SE. - URS Corporation.

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1.0 EXECUTIVE SUMMARY

This research report presents the inspection results and evaluations of sewer and culvert condition performed in 2011 in Michigan and compares them against inspections and evaluations of the same pipe performed in 1994. The study includes additional pipe not previously examined in 1994 to compliment and expand the research sample, diversity of pipe diameter and geography. The research presents conclusions about anomalies of in-service pipe based on pipe performance comparisons and analysis.

The study relates observed pipe performance to guidelines for newly installed pipe specified by the *American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Construction Specifications* and the *AASHTO LRFD Bridge Design Specifications*, and provides conclusions for new pipe installation. The current *Michigan Department of Transportation (MDOT) Standard Specifications for Construction and Standard Plans* are reviewed against these conclusions, and recommended changes are presented.

The 2011 study includes laser profiling and micrometer measuring inspection of all pipe in addition to the conventional Closed Circuit Television (CCTV) camera inspection and the mandrel testing of plastic pipe performed by the 1994 study. This research confirms that the laser profiling inspection method provides further insight regarding pipe condition and pipe shape deformation when compared to the CCTV camera and mandrel pipe inspection methods. The study suggests changes to the current *MDOT* laser profiling specification.

The research reviews and compares available laser profiler and micrometer technologies and suggests how *MDOT* can implement them into standard practice. The research recommends *MDOT* to implement laser profilers, micrometers and inclinometers for inspection of sewers and culverts. As part of this research project *MDOT* purchased for their own use a laser profiler, micrometer and CCTV camera pipe inspection system.

The research proposes a summary reporting format for the collected pipe inspection data and recommends laser profiler and micrometer implementation measures with inspection system certification that verifies device accuracy.

The study recommends that *MDOT* conduct further pipe condition and performance research.

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2.0 INTRODUCTION

MDOT initiated a research study in 1994 to inspect sewer and culvert pipe in both southeast and southwest Michigan and to report on the condition of the pipe. For the research in 2011 MDOT returned to the same sewer and culvert pipe. The 2011 study included additional test pipe in two new locations - one in Central Michigan and one in Upper Peninsula Michigan.

The sewer and culvert pipe material included for study was one of three types: concrete, metal or plastic. The pipe diameters ranged in size from 12 to 24 inches for concrete pipe, from 12 to 18 inches for metal pipe, and from 12 to 36 inches for plastic pipe.

Pipe performance was evaluated by comparison of the inspection and research results between the 1994 and 2011 studies, taking into consideration the pipe aging of approximately 20 years in between the studies. The pipe performance evaluations utilized as built plans when available, and *MDOT Standard Specifications for Construction* that were current at time of installation, and observed groundwater, pavement and traffic conditions.

The pipe performance research utilized in situ evaluation recommendations and rating systems from the *Federal Highway Administration (FHWA) Culvert Inspection Manual*, the *Ohio Department of Transportation Culvert Management Manual*, and the *National Association of Sewer Service Companies (NASSCO) Pipeline Assessment and Certification Program (PACP)*.

A Cues CCTV camera and laser micrometer, and a Cleanflow continuous ring laser profiler were used to gather test pipe condition data.

CCTV, laser micrometer, laser profiler and field log inspection data was collected at each test pipe. Mandrel testing was performed on all plastic pipe. Laser micrometer and profiler performance was evaluated by comparing their data to CCTV and mandrel data collected during the same inspection.

As part of this research, several other laser profiler, micrometer and CCTV devices were evaluated and compared at a mock pipe inspection demonstration event in order to learn about their operation, with the objective to recommend a preferred device for future MDOT use.

3.0 OVERVIEW OF THE 1994 STUDY

In 1994 MDOT's *Materials and Technology (M&T)* division conducted research study and field inspection of recently installed and randomly selected plastic, metal and concrete culverts and sewers. The 1994 field inspections included video recording of all pipe in this study plus mandrel testing of the plastic pipe. The inspections identified and recorded the anomalies found. The original study consisted of two parts, ND94-1761 and ND94-1762. ND94-1761 included 8 sites in Southeast Michigan with concrete, plastic and metal pipe varying in diameter from 12 to 24 inches. The total number of inspected test pipes was 43, with a combined total pipe length of 4646 feet. ND94-1762 included 10 sites in Southwest Michigan with concrete, plastic and metal pipe that varied in diameter from 12 to 24 inches. The total number of test pipes was 32, with a combined total pipe length of 3769 feet.

The 2011 research included all ND94-1761 test pipes plus 10 metal test pipes from ND94-1762. The 10 metal pipe installations were included in the 2011 study to provide sufficient metal pipe representation. The 1994 data included in the 2011 study is presented in **Appendix C**. Any referenced PVC pipe in the 1994 evaluation forms was actually HDPE pipe as clarified in the 1994 summary report. PVC pipe was not included in either the 1994 or 2011 study.

The 2011 mandrel tests were performed based on 95 percent of the nominal pipe diameter, as directed by the 1990 *MDOT Standard Specifications for Construction* that were current in 1994. In sections 3.0 of both ND94-1761 and ND94-1762 the study discussed plastic pipe mandrel test criteria and suggested use of adjustable mandrels. Subsection 4.1 of ND94-1761 stated that "52 percent" of the plastic pipe "did not pass the MDOT Mandrel Test".

Sections 3.0 of ND94-1761 and ND94-1762 noted the following basic types of anomalies observed in the inspected pipe: offsets between pipe sections, deflections of the plastic and metal pipe, concrete pipe cracks and metal pipe punctures. Sections 4.0 of ND94-1761 and ND94-1762 speculated that some observed anomalies were possibly related to installation and post installation procedures and suggested that these should be reviewed. Subsection 4.1 of ND94-1761 suggested that "the design parameters for flexible pipe be reviewed and modified". Subsection 4.3 of ND94-1762 suggested that the plastic pipe anomalies "may represent variations either in quality control" or "in contractor awareness of the additional care needed with the flexible pipe system".

Appendix K1 includes the 1994 research for reference. **Appendix K2** includes results of review and reassessment of the 1994 evaluations.

4.0 OBJECTIVES, SCOPE AND METHODOLOGY OF THE 2011 STUDY

4.1 OBJECTIVES

The 2011 research was performed with the following main objectives:

- ***Identify Pipe Anomalies***

Identify pipe anomalies and speculate what caused the anomalies. Compare the 2011 anomalies against the 1994 anomalies and make an attempt to determine the cause if there was no anomaly at the same location when compared to the 1994 inspection.

- ***Evaluate Pipe Performance***

Assess the change in pipe condition from 1994 to 2011 for the same sewer and culvert installations. Review the available design plans and other documentation and assess the design practices at the time of construction. Determine pipe performance based on the results of the pipe condition evaluations.

- ***Evaluate Pipe Deformation Inspection Methods***

Review the mandrel test results from 1994 and repeat the mandrel procedure in 2011 in order to determine any pipe shape changes. Review the use of laser profiling technology for pipe deformation detection as a supplement or replacement of mandrel tests. Compare laser profiling accuracy against traditional mandrel evaluation.

- ***Hold Demonstration Event to Test Laser Profiler Equipment***

Conduct a laser profiler vendor demonstration event to obtain direct knowledge of the different laser profiler technologies currently available in 2011 on the market. Document how each type of equipment operates by testing them on concrete, metal, and plastic pipe. Compare the laser test results against physical measurements taken manually. Compare performance and results of laser profilers and micrometers of different vendors. Prepare a comparative analysis presentation for *MDOT* regarding the event.

- ***Evaluate Laser Profiler Hardware and Software***

Evaluate the functionality and usability of currently available laser profiler hardware and software and use the conclusions to make suggestions for modifications to the *2010 MDOT Laser Profiler Specification*. Explore how

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inclusion of laser profiling in *MDOT*'s current post-installation/pre-paving pipe inspection process can provide benefit to the construction project stakeholders.

- ***Recommend Laser Profiling System for MDOT Purchase***

Recommend a laser profiler system for *MDOT* purchase. Base the recommendation on past experience in laser profiler use, on the vendor demonstration event, and on a comparative analysis. Purchase the laser profiler system selected by *MDOT*. Organize a laser profiler workshop for training *MDOT* staff in laser profiler hardware and software use.

- ***Suggest a Protocol for Laser Profiler and CCTV Certification System***

Use past experience and benchmarking against other states, including the *Florida DOT* requirement for an independent laboratory certification and the *Kentucky Transportation Cabinet* requirement for a signed certificate by the equipment manufacturer, to suggest a vendor certification process for the laser profiling.

Evaluate if an *MDOT* controlled process based on comparison to manual anomaly measurements, can be suggested for laser profiling equipment certification. Consider whether a laser profiler can be certified if its measurements meet *MDOT* defined tolerances in a repeatable manner.

4.2 SCOPE

4.2.1 Pipe Inspection & Evaluation

The research re-inspected all pipe included in the *MDOT ND94-1761* (Southeast Michigan) study, metal pipe included in the *ND94-1762* (Southwest Michigan) study, and additional pipe selected by *MDOT* in 2011 located in the Cities of Bad Axe and Munising.

The following sites and test pipes were included in the study (see **Figure 3**):

- 8 Southeast Michigan sites (43 test pipes) from the 1994 study (4,646 feet total length)
- 3 Southwest Michigan sites (10 test pipes) from the 1994 study (640 feet total length)
- 1 Central Michigan site (City of Bad Axe, 3 test pipes, 444 feet total length)
- 1 Upper Peninsula Michigan site (City of Munising, 5 test pipes, 848 feet total length)

The research pipes vary in size from 12 inches to 36 inches diameter, and in type of material - concrete, plastic and metal. **Figure 1** presents details on the pipes included in the research, including diameters, lengths, locations and the approximate age at the time of study.

The concrete test pipes were reinforced concrete sewers and culverts. The plastic test pipes were corrugated HDPE sewers. The metal test pipes were helically corrugated steel culverts.

Pipe condition data was compiled and analyzed for each pipe. *Section 12* of the 2011 version of *AASHTO LRFD Bridge Design Specifications* and *Sections 26, 27 and 30* of the current *AASHTO LRFD Bridge Construction Specifications* were used as an analysis guide. The *MDOT 1990 and 2012 Standard Specifications for Construction* were reviewed considering the previous (from 1994) and present (from 2011) observed pipe anomalies, general condition and performance.

The 2011 study was initiated with the intent to include all pipe in the *ND94-1761* study. All in-service metal pipe from the *ND-94-1762* study was added to the 2011 study because most *ND94-1761* metal pipe had been removed by roadway reconstruction work and therefore metal pipe was underrepresented. Pipe in Munising and Bad Axe was added to diversify the age, location, and size of pipe within the study. We note that all plastic pipe included in the 2011 study is polyethylene. Polyvinyl chloride pipe was not included in the 1994 study, and therefore was not included in the 2011 study.

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		CONCRETE PIPE (RCP)				PLASTIC (POLYETHYLENE) PIPE (HDPE)					METAL (CSP)											
		Nominal Diameter																				
		12"	15"	18"	24"	12"	15"	18"	24"	36"	12"	18"										
		Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft										
1	STORM SEWERS	20 YEARS +/- OLD PIPE																				
2		Southeast Michigan Site 1-1																				
3		Southeast Michigan Site 1-2																				
4		Southeast Michigan Site 1-3																				
5		Southeast Michigan Site 1-4																				
6		Southeast Michigan Site 2-1																				
7		Southeast Michigan Site 2-2																				
8		Southeast Michigan Site 2-3																				
9		Southeast Michigan Site 3-1																				
10		Southeast Michigan Site 3-2																				
11		Southeast Michigan Site 3-3																				
12		Southeast Michigan Site 3-4																				
13		Southeast Michigan Site 3-5																				
14		Southeast Michigan Site 3-6																				
15		Southeast Michigan Site 4-1																				
16		Southeast Michigan Site 4-2																				
17		Southeast Michigan Site 4-3																				
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31		Southeast Michigan Site 6-3																				
32		Southeast Michigan Site 6-4																				
33		Southeast Michigan Site 6-5																				
34		Southeast Michigan Site 6-6																				
35		Southeast Michigan Site 6-7																				
36		Southeast Michigan Site 6-8																				
37		Southeast Michigan Site 6-9																				
38	Southeast Michigan Site 6-10																					
39	CULV.	Southeast Michigan Site 7-1																				
40		Southeast Michigan Site 7-2																				
41		Southeast Michigan Site 7-3																				
42	STORMS SEWERS	10 YR +/-																				
43		Southeast Michigan Site 8-1																				
44		Southeast Michigan Site 8-2																				
45	City of Bad Axe Site 9-1																					
46	City of Bad Axe Site 9-2																					
47	City of Bad Axe Site 9-3																					
48	STORMS SEWERS	30 YR +/- OLD																				
49		City of Munising Site 10-1																				
50		City of Munising Site 10-2																				
51		City of Munising Site 10-3																				
52		City of Munising Site 10-4																				
53	CULVERTS	20 YEARS +/- OLD																				
54		Southwest Michigan Site 7-1																				
55		Southwest Michigan Site 7-2																				
56		Southwest Michigan Site 10-1																				
57		Southwest Michigan Site 10-2																				
58		Southwest Michigan Site 10-3																				
59		Southwest Michigan Site 10-4																				
60		Southwest Michigan Site 10-5																				
61	Southwest Michigan Site 11-1																					
	Southwest Michigan Site 11-2																					
	Southwest Michigan Site 11-3																					
	Total Length:		832	308	372	208	963	613	406	1327	444	473										
	Total feet by type of material:		1720				3753					1105										
	Total feet by size:		12"=		2427		15"=		921		18"=		1251		24"=		1535		36"=		444	
	TOTAL PIPE IN RESEARCH:		6578 Feet																			

Figure 1 Pipe Types, Locations, Diameters, Lengths and Age

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4.2.2 Laser Profiler Evaluation

Four different laser profiler hardware and software vendors were identified. They represented three currently available laser profiler technologies. Each equipment system was analyzed and compared. A demonstrational comparative analysis was also undertaken, resulting in a recommendation of a laser profiler to *MDOT* for purchase. The analysis included requirements specified in the current *MDOT Special Provision 03DS401(305) Laser Inspection of Sewer and Culvert Pipe* included in **Appendix H**. A laser profiling training workshop for *MDOT* staff was organized to take place both in the field and in classroom setting. The training included Operations and Maintenance (O&M) manual instruction study and hands-on equipment training time.

The research provided recommendations to enhance the current *MDOT* laser profiling specification and to implement laser profiling. This included suggestions for the use of devices that are related to the laser profiling, such as micrometers and inclinometers, and related inspection CCTV cameras and software. It also included recommendations to replace or supplement the traditional mandrel testing with laser profiling.

4.2.3 Final Report

A final report was prepared to document the research activities.

4.3 METHODOLOGY

4.3.1 Planning

The research scope was to re-examine all the pipe included in the 1994 *MDOT* study ND94-1761 (conducted in Southeast Michigan). The study scope was expanded by adding pipe installations located in the cities of Bad Axe (Central Michigan) and Munising (Upper Peninsula Michigan). Ten additional metal pipes from the 1994 *MDOT* study, ND94-1762, (conducted in Southwest Michigan) were subsequently added to expand the metal pipe statistical sample. Pipe sizes varied in diameter from 12 to 24 inches in the 1994 study. The inclusion of the Bad Axe site expanded the pipe diameter scope to 36 inches.

The need for pipe cleaning/dewatering, MDEQ Part 301 compliance and traffic control permit requirements were determined for each pipe location, and the necessary permits were obtained. Permit copies are provided in **Appendix I**. The laser profiler demonstration event and the presentation of the results were carried out early in the study, before start of the field work. This provided both the research team and *MDOT* a better understanding of the different laser technologies. One system was selected for use in the study to ensure result consistency.

4.3.2 Research Team

The research team was organized and directed by URS Corporation (URS) and included the following participants:

- Spartan Construction, Inc. of Lexington, Kentucky
- Powervac Co. of Novi, Michigan
- Tunnelvision Co. of Escanaba, Michigan
- Terra Contracting, LLC of Kalamazoo, Michigan
- POCO, Inc, of Ypsilanti, Michigan

URS Corporation coordinated the field inspection and result evaluation. This included obtaining necessary permits, synchronization of subcontractor services, and organizing the field data compilation, analysis and report preparation. Spartan Construction performed the pipe inspections and provided support in the analysis, discussion of results and developing of conclusions based on the field data. Spartan Construction also provided input in recommending a laser profiler for *MDOT*. The necessary traffic control was performed by POCO and

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Terra Contracting. The pipe cleaning and dewatering was performed by Powervac, Tunnelvision and Terra Contracting.

The inspection and engineering credentials of the staff that collected and evaluated the data included six NASSCO certified operators, one professional geologist and seven professional engineers.

4.3.3 Research Schedule

The research was conducted from May 2011 to May 2012. The field work schedule was as follows:

Field Work Task 1

Bad Axe Site 9 – City of Bad Axe	June 20, 2011
SE Mi Site 4 – Macomb & Clinton Twp	June 21/25, 2011
SE Mi Site 5 – Clinton, Macomb & Chesterfield Twp	June 22, 2011
SE Mi Site 7 – Chesterfield Twp	June 23, 2011
SE Mi Site 1 – Waterford & Independence Twp	June 20/24, 2011
SE Mi Site 2 – City of Auburn Hills	August 17 & 18, 2011

• Field Work Task 2

Munising Site 10 – City of Munising	August 15 & 16, 2011
SE Mi Site 6 – City of Novi	August 17, 2011
SE Mi Site 3 – Ypsilanti Twp	August 18, 2011
SE Mi Site 8 – City of Romulus	August 17 & 18, 2011
SE Mi Site 2 – City of Pontiac	August 17 & 18, 2011

• Field Work Task 3 (finishing tasks 1 & 2)

Finishing SE Mi Site 6 – City of Novi	September 28/30, 2011
Finishing SE Mi Site 1 – Waterford Twp	September 28/30, 2011
Finishing SE Mi Site 3 – Ypsilanti Twp	September 28/30, 2011

• Field Work Task 4 (metal pipes)

SW Mi Site 11 – City of Norton Shores	December 06, 2011
SW Mi Site 7 – Georgetown Township	December 07, 2011
SW Mi Site 10 – Arlington Township	December 08, 2011

• Laser Profiler Demonstration

June 13 to 15, 2011

• Laser Profiler Demonstration Presentation to MDOT

July 7, 2011

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4.3.4 Procedure

4.3.4.1 Pipe Inspections

The test pipes were scheduled for inspection in groups by location, considering factors such as traffic control limitations, ongoing construction activities, weather limitations and crew coordination. The research team used as built plans to locate the pipes and verify pipe size and type. The research pipe as built plans are presented in **Appendix A**.

Inspection Report Field Logs were filled in manually. The Logs provided an opportunity to supplement the electronic data logging and pipe condition assessment, performed by the CCTV/Laser profiler crew, with traditional manual data logging and assessment. The Logs describe the condition of the pipe as determined by the field inspector. Newly collected data was compared against data collected in the 1994 study, including video and written descriptions of cracks, joint offsets and separations, surface damage, leakages, soil migration and other physical changes. The digitized version of the field inspection report logs are provided in **Appendix B**.

Special attention was given by data analyzers to compare the laser profiling and mandrel test data. The mandrel test consisted of manually hand pulling nine point mandrels sized at 95 percent nominal pipe diameter through the test pipes, as required by *the 2012 MDOT Standard Specifications for Construction*. The mandrel test results were compared to the laser profiler shape deformation measurements. The laser assessments were based on actual pipe diameter that was measured by the laser profiling equipment.

The 2011 inspection utilized a Cues CCTV camera, a Cleanflow laser profiler and laser profiler data processing software, and *Pipeline Observation System Management (POSM)* data collection and reporting software.

The camera was mounted on a wheeled transporter with an adjustable height. For some corrugated pipe locations, the camera was mounted on a crawler to reduce the vibrations during laser profiling. The laser device was mounted on a slide that was attached to either the transporter or the crawler.

The speed of the transporter or crawler was generally maintained at 30 feet per minute (fpm). The camera was stopped for recording at each joint and anomaly during the “way through” run (camera run). During the “way out” run (laser run), the speed was reduced when a more precise record was deemed necessary.

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The laser profiler unit was field calibrated after each pipe run. The micrometer was field calibrated before the beginning of each of the four field work task mobilizations. **Figure 2** shows the Cues/Cleanflow system calibration after inspection of a 36 inch diameter pipe.

The CCTV camera performed purely visual inspection. The micrometer anomaly measuring device utilized visual software assisted distance estimates that were based on comparison to the distance of projections from two laser diodes incorporated in the camera head. The laser profiler utilized the laser light from a laser profiling device projected over the pipe inside walls. The location of the laser profiler light projections was recorded by the CCTV camera and processed by special laser profiling software to determine the shape along the length of the pipe.



Figure 2 Field Calibrating the Cues/Cleanflow CCTV and Laser System

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During the inspections, an attempt was made in the field to reach an opinion for the following items:

- compare on-site visual laser profiling images versus mandrel testing
- compare on-site laser profiling versus data provided by the CCTV
- estimate benefits and shortcomings of each pipe inspection method
- evaluate pipe condition state after approximately 30, 20 and 10 years in service
- estimate pipe distresses and if the test pipe is acceptable to remain in place for future research

The pipe inspection field procedure was as follows:

1. Locate test pipe, establish traffic control and clean the test pipe.
2. Survey coordinates of pipe end points and installation depth, fill in log forms.
3. Set up CCTV camera and laser equipment.
4. Perform way through CCTV camera run, stop at every joint for a 360 degree video record, measure with micrometer dimensions of observed anomalies, fill in log forms.
5. Perform way out laser profiler run, perform laser profiler calibration.
6. Perform mandrel test at plastic test pipes.
7. Complete filling in field log inspection forms.
8. Compare 2011 inspection results to 1994 study records and physical measures.

4.3.4.2 Rating Systems

The study utilized the following available sewer and culvert rating systems:

- FHWA and Ohio DOT based Condition Rating
- NASSCO PACP based Structural Rating, Structural Rating Index, and Field Log Score

The research concluded that no current rating system is complete, thorough and exact, and there is variability in the rating results.

The *FHWA Condition Rating System*, and the related *Ohio DOT* system, are based on the *FHWA National Bridge Inspection Standards*. These rating systems allow inspectors and engineers, who are familiar with performing bridge safety inspections, to easily use a similar approach to rate culverts and sewers. However, these rating systems seem to be geared more towards larger diameter culverts.

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The *FHWA* system does not currently include plastic pipe ratings. The *Ohio DOT* system is a modified *FHWA* system that includes plastic pipe ratings. It was chosen because of geographic proximity of Ohio and Michigan, similarity to *FHWA* condition rating and inclusion of plastic pipe ratings.

The *NASSCO PACP* based ratings have comprehensive coding, but currently are not yet well fitted to represent the plastic pipe anomalies. Deflection, one of the most common anomalies with flexible pipes, is not included in *PACP* coding. *NASSCO's* Structural Rating and Structural Index Rating systems allowed convenient computer processing. The rating is under constant development by *NASSCO* and has potential to spread nationwide.

A proprietary Field Assessment Rating was added to the study in order to “on site” assess if the pipe can be kept for future research.

This study utilized the above listed ratings despite their discontinuities in order to compile a possibly fuller picture about pipe condition, realizing at same time the necessity for additional nationwide research to establish a complete and comprehensive pipe inspection rating system.

The following is a detailed description of the rating systems used during the inspection process:

- **Condition Rating** - Culvert Inspection Condition Rating

The research included pipe condition rating as suggested by the *FHWA Culvert Inspection Manual (July 1986)* and the *Ohio DOT Culvert Management Manual (December 2003)*. These ratings vary from zero to nine. A value of nine (9) is assigned for the pipes that are in a “best” condition.

A value of zero (0) is assigned to failed pipe. These rating systems also have measurements and numerical values in them that can mathematically quantify the defects seen. There is no ambiguity or operator judgment. Rather, measurements are compared to determine code numbers.

The *FHWA* rating system currently covers only concrete and metal pipe. The *Ohio DOT* has added plastic pipe to the rating system. Portions from those manuals that deal with both rating systems are presented in **Appendix D1**. The complete manuals can be found on the internet as pdf files by Google search.

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- **Structural Rating** - NASSCO PACP Structural Rating assigned automatically through POSM

The POSM data collection software was used during all CCTV inspections. POSM is PACP certified software. PACP is created and developed by NASSCO. The basic PACP coding and structural ratings criteria are presented in **Appendix D2**.

Currently, deflection is not part of PACP. Adjusted PACP rating of 1 is given to minor anomalies. Adjusted PACP rating of 2 is given to anomalies that have not begun to deteriorate. Adjusted PACP rating of 3 is given to moderate anomalies that are expected to continue to deteriorate. Adjusted PACP rating of 4 is given to severe anomalies that are expected to require attention in the near future. Adjusted PACP rating of 5 is given to anomalies that require immediate attention.

The PACP anomaly coding scale is in opposition of the 1986 FHWA and the Ohio DOT coding where high numbers are associated with good pipe condition, and lower numbers are associated with poor pipe condition.

The PACP reported analysis included assigning structural distress rating numbers consisting of four digits. The first digit is the maximum structural distress anomaly code observed at the pipe. The second digit is the number of occurrences of the maximum distress anomaly. The third digit is the second highest maximum structural distress anomaly code observed at the pipe. The fourth digit is the number of occurrences of the second highest maximum distress anomaly.

The structural distress anomaly code varies from zero when no anomalies have been registered, to a maximum of five for the most severe anomalies (i.e. the structural distress coding scale is in opposition of the 1986 FHWA and the Ohio DOT coding, where high numbers are associated with less structural distress, and lower numbers are associated with more structural distress). The numerical anomaly occurrence code varies from zero (for no occurrences) to nine (for nine occurrences). When the occurrences are more than nine, the rating system uses the alphabet letters from A to Z as a code. The letter A represents 10 to 14 occurrences. Then each subsequent letter represents from 1 to 5 occurrences above the maximum number of occurrence that the preceding letter of the alphabet represents. Thus the letter B equals $\max(A)+(1 \text{ to } 5)=15$ to 19 occurrences. The letter C equals $\max(B)+(1 \text{ to } 5)=20$ to 24 occurrences.

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For example: the Southeast Michigan Site 6-10 test pipe was given a structural rating of 2212. This meant that the maximum observed structural distress was 2 (the first digit) and it was observed 2 times (the second digit). The second highest structural distress recorded at this pipe location was 1 (the third digit) and it was observed 2 times (the fourth digit).

- **Structural Rating Index** – NASSCO PACP Structural Rating Index assigned automatically through POSM
The POSM software automatically assigns a structural rating index to each pipe as an indicator to the distribution of anomaly severity. The index is dependent on the observed anomalies as registered by the technician during the inspection following the NASSCO PACP coding. This index is a weighted average calculated as the sum of the structural distress numbers, each multiplied by the number of their occurrences, divided by the sum of the number of their occurrences.

The rating can be expressed with the following mathematical equation:

Structural Rating Index = (distress code five times number of occurrences of distress code five + distress code four times number of occurrences of distress code four + distress code three times number of occurrences of distress code three + distress code two times number of occurrences of distress code two + distress code one times number of occurrences of distress code one) / (number of occurrences of distress code five + number of occurrences of distress code four + number of occurrences of distress code three + number of occurrences of distress code two + number of occurrences of distress code one).

The rating is rounded to a single digit number that ranges from one to five as shown in **Appendix D2**. A rating index of five corresponds to a close to failing or a failed pipe. A rating index of one corresponds to a pipe with either minor anomalies or no anomalies at all. POSM automatically rounds the weighted average to the closest integer. In the cases when there were no observed anomalies, or very minor anomalies, and the POSM software automatically rounded the results not to one (1), but to zero (0), which is not part of the rating range, the value of the structural index was assumed to be one (1).

For example: the Southeast Michigan Site 6-10 test pipe was given structural rating index of 2 because there were two code 2 distress anomalies and two code 1 anomalies, i.e. $(2 \times 2 + 1 \times 2) / 4 = 2$ (rounded). There were no anomalies registered with the other codes 5, 4 and 3. The sum of the distress codes times their occurrences come to be $5 \times 0 + 4 \times 0 + 3 \times 0 + 2 \times 2 + 1 \times 2 = 6$. This sum was divided by the total number of anomaly occurrences

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which is $0+0+0+2+2=4$. The structural index was calculated to be 2, i.e. $(5 \times 0 + 4 \times 0 + 3 \times 0 + 2 \times 2 + 1 \times 2) / (0 + 0 + 0 + 2 + 2) = 2$ (rounded).

- **Field Log Score** - NASSCO Structural Coding and Scoring assigned in the Inspection Report Field Logs
The field logs contain anomaly coding and field log scores based on engineering assessments during the inspection process and report preparation. The field log score was based on expectations of how the worst observed structural anomaly distress can affect the life span of the pipe. The expectations are based on the NASSCO's *Structural Scoring Table* presented in **Appendix D2**.

Each pipe was assigned a field log score from one (1) to five (5). A score of one (1) was to be assigned to pipe with no or minor structural defects. For such pipe, failure is unlikely in the foreseeable future (which was assumed to be 30 to 50 years), as in the case of concrete pipe isolated crack not wider than 0.06 inches that had no signs of reinforcement corrosion, soil migration or infiltration. A score of five (5) was to be assigned to pipe with anomalies that require immediate attention. A pipe with this score would be likely to fail within the next five years. None of the pipes studied scored 4 or 5.

- **1994 Assessment** – Proprietary Rating presented in the 1994 Condition Assessment Forms
To facilitate the historical performance evaluations, the 2011 report and field logs include the pipe condition assessments from 1994. The 1994 assessments were based on a rating scale from five (5), that equals “good” to one (1) that equals “poor”. The assessments are based on inspection observations and anomaly coding as presented in **Appendix D3**.

- **2011 Field Assessment** – Proprietary Rating used in the 2011 Field Report Logs
A simplified general pipe condition assessment was used in the field logs with the purpose to state an opinion about fitness of a test pipe to be kept for future research. This rating is not as complete and thorough as the other ratings, which are based on comprehensive published rating systems.

Four field assessments were assigned: good, fair, poor and not acceptable. To determine the assessments, the field inspector used previous experience, common sense judgment, type and severity of visually detected anomalies, pavement condition over the pipe run, and the log form field notes and remarks. Although some of the test pipe runs were considered to be in relatively bad condition, because the sewers and culverts still were

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functioning and without anticipation of an impending immediate failure, they all were ruled acceptable to be kept in place for future research.

4.3.4.3 Laser Profiler Evaluation, Recommendation, and Purchase

A demonstration site for the laser profiler vendors was provided at MDOT's garage near the City of Williamston, Michigan. Concrete, plastic and metal pipe suppliers provided test pipes. Some of the pipes had manufacturing anomalies. To provide a greater variation of pipe conditions for testing purposes, the research team deliberately added more anomalies to the test pipes.

The test pipes included two 60 foot long runs of 24 inch diameter concrete pipe, one 20 foot long run of 24 inch diameter plastic pipe, one 60 foot long run of 12 inch diameter metal pipe and one 40 foot long run of 12 inch diameter metal pipe. A total of four laser profiler vendors participated in the demonstration event.

Based on the vendor performance, the research team prepared a comparative analysis of the participating laser profiler hardware and software systems. The laser profiler vendors were compared against each other considering result accuracy, report preparation procedures, calibration requirements, field operation techniques, safety features, capability to laser profile pipe corrugations, laser features, CCTV camera characteristics, inclinometer operation, micrometer use and precision, capability to laser profile all of the pipe length and the ability to measure and present the transporter speed onscreen. The comparative analysis, as presented to MDOT, is provided in **Appendix F**.

4.3.4.4 Quality Assurance and Quality Control

The QA/QC for this study was overseen by URS professional engineers, a Spartan Construction professional geologist and NASSCO certified staff with extensive experience in sewer and culvert inspections, construction engineering and design. The research team members checked the work on a continuous basis. An independent technical review was conducted to verify general compliance with the *Professional Standards of Care* and the *U.S. Electronic Code of Federal Regulations (CFR 23.420.209.a.6)* Final Reporting requirements, that were provided by MDOT's Office of Research & Best Practices (ORBP).

5.0 RESULTS, ANALYSIS AND DISCUSSION

5.1 RESULTS

The test pipe sites were spread out over four general areas: Southeast Michigan (SE MI sites 1 to 8), Central Michigan (City of Bad Axe site 9), Upper Peninsula Michigan (City of Munising site 10) and Southwest Michigan (SW MI sites 7, 10 & 11). The general locations of the test pipes sites are presented in **Figure 3**.

The test pipe locations are shown in detail on site plans included in **Appendix A**. Pipe inspection field log data is presented in **Appendix B**. Detailed site reports are presented in **Appendixes E1 to E13**. The pertinent inspection data is summarized in **Figure 4**.

The inspections revealed common factors that affect performance of each type of pipe material. Improper bedding or backfill installations can influence the performance of all pipe types negatively.

The majority of the storm sewers and culverts included in the study were about 20 years old at the time of the 2011 inspection. When inspecting them, a number of assumptions was made concerning expected performance based on the *1986 FHWA Culvert Inspection Manual* and the *Ohio DOT Culvert Management Manual Condition Rating Guidelines*, and the *AASHTO LRFD Bridge Design and Construction Specifications*. The basic criteria used for the in-service pipe anomaly comments at end of each pipe analysis summary were as follows:

- joint offsets of more than 0.5 inch and separations more than 1 inch wide of any pipe type based on the *1986 FHWA Culvert Inspection Manual* rating guidelines that allow minor openings and exfiltration/infiltration at joints for “in-situ” pipe performance of 7 “good” per scale from nine (new condition) to zero (total failure) and assuming normal joint widths of 0.5 inch or less, and joint misalignment allowance of 0.5 inch based on the *Ohio DOT Culvert Management Manual* rating guidelines for pipe performance of 7 “good” per scale from nine (excellent) to zero (failed). The plastic band joints of Southeast Michigan sites 3, 4 and 5 were assumed to be within design limits for up to 2 inches wide band.
- sagging/settlements of any pipe type more than 1.5 inches based on averaging of the “no settlement” rating guidelines of the *1986 FHWA Culvert Inspection Manual* for “in-situ” pipe performance of 7

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“good” per scale from nine (new condition) to zero (total failure) and the 3 inches allowed by the *Ohio DOT Culvert Management Manual* rating guidelines for pipe performance of 7 “good” per scale from nine (excellent) to zero (failed)

- concrete pipe crack\fracture\hole size above 0.06 inches width based on the *Ohio DOT Culvert Management Manual* rating guidelines for pipe performance of 7 “good” per scale from nine (excellent) to zero (failed)
- concrete pipe spalling and scaling that are beyond the “slight spalling and scaling present on invert” allowed by the *1986 FHWA Culvert Inspection Manual* rating guidelines for “in-situ” pipe performance of 7 “good” per scale from nine (new condition) to zero (total failure) and surface damage or light scaling on more than 10% of exposed area that is more than 0.12 inches deep and delaminated/spalled area that is more than 1% of the surface based on *the Ohio DOT Culvert Management Manual* rating guidelines for pipe performance of 7 “good” per scale from nine (excellent) to zero (failed)
- metal pipe shape deformations more than 10%, moderate rust, loss of invert material or punctures based on the *1986 FHWA Culvert Inspection Manual* rating guidelines for “in-situ” pipe performance of 7 “good” per scale from nine (new condition) to zero (total failure)
- plastic pipe splits longer than 6 inches or wider than 0.25 inches and structural buckling\dimpling based on requirements of the *Ohio DOT Culvert Management Manual* rating guidelines for pipe performance of 7 “good” per scale from nine (excellent) to zero (failed)
- plastic pipe shape deformation more than 7.5% based on the *AASHTO LRFD Bridge Construction Specifications Article 30.7.2*

When evaluating storm sewer and culvert performance the leading factors were the retained ability to allow movement of fluids from one end to the other, the uninterrupted traffic if the pipe is under roadway, and the capability to maintain structural integrity.

Pipe failure was understood as the inability of a sewer or culvert to transport fluids, the interrupted traffic if the pipe is under roadway, and the loss of capability to maintain structural integrity.

Pipe in the ground that was capable of moving storm drainage from one end to the other, allowed the traffic to pass above, and was not in dire need of replacement for fear of imminent collapse and lost capability to

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maintain structural integrity, was considered functional even if the anomalies were severe, and was not considered “in-situ failure” pipe.

Of note, the inspections in 2011 determined that plastic test pipes did not pass the mandrel tests mostly in vicinity of drainage structures where improper compaction is more prevalent than along the pipe length. Deflection of 5% or greater of newly installed pipe is considered mandrel test failure per *MDOT Standard Specifications for Construction* that requires removal and reinstallation or replacement of the pipe.

Differences were observed between the measured 1994 and 2011 lengths of same pipes. They were considered caused by the different equipment measuring accuracy and distance counter slippage. For consistency, and to accommodate the comparative analysis, the 1994 pipe length data was retained as a baseline.

The inspection data is summarized, analyzed and discussed below:

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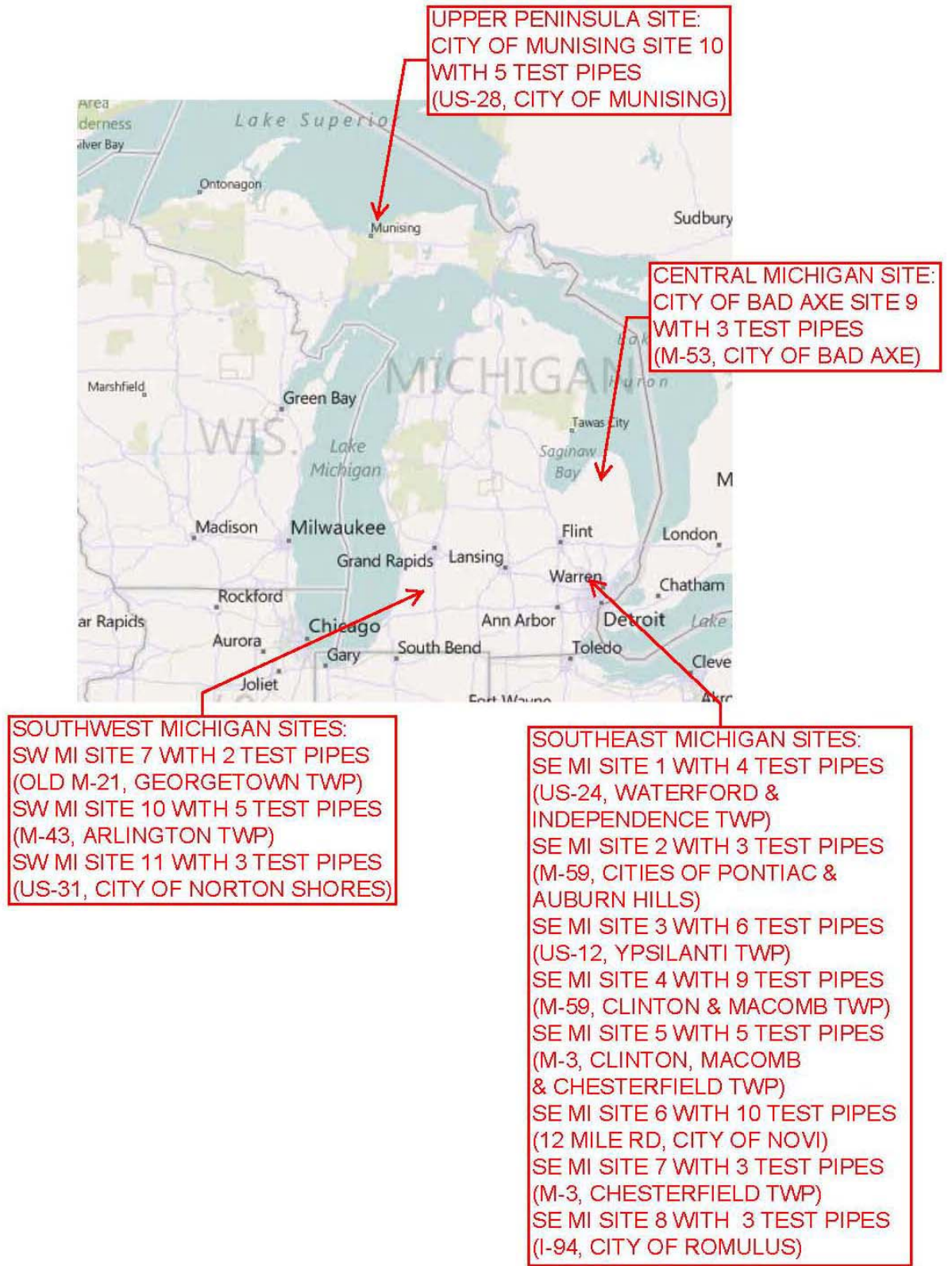


Figure 3 Test Pipe Site Location Map

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Pipe # and Rounded Length	Pipe Diameter & Type	Pipe Material	Pavement/Surface Type above Pipe	Approx. Depth of Cover	Maximum Crack Width	Mandrel Pass % of Pipe Length	Max. Deflection	Maximum Sagging/Settlement	Max. Joint Offset/Separation	Observed Changes	Observed In Situ Pipe Anomaly Occurrence
SE 1-1 57'	12" sewer	concrete	composite w/cracks	5'	<0.01"			none	0.5-1"	minor	0 ea/100 ft
SE 1-2 56'	18" sewer	concrete	composite w/cracks	4'				no data, under water			
SE 1-3 50'	12" sewer	concrete	composite w/cracks	6'	<0.01"			none	0.5-1"	minor	0 ea/100 ft
SE 1-4 97'	15" sewer	concrete	composite w/cracks	5'	<0.01"			1.2"	0.84"	minor/moderate	1 ea/100 ft
SE 2-1 167'	18" sewer	concrete	bitum. w/no cracks	5'	0.43"			0.6"	1.96"	moderate/severe	7 ea/100 ft
SE 2-2 99'	12" sewer	concrete	concrete w/cracks	3'	0.10"			0.9"	2.12"	moderate	9 ea/100 ft
SE 2-3 93'	12" sewer	concrete	concrete w/cracks	3'	0.63"			1.7"	3.54"	severe	14 ea/100 ft
SE 3-1 306'	15" sewer	plastic	grass/bit. w/no cracks	5'	none	33%	7%	0.5"	2.0"	moderate	2 ea/100 ft
SE 3-2 65'	12" sewer	plastic	composite w/cracks	3'	0.34"	8%	5.6%	1.1"	2.0"	severe	8 ea/100 ft
SE 3-3 67'	12" sewer	plastic	composite w/cracks	3'	none	6%	5.8%	0.7"	2.0"	moderate	3 ea/100 ft
SE 3-4 72'	12" sewer	plastic	comp. w/no cracks	3'	none	7%	4.9%	0.9"	2.71"	moderate/severe	8 ea/100 ft
SE 3-5 69'	12" sewer	plastic	grass	4'	none	99%	5-6%	1.0"	2.0"	moderate	4 ea/100 ft
SE 3-6 76'	12" sewer	concrete	composite w/cracks	3'	none			1.1"	1.2"	moderate	3 ea/100 ft
SE 4-1 52'	12" sewer	plastic	concrete w/cracks	5'	minor	16%	10.6%	2.7"	2.16"	moderate/severe	12 ea/100 ft
SE 4-2 53'	12" sewer	plastic	concrete w/cracks	4'	rad. fract.	100%	5.7%	1.9"	3.07"	moderate	11 ea/100 ft
SE 4-3 153'	18" sewer	plastic	concrete w/no cracks	5'	none	100%	7.6%	2.3"	2.0"	moderate	3 ea/100 ft
SE 4-4 53'	12" sewer	plastic	concrete w/cracks	5'	none	100%	6.1%	1.1"	2.0"	moderate	6 ea/100 ft
SE 4-5 55'	12" sewer	plastic	concrete w/no cracks	6'	small crack	3%	12.1%	2.1"	2.0"	moderate/severe	11 ea/100 ft
SE 4-6 65'	12" sewer	plastic	concrete w/no cracks	5'	none	88%	6.7%	1.1"	2.23"	minor/moderate	8 ea/100 ft
SE 4-7 51'	12" sewer	plastic	concrete w/cracks	4'	none	3%	6.5%	1.0"	<2.0"	minor/moderate	6 ea/100 ft
SE 4-8 262'	24" sewer	plastic	concrete w/no cracks	5'	none	60%	6.8%	5.4"	3.4"	moderate	2 ea/100 ft
SE 4-9 250'	24" sewer	plastic	concrete w/no cracks	5'	0.23"	17%	8.6%	1.9"	3.48"	moderate/severe	4 ea/100 ft
SE 5-1 235'	24" sewer	plastic	bituminous w/cracks	6'	none	27%	5.6%	1.4"	2.0"	minor	1 ea/100 ft
SE 5-2 80'	12" sewer	concrete	grass/gravel	2'	0.08"			none	roots@joint	moderate/severe	5 ea/100 ft
SE 5-3 68'	12" sewer	concrete	grass/gravel	1'	0.58"			1.0"	1.0-2.0"	moderate/severe	9 ea/100 ft
SE 5-4 170'	12" sewer	plastic	bituminous w/cracks	3'	0.75"	5%	11-12%	1.3"	2.0"	severe	11 ea/100 ft
SE 5-5 253'	18" sewer	plastic	bituminous w/cracks	5'	none	1%	10.8%	1.5"	3.5"	moderate	3 ea/100 ft
SE 6-1 84'	12" sewer	concrete	concrete w/no cracks	4'	0.11"			1.1"	1.0-2.0"	moderate	6 ea/100 ft
SE 6-2 51'	12" sewer	plastic	concrete w/cracks	4'	none	4%	8.3%	1.5"	1.0"	moderate	8 ea/100 ft
SE 6-3 161'	15" sewer	concrete	grass	6'	0.09"			0.7"	0.5-1.0"	moderate	1 ea/100 ft
SE 6-4 53'	12" sewer	concrete	concrete w/no cracks	3'	0.34"			0.9"	<0.5"	moderate	4 ea/100 ft
SE 6-5 52'	12" sewer	plastic	concrete w/cracks	4'	none	93%	6%	1.5"	0.5"	minor/moderate	0 ea/100 ft
SE 6-6 247'	15" sewer	plastic	grass/gravel	6'	0.78"	1%	18%	1.5"	0.5-1.0"	moderate/severe	5 ea/100 ft
SE 6-7 50'	12" sewer	plastic	concrete w/cracks	3'	0.23"	4%	8.2%	3.4"	1.65"	moderate/severe	28 ea/100 ft
SE 6-8 38'	12" sewer	concrete	concrete w/no cracks	3'	<0.01"			1.0"	1.91"	moderate	5 ea/100 ft
SE 6-9 38'	12" sewer	plastic	concrete w/no cracks	4'	0.19"	4%	7.8%	1.1"	<0.5"	moderate/severe	18 ea/100 ft
SE 6-10 41'	12" sewer	concrete	concrete w/cracks	3'	0.02"			1.4"	1.0"	moderate	2 ea/100 ft
SE 7-1 195'	12" culvert	metal						removed by reconstruction after 1994			
SE 7-2 93'	12" dv/swr	concrete	grass	2'	<0.01"			1.0"	2.07"	minor	2 ea/100 ft
SE 7-2 119'	12" dv/swr	metal	grass	2'	4.5" hole		Est. >10%	1.0"	0.5-1.0"	severe	8 ea/100 ft
SE 7-3 151'	12" culvert	metal						removed by reconstruction after 1994			
SE 8-1 73'	18" culvert	concrete	composite w/no cracks	4'	<0.01"			2.7"	>4.2"	severe	4 ea/100 ft
SE 8-2 76'	18" culvert	concrete	concrete w/no cracks	4'	0.03"			0.9"	4"	moderate/severe	3 ea/100 ft
SE 8-3 50'	15" culvert	concrete						removed by reconstruction after 1994			
BA 9-1 44'	36" sewer	plastic	bituminous w/cracks	5'	1.53"	2%	9%-10%	3.5"	1.53"	no prev. insp.	25 ea/100 ft
BA 9-2 143'	36" sewer	plastic	bitum. w/no cracks	5'	1.07"	4%	7.4%	2.2"	1.87"	no prev. insp.	6 ea/100 ft
BA 9-3 257'	36" sewer	plastic	bitum. w/no cracks	6'	0.30"	1%	8.3%	2.1"	1.91"	no prev. insp.	8 ea/100 ft
MU 10-1 60'	15" sewer	plastic	grass/gravel/bitum.	2'	1.3" hole	25%	>15%	2.8"	0.5"	no prev. insp.	17 ea/100 ft
MU 10-2 300'	24" sewer	plastic	grass/bitum.	2'	1" hole	n/a	14%	4.6"	3.03"	no prev. insp.	7 ea/100 ft
MU 10-3 208'	24" sewer	concrete	grass, bit w/no cracks	2'	<0.01"			3.9"	1.35"	no prev. insp.	3 ea/100 ft
MU 10-4 97'	24" sewer	plastic	grass	2'	fracture	0%	7-9%	1.8"	<2.0"	no prev. insp.	5 ea/100 ft
MU 10-5 183'	24" sewer	plastic	grass, conc w/cracks	2'	4" hole	3%	7-9%	4.3"	<1.0"	no prev. insp.	4 ea/100 ft
SW 7-1 119'	18" culvert	metal	bitum. w/no cracks	4'	4" hole		<5%	1.6"	<0.5"	moderate/severe	4 ea/100 ft
SW 7-2 142'	18" culvert	metal	bitum. w/no cracks	4'	none		10.3%	1.7"	1.66"	moderate	3 ea/100 ft
SW 10-1 35'	12" culvert	metal	bitum w/no cracks	2'	none		<5%	0.8"	1.17"	minor	3 ea/100 ft
SW 10-2 35'	12" culvert	metal	bitum. w/no cracks	2'	none		<5%	1.4"	0.86"	minor	0 ea/100 ft
SW 10-3 36'	12" culvert	metal	concrete w/no cracks	2'	none		<5%	1.1"	0.96"	minor	0 ea/100 ft
SW 10-4 35'	12" culvert	metal	concrete w/no cracks	2'	none		<5%	1.4"	1.08"	moderate	6 ea/100 ft
SW 10-5 26'	12" culvert	metal	grass/gravel	2'	none		7.3%	0.5"	no joints	moderate	4 ea/100 ft
SW 11-1 98'	18" culvert	metal	bitum. w/no cracks	20'	none		<5%	0.5"	0.5-1.0"	moderate	3 ea/100 ft
SW 11-2 62'	18" culvert	metal	bitum. w/no cracks	5'	none		<5%	1.6"	<0.5"	minor/moderate	2 ea/100 ft
SW 11-3 52'	18" culvert	metal	bitum. w/no cracks	5'	none		<5%	1.3"	<0.5"	minor/moderate	2 ea/100 ft

Figure 4 Pipe Inspection Summary of 2011 Study



5.2 ANALYSIS

The analyses that interpreted the inspection results at each pipe location are presented in this section. The inspections identified the current pipe anomalies and speculated on what caused the anomaly. For the sewers that were first inspected in 1994, the pipe anomalies identified in 2011 are compared against the 1994 anomalies.

The following Pipe Condition Summary tables contain combined *1986 FHWA Culvert Inspection Manual* and *2003 Ohio DOT Culvert Management Manual* Condition Rating assessments for each test pipe. The *Ohio DOT* system supplemented the *FHWA* system with plastic pipe rating criteria, and with additional rating criteria for concrete and metal pipe. The *Ohio Manual* was recognized as applicable because of relation to the current *FHWA Culvert Inspection Manual* and because of geographic proximity of the states of Ohio and Michigan.

The Pipe Condition Summary tables also contain Structural Rating, Structural Rating Index, and Field Log Score assessments based on the NASSCO PACP rating system.

Structural Rating and Structural Rating Index assessments were assigned automatically through the POSM software based on the inspection video record. They did not include coding and ratings for flexible pipe deflection. They also did not include PACP ratings for the coded flexible pipe buckling consisting of wall buckling, inverse curvature and dimpling that can be of structural and non-structural magnitude.

The Field Log Score assessments were assigned based on field inspection records and engineering reviews during report preparation. They did not include coding and ratings for flexible pipe deflection. They included PACP ratings for the coded buckling consisting of wall buckling, inverse curvature and dimpling that can be of structural and non-structural magnitude.

The above listed four assessments, to some extent differing because of their limitations, but supplementing each other in their judgment, together with the laser profiler and mandrel test data, were all taken into consideration to provide comprehensive analyses of pipe performance.

The 1994 assessments were reviewed for completeness in 2013, as presented in **Appendix K2**, and reevaluation results added in the pipe condition summary tables.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 1-1

The research pipe was a 57 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 13600A, CS 63053 approximately 20 years ago at Station 276+35 across M-24 (Dixie Highway) in Waterford Township, Oakland County. The pipe showed some age degradation. The pipe appears to have been repaired with grout. Moisture penetration through the pipe walls had caused tips of reinforcing stool/spacers to rust. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the findings:

Table SE 1-1: Southeast Michigan Site 1-1 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	No significant cracking was observed. Maximum crack was less than 0.01 inches wide.
Exposed Reinforcing Steel	Ghosting/corrugated appearance in inner wall of pipe. Tips of reinforcing stool/spacer visible through the pipe.
Sagging/Settlement	No significant sagging was observed within the pipe. Settlement was observed above the pipe at the pavement surface.
Joint Condition	Bituminous mastic was observed hanging down at several joints. No significant joint separation was noted or measured. Maximum joint separations were from 0.5 to 1.0 inches wide.
Structural Rating	3100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (subject to rating upgrade if not rebar, but spacer exposure is confirmed)
Structural Rating Index	3 per rating scale from one (no/minor anomalies) to five (failing/failed pipe) (subject to rating upgrade if not rebar, but spacer exposure is confirmed)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No significant distress changes were apparent since 1994. No signs of significant sagging, cracking, or other distresses were apparent in the pipe.

The inspection found minor changes of rust from tips of reinforcing stool/spacers (pipe production issue) and bitumastic material hanging from the joints (associated with old type of joint material). The pavement had shown signs of trench settlement in vicinity of the drainage structures. In the 57 feet pipe run zero anomalies were observed that averaged out to zero anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 1-2

The research pipe was a 56 feet long, 18 inch diameter **concrete** storm sewer installed under contract MDOT JN 13600A, CS 63053 approximately 20 years ago, at Station 280+40 across M-24 (Dixie Highway) in Waterford Township, Oakland County. The pipe could not be inspected due to the high groundwater levels flooding the surrounding sewer system, making it impossible to isolate the pipe. The 1994 overall condition was evaluated slightly less than good because at that time, the lower half of the pipe was under water, and only the upper half could be inspected. In the opinion of the field assessment, the test pipe was in poor but acceptable overall condition for future research, assuming that the high groundwater is lowered by downstream drainage reconstruction.

Table SE 1-2: Southeast Michigan Site 1-2 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 4' depth of cover.
Pipe Cracking	not inspected in 2011
Exposed Reinforcing Steel	not inspected in 2011
Sagging/Settlement	not inspected in 2011
Joint Condition	not inspected in 2011
Structural Rating	not inspected in 2011
Structural Rating Index	not inspected in 2011
Field Log Score	not inspected in 2011
Condition Rating	not inspected in 2011
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	not inspected in 2011

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 1-3

The research pipe was a 50 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 13600A, CS 63053 approximately 20 years ago, at Station 343+20 across M-24 (Dixie Highway) in the Waterford Township, Oakland County. The joint obstructions observed at three locations were judged to be bituminous mastic material hanging from the joints. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 1-3: Southeast Michigan Site 1-3 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 6' depth of cover.
Pipe Cracking	No significant cracking was observed. Hairline cracking was noted at some of the bells. Maximum crack width was less than 0.01 inches.
Exposed Reinforcing Steel	Ghosting/corrugated appearance in inner wall of pipe. Tips of reinforcing stool/spacer visible through the pipe.
Sagging/Settlement	No significant sagging was observed within the pipe. Settlement was observed above the pipe at the pavement surface.
Joint Condition	Bituminous mastic was observed hanging down at several joints. No significant joint separation was noted or measured. Maximum joint separations were from 0.5 to 1.0 inches wide.
Structural Rating	1100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No significant distress changes were apparent since 1994. No signs of significant sagging, cracking, or other distress were apparent in the pipe. Joint mastic appears to be creeping out of the joints.

The crack at 10 feet from access manhole A in the 1994 video was determined to be skid mark in 2011/2013.

The inspection showed minor changes such as a few hairline cracks, rust from tips of reinforcing stool/spacers (pipe production issue) and bitumastic material hanging from the joints (associated with old type of joint material). The hairline cracks were considered minor and acceptable at this time. In the 50 feet pipe run were observed zero anomalies that averaged out to zero anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 1-4

The research pipe was a 97 feet long, 15 inch diameter **concrete** storm sewer installed under contract MDOT JN 13600A, CS 63053 approximately 20 years ago, between Station 412+40 and Station 413+40 along the outer southbound lane of M-24 (Dixie Highway) in Independence Township, Oakland County. The observed repeating rust spots were possibly caused by a concrete material issue during production and/or abrasion that has reduced the concrete cover of the pipe reinforcing stool/spacers. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 1-4: Southeast Michigan Site 1-4 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	No major cracking was observed. Hairline cracking at some of the bells and mid barrel was noted. Maximum crack width was less than 0.01 inches.
Exposed Reinforcing Steel	Ghosting/corrugated appearance in inner wall of pipe. Tips of reinforcing stool/spacer visible through the pipe.
Sagging/Settlement	Minor sagging was noted in some areas. Settlement was observed around the pipe at the pavement surface. Sagging was approximately 1.2 inches.
Joint Condition	Bituminous mastic was observed hanging down at several joints. No significant joint separation was noted or measured. Maximum joint separation observed was 0.84 inches wide.
Structural Rating	1400 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Minor changes since the 1994 inspection. An additional hairline crack was noted, and the stools/spacers for the reinforcing steel are clearly visible. No significant sagging, changes in grade or joint separations have occurred.

The crack at 28 feet from access manhole A in the 1994 video was determined to be skid mark in 2011/2013. The inspection showed minor to moderate changes of sagging, spalling (1 ea, production issue), hairline cracks, rust from reinforcing stool/spacers (production issue) and bitumastic material hanging from the joints (old type of material). In the 97 feet pipe run was observed 1 anomaly that averaged out to 1 anomaly per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 2-1

The research pipe was a 167 feet long, 18 inch diameter **concrete** storm sewer installed under contract MDOT JN 26069A, CS 63043 approximately 20 years ago, between Station 67+00 and Station 68+70 along the median of westbound M-59 in the City of Pontiac, Oakland County. The observed crack development is possibly due to variations in bedding and longitudinal or lateral support. Cracks will continue to develop if causes are not addressed. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 2-1: Southeast Michigan Site 2-1 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Undergoing reconstruction to bituminous and composite pavement. Approximately 5' depth of cover.
Pipe Cracking	Significant cracking was noted throughout the pipe. Several cracks were well in excess of 0.10 inches wide. Maximum crack width was 0.43 inches.
Exposed Reinforcing Steel	None observed.
Sagging/Settlement	No significant sagging was observed. Maximum sagging was 0.6 inches deep.
Joint Condition	Several of the joints were cracked, fractured, and broken. Maximum joint separation was 1.96 inches.
Structural Rating	312G(max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	4 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	Cracking was noted in several areas of the pipe during the 1994 inspection and it was rated as fair to good condition at the time. It is apparent from the 2011 inspection that the amount of cracking has increased. Several of the cracks were greater than 0.10 inches wide and several of the joints were fractured and broken.

The crack at 40 feet from access manhole A in the 1994 video was determined to be skid mark in 2011/2013. The inspection showed moderate to severe changes of significant cracking (7 ea, construction issue) and offset/separated and fractured joints (4 ea, construction issue). Several of the cracks were greater than 0.10 inches wide. In the 167 feet pipe run were observed 11 anomalies that averaged out to 7 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 2-2

The research pipe was a 99 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 26069A, CS 63043 approximately 20 years ago, at Station 107+93 across eastbound M-59 in the City of Auburn Hills, Oakland County. The observed cracking in the pipe crown suggests insufficient bedding support with backfill that was not properly compacted. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 2-2: Southeast Michigan Site 2-2 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with cracks. Undergoing reconstruction to concrete and composite pavement. Approximately 3' depth of cover.
Pipe Cracking	Cracking was observed in several areas throughout the pipe. The largest crack was approximately 0.10 inches.
Exposed Reinforcing Steel	No steel exposure was visible, rust/minerals staining coming from several of the joints.
Sagging/Settlement	Vertical offset at several of the joints was observed, indicating pipe settlement. Maximum sagging was 0.9 inches deep.
Joint Condition	Several of the joints were cracked and offset vertically. Largest joint separation was 2.12 inches.
Structural Rating	2615 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	3 per rating scale from five (good) to one (poor) (3 per review in 2013)
Historical Performance	Cracking, joint leakage and offset joints were noted in the 1994 inspection. No staining was noted during the 1994 inspection but was observed in several areas during the 2011 inspection.

The inspection showed moderate changes of cracking/fracturing (6 ea, construction issue), minor sagging, and offset/separated joints (3 ea, construction issue). The separated/offset joints and the sagging could be due to poor installation of the pipe. The hairline cracks were considered minor and acceptable at this time. In the 99 feet pipe run were observed 9 anomalies that averaged out to 9 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 2-3

The research pipe was a 93 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 26069A, CS 63043 approximately 20 years ago, at Station 131+06 across westbound M-59 in the City of Auburn Hills, Oakland County. The observed cracks and joint displacement suggest loss in bedding support. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 2-3: Southeast Michigan Site 2-3 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with cracks. Undergoing reconstruction to concrete and composite pavement. Approximately 3' depth of cover.
Pipe Cracking	Severe fracturing and slabbing, missing material in invert at 24.9 ft and 41.0 ft, measured from the start of inspection MH. Largest crack width was 0.63 inches.
Exposed Reinforcing Steel	No reinforcing steel was exposed.
Sagging/Settlement	Lack of pipe support was causing damaged invert and presence of signs of impending structural failures at joints. Maximum sagging was 1.7 inches deep.
Joint Condition	Several broken joints, largest joint separation 3.54 inches wide.
Structural Rating	5131 (max-distress max-occurrences 2 nd -max-distress 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (3 per review in 2013)
Historical Performance	Major changes have occurred since the 1994 inspection. The pipe showed signs of impending failure in 2011. Early signs of joint displacement were present during the 1994 inspection. The joint displacement has continued to deteriorate. The pipe now shows signs of severe damage. Roadway settlement was visible above the damage areas within the pipe.

The inspection showed severe changes of cracking/fracturing (5 ea, construction issue), broken pipe (1 ea, construction issue), joint offset/separation (5 ea, construction issue) and settlement/sagging (2 ea, construction issue). Signs of impending structural failure were observed at several locations. The pipe should be monitored for additional signs of impending structural failure. In the 94 feet pipe run were observed 13 anomalies that averaged out to 14 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 3-1

The research pipe was a 306 feet long, 15 inch diameter **plastic** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, between Station 138+00 and Station 135+00 along westbound US-12 in Ypsilanti Township, Washtenaw County. The pipe appears to have been installed with proper bedding. Small wrinkles in the pipe walls are possibly caused by age degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-1: Southeast Michigan Site 3-1 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement w/no cracks. Approx. 5' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	Some longitudinal compression, wrinkling of the inner liner was noted.
Mandrel	In 2011 mandrel passed 33% of pipe length. Mandrel data from the 1994 & the 2011 differ. Distance from MH A in 1994 was 40 feet, but 12.3 feet in 2011. Distance from MH B in 1994 was 20 feet but 89.3 feet in 2011. The 2011 laser deflection matches the 2011 mandrel data from access MH A, and the 1994 mandrel test data from access MH B.
Deflection	Measureable maximum deflection was approximately 7 percent. Pipe was slightly racked near MH B.
Sagging/Settlement	Slight sagging up to 0.5 inches deep was noticeable in a few areas.
Joint Condition	Max. separation (joint plastic band width) was approx. 2.0 inches wide, coupling was holding ends of pipe apart.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The mandrel and laser test data indicated some minor additional deflection near access MH A had occurred.

The inspection showed moderate changes of compression/wrinkling (5 ea, construction issue) and minor sagging. In the 306 feet pipe run were observed 5 anomalies that averaged out to 2 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 3-2

The research pipe was a 65 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, at Station 164+00 across US-12 in Ypsilanti Township, Washtenaw County. There were pavement cracks across US-12 that roughly coincided with the pipe location below. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-2: Southeast Michigan Site 3-2 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	Crack/tear was approximately 0.34 inches wide.
Wall Distress	Pipe was tearing/ripping outside of access MH B.
Mandrel	In 2011 mandrel passed 8% of pipe length. Mandrel passed in 1994, but stopped 1'-10" from MHA and 3'-2" from MH B in 2011.
Deflection	Measureable maximum deflection was approximately 5.6 percent
Sagging/Settlement	Sagging was noted at MH A in 1994. Sagging/settlement at access MH B was causing structural damage to the pipe wall in 2011. Sagging was approximately 1.1 inches deep.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately .2.0 inches wide. Coupling design apparently was holding the ends of pipe apart.
Structural Rating	2111 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Pipe has continued to sag/deflect. Mandrel testing passed in 1994, but was stopping near each access MH in 2011. The pipe wall was ripping/tearing due to settlement near access MH B. This was not noted in the 1994 inspection.

The inspection showed severe changes of buckling/dimpling (1 ea, construction issue) and cracks/fractures (2 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. It should be monitored for additional signs of impending structural failure. In the 65 feet pipe run were observed 5 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 3-3

The research pipe was a 67 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, at Station 171+70 across US-12 in Ypsilanti Township, Washtenaw County. Pavement cracks were observed across US-12 that roughly coincide with pipe location. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-3: Southeast Michigan Site 3-3 Pipe Condition Summary

Surface Observations	Composite pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	No cracking in pipe observed.
Wall Distress	No distress noted.
Mandrel	In 2011 mandrel passed 6% of pipe length. Mandrel passed in 1994 but was stopping just outside each access MH in 2011 (from A at 1'-3", from at B at 2'-7").
Deflection	Measureable maximum deflection was approximately 5.8 percent.
Sagging/Settlement	Sagging was observed in both the 1994 and the 2011 inspections. Maximum sagging depth was approximately 0.7 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was less than 2.0 inches. Coupling design was apparently holding the ends of the pipe apart.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Historical performance is indicating that the pipe has continued to sag/deflect outside of each access MH. Mandrel testing passed in 1994, but was failing near each access MH in 2011.

The inspection showed moderate changes including minor sagging. The mandrel stopped (2 ea, construction issue) at pipe ends. In the 67 feet pipe run were observed 2 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 3-4

The research pipe was a 72 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, at Station 199+95 across US-12 in Ypsilanti Township, Washtenaw County. The observed limited damage on pipe walls is possibly caused by age degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-4: Southeast Michigan Site 3-4 Pipe Condition Summary

Surface Observations	Composite pavement with no cracks. Approximately 3' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	Compression/wrinkling in the crown occurred at approximately 62 feet from access MH A.
Mandrel	In 2011 mandrel passed 7% of pipe length. Mandrel passed in 1994, but stopped 2'-0" from MHA and 2'-10" from MH B in 2011.
Deflection	Measureable maximum deflection was approximately 4.9 percent
Sagging/Settlement	Sagging was observed in both the 1994 and the 2011 inspections. Maximum sagging depth was approximately 0.9 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 2.71 inches. Coupling design does not allow pipe sections to be matched properly.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Mandrel data indicated that pipe has continued to deflect. Mandrel passed in 1994, but stopped near each MH in 2011. The maximum deflection picked up by the laser profile was 4.9 percent. Laser may be was missing the greater deflections near each access MH.

The inspection showed moderate to severe changes of compression/buckling/dimpling (2 ea, construction issue) and joint offset/separation (2 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. In the 72 feet pipe run were observed 6 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 3-5

The research pipe was a 69 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, between Station 305+30 and Station 304+72 in the median of US-12 in Ypsilanti Township, Washtenaw County. The pipe generally had retained its shape and wall surface condition, possibly because most of the pipe length was located outside of traffic influence. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-5: Southeast Michigan Site 3-5 Pipe Condition Summary

Surface Observations	Grass. Approximately 4' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	Compression/wrinkling in the crown occurring near access MH B.
Mandrel	In 2011 mandrel passed 99% of pipe length. Mandrel passed in 1994, but was stopping just outside access MH B in 2011 (from A at 66'-6", from B at 1'-9").
Deflection	Measureable maximum deflection was approximately 5 to 6 percent.
Sagging/Settlement	Sagging up to 1 inch deep was apparent in the 2011 inspection, but was not noted in the 1994 inspection.
Joint Condition	Maximum joint separation (joint plastic band width) was less than 2.0 inches, controlled largely by coupling.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Mandrel data indicated the pipe has deflected near MH B since the 1994 inspection. Sagging, in addition to dimpling/buckling/compression of inner liner in the crown had occurred since the 1994 inspection.

The inspection showed moderate changes of buckling/dimpling (2 ea, construction issue) and sagging. The mandrel stopped (1 ea, construction issue) near one of pipe ends. In the 69 feet pipe run were observed 3 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 3-6

The research pipe was a 76 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 26955A, CS 81032 approximately 20 years ago, at Station 216+00 across westbound US-12 in Ypsilanti Township, Washtenaw County. The pipe appears to be constantly submerged because of the high water level in the median ditch. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 3-6: Southeast Michigan Site 3-6 Pipe Condition Summary

Surface Observations	Grass and composite pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	No cracks observed.
Exposed Reinforcing Steel	No visible steel or staining at joints.
Sagging/Settlement	Sagging was noted in both the 1994 and the 2011 inspections. The maximum sag depth was 1.1 inches.
Joint Condition	Widest joint was approximately 1.2 inches wide. The joint located at 11.4 feet from pipe end A was showing significant signs of infiltration.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Distress in the pipe had not significantly increased since the last inspection other than the observed infiltration located at 11.4 feet from pipe end A.

The inspection showed moderate changes of infiltration, spalling at joint (1 ea, production issue), joint offset/separation (1 ea, construction issue) and minor sagging. There were no hairline cracks observed. In the 76 feet pipe run were observed 2 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-1

The research pipe was a 52 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 393+85 across westbound M-59 (Hall Road) in Macomb Township, Macomb County. The pipe had generally retained its shape. Hairline crack development had started. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-1: Southeast Michigan Site 4-1 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	Minor cracking in pipe wall.
Wall Distress	Dimpling and buckling, hairline cracks through buckled areas.
Mandrel	In 2011 mandrel passed 16% of pipe length. Mandrel testing stopped near the manholes on each end of the pipe, approximately 7 feet from access MH B and 17 inches from access MH A.
Deflection	Measureable maximum deflection was approximately 10.6 percent. Significant dimpling was occurring in this area.
Sagging/Settlement	Standing water at MH A. Buckling in invert due to sagging at MH B. Sagging depth was approximately 2.7 inches at 27 feet from MH A.
Joint Condition	Max. separation (joint plastic band width) was 2.16 inches wide. Possible soil migration through band.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The 1994 inspection noted a sag at 46 feet from MH A. This is in the general areas where maximum deflection, dimpling, and joint separation observed in 2011. Apparently pipe had continued to degrade in this area.

The inspection showed moderate to severe changes of dimpling/buckling (2 ea, construction issue), joint offset/separation (1 ea, construction issue), sagging (1 ea, construction issue) and minor cracking. The maximum pipe deflection was greater than 10.6% (1 ea, construction issue). The mandrel stopped (1 ea, construction issue) at pipe end A. It should be monitored for additional signs of impending structural failure. In the 52 feet pipe run were observed 6 anomalies that averaged out to 12 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-2

The research pipe was a 53 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 465+50 across westbound M-59 (Hall Road) in Macomb Township, Macomb County. The pipe had retained its shape with limited degradation. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-2: Southeast Michigan Site 4-2 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 4' depth of cover.
Pipe Cracking	Offset radial fracture near access MH B.
Wall Distress	Several wall distresses were noted, including puncture and radial fracture.
Mandrel	In 2011 mandrel passed 100% of pipe length. It also passed in the 1994. Laser data indicated the pipe was deflected approximately 5.4 to 5.7 percent. Standing water in the area affected the accuracy of the laser data.
Deflection	Measureable maximum was approximately 5.7 percent. Sagging, crown flattening, and radial fracture also were observed in this area.
Sagging/Settlement	Sagging near both MH. Max. sag was approx..1.9 inches near MH A.
Joint Condition	Maximum joint separation (joint plastic band width) was 3.07 inches wide.
Structural Rating	2100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	The mandrel tests performed in 1994 and 2011 both passed . The only issue mentioned in the 1994 inspection was an open joint. It appeared that additional distresses have occurred since the 1994 inspection, including post construction related damage, settlement, and cracking.

The inspection showed moderate changes of puncture (1 ea, construction issue), dimpling/buckling (2 ea, construction issue), crack/fracture (1 ea, construction issue) and joint offset/separation (1 ea, construction issue) and sagging (1 ea, construction issue). The pipe should be monitored for additional signs of impending structural failure. In the 53 feet pipe run were observed 6 anomalies that averaged out to 11 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-3

The research pipe was a 153 feet long, 18 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, from Station 462+40 to Station 463+95 under the outside westbound lane of M-59 (Hall Road) in Macomb Township, Macomb County. The pipe had retained its original shape. There is limited pipe degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-3: Southeast Michigan Site 4-3 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks above the test pipe. Cracks present above other pipes tapping in the same MH. Approximately 5' depth of cover.
Pipe Cracking	No cracking noted.
Wall Distress	Puncture noted in the pipe wall, pipe appears corrugated, loss of laser light behind corrugations.
Mandrel	In 2011 mandrel passed 100% of pipe length. Mandrel testing passed also in the 1994 inspection. Invert flattening was noticeable. The nine point mandrel was not picking up invert flattening.
Deflection	Measureable maximum was approximately 7.6 percent
Sagging/Settlement	Sagging was noticed in several areas throughout the pipe. Maximum sag depth was approximately 2.3 inches near access MH B.
Joint Condition	Maximum joint separation (joint plastic band width) was 2.0 inches wide.
Structural Rating	3100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	3 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	The mandrel tests performed in 1994 and 2011 both passed . Sagging was observed in two locations in the 1994 inspection. Additional sagging was shown in the laser profile data.

The inspection showed moderate changes of puncture (1 ea, construction issue), buckling (1 ea, construction issue), sagging (1 ea, construction issue) and joint offset/separation with infiltration (1 ea, construction issue). In the 153 feet pipe run were observed 4 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-4

The research pipe was a 53 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 417+00 across westbound M-59 (Hall Road) in Macomb Township, Macomb County. The pipe had generally retained its original shape. There was limited degradation of the pipe walls. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-4: Southeast Michigan Site 4-4 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	No cracking noted.
Wall Distress	Pipe appeared to be corrugated. Some dimpling was observed in the crown near access MH B.
Mandrel	In 2011 mandrel passed 100% of pipe length. Mandrel testing passed also in the 1994 inspection.
Deflection	Measureable maximum was approximately 6.1 percent.
Sagging/Settlement	Standing water was observed at access MH A. Buckle in the pipe invert was observed at access MH B. Maximum sagging depth was approximately 1.1 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was 2.0 inches wide allowed by coupling design.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The mandrel tests performed in 1994 and 2011 both passed . Sagging was observed at 33 feet from access MH B in 1994. Joint separation was largest in this area. Sagging also had occurred near access MH A since the 1994 inspection.

The inspection showed moderate changes of buckling (2 ea, construction issue), minor sagging and joint offset/separation with void (1 ea, construction issue). In the 53 feet pipe run were observed 3 anomalies that averaged out to 6 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 4-5

The research pipe was a 55 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 406+10 across westbound M-59 (Hall Road) in Macomb Township, Macomb County. The pipe had lost its shape in the vicinity of the drainage structures due to settlement. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-5: Southeast Michigan Site 4-5 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks. Approximately 6' depth of cover.
Pipe Cracking	Small crack in inner liner at 4.4 feet from access MH A.
Wall Distress	Pipe was severely dimpled in the area of high deflection.
Mandrel	In 2011 mandrel passed 3% of pipe length. It did not pass in the 1994 inspection. Significant settlement and deflection had occurred near each MH. The mandrel stopped at 10 ft from MH B in 1994 and at 1.33 ft in 2011. The mandrel stopped from MH A at 5 feet in 1994 and 0.17 feet in 2011.
Deflection	Measureable maximum was approximately 12.1 percent.
Sagging/Settlement	Significant sagging was noticed at both MH. Buckling was observed in invert at access MH B. Maximum sagging depth was approximately 2.1 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was 2.0 inches wide allowed by coupling design.
Structural Rating	1100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	It was evident that additional sagging and deflection had occurred near the manholes since the 1994 inspection.

The inspection showed moderate to severe changes of dimpling (1 ea, construction issue), cracking (1 ea, construction issue) and sagging (2 ea, construction issue). Pipe deflection was approximately 12.1 percent (1 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. The pipe should be monitored for additional signs of impending structural failure. In the 55 feet pipe run were observed 6 anomalies that averaged out to 11 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-6

The research pipe was a 65 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 407+20 across eastbound M-59 (Hall Road) in Clinton Township, Macomb County. The pipe had lost its shape only at a segment located under a lane with heavy traffic. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-6: Southeast Michigan Site 4-6 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks above the test pipe. Approximately 5' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	No visible wall distress was observed.
Mandrel	In 2011 mandrel passed 88% of pipe length. Mandrel was not performed in 1994. Mandrel stopped at 3.3 feet when pulled from MH A and at 54 feet when pulled from MH B in 2011.
Deflection	Measureable maximum was approximately 6.7 percent.
Sagging/Settlement	Long sag with standing water was observed at access MH A. Sag depth was approximately 1.1 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was 2.23 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No mandrel testing was conducted and no distress documented in 1994. Sagging/standing water was observed in 2011 at access MH A. This was also the area of highest deflection.

The inspection showed minor to moderate changes consisting of joint offset/separation (3 ea, construction issue). A surface damage defect from casting was also observed (1 ea, production issue) at approximately 18 feet from MH A. The mandrel stopped (1 ea, construction issue) in vicinity of MH A. In the 65 feet pipe run were observed 5 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 4-7

The research pipe was a 51 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, at Station 426+45 across eastbound M-59 (Hall Road) in Clinton Township, Macomb County. The pipe had lost its shape only in the vicinity of the drainage structures. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-7: Southeast Michigan Site 4-7 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 4' depth of cover.
Pipe Cracking	No cracking was observed.
Wall Distress	Buckle/wrinkle in inner liner.
Mandrel	In 2011 mandrel passed 3% of pipe length. Mandrel test was not performed in 1994. Mandrel stopped at 0.33 feet from access MH A and 1.04 feet from access MH B in 2011.
Deflection	Measureable maximum was approximately 6.5 percent.
Sagging/Settlement	No standing water was present in the pipe. Staining in invert outside of access MH A indicates some previous standing water. Maximum sagging was approximately 1 inch deep.
Joint Condition	Maximum joint separation (joint plastic band width) was less than 2.0 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No mandrel testing was conducted in 1994 and no distress was documented.

The inspection showed minor/moderate changes including buckling/wrinkling (1 ea, construction issue) and a small dent. The mandrel stopped (2 ea, construction issue) at pipe ends. In the 51 feet pipe run were observed 3 anomalies that averaged out to 6 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 4-8

The research pipe was a 262 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, from Station 462+25 to Station 459+55 under the outside eastbound lane of M-59 (Hall Road) in Clinton Township, Macomb County. The pipe had limited degradation and had accumulated deposits. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-8: Southeast Michigan Site 4-8 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks above test pipe. Cracks were present above other pipes tapping into MH B. Approximately 5' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	Heavy corrugation expression was observed near access MH B.
Mandrel	In 2011 mandrel passed 60% of pipe length. Mandrel test was not performed in 1994. In 2011 the mandrel stopped at 157 feet from MH A and was not pulled from MH B in 2011 because the debris present in the pipe could not be removed.
Deflection	Measureable maximum was approximately 6.8 percent.
Sagging/Settlement	Standing water and debris were observed in several areas throughout the pipe. Standing water was approximately 5.4 inches deep near access MH B.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 3.4 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	No mandrel testing was conducted in 1994 and no distress documented.

The inspection showed moderate changes including joint offset/separation (1 ea, construction issue) and sagging (3 ea, construction issue). In the 262 feet pipe run were observed 4 anomalies that averaged out to 2 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 4-9

The research pipe was a 250 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 05674, CS 50022 approximately 20 years ago, from Station 472+82 to Station 475+32 under the outside lane of eastbound M-59 (Hall Road) in Clinton Township, Macomb County. The pipe had limited deterioration. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 4-9: Southeast Michigan Site 4-9 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks above the test pipe. Cracks were present above other pipes tapped in both end MH. Approximately 5' depth of cover.
Pipe Cracking	Radial crack with staining. Maximum crack width was 0.23 inches.
Wall Distress	Radial crack with staining.
Mandrel	In 2011 mandrel passed 17% of pipe length, stopping at 3.08 feet from MH A and at 39 feet from MH B. Mandrel test was not performed in 1994.
Deflection	Measureable maximum was approximately 8.6 percent.
Sagging/Settlement	Standing water was noticed in several areas. Sagging was observed at access MH B. Maximum sag depth was approximately 1.9 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 3.48 inches wide. Several joints were leaking.
Structural Rating	2100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	4 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No mandrel testing was conducted in 1994, and no distress was observed during the video. Mandrel test in 2011 did not pass, radial cracking, joint separation and sagging were observed.

The inspection observed moderate to severe changes of dent (1 ea, construction issue), sagging (1 ea, construction issue), joint offset/separation (4 ea, construction issue) and cracking/fracture (1 ea, construction issue). The maximum pipe deflection was approximately 8.6 percent (2 ea, construction issue). The mandrel stopped (1 ea, construction issue) at pipe end A. In the 250 feet pipe run were observed 10 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 5-1

The research pipe was a 235 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 26738, CS 50052 approximately 20 years ago, from Station 265+57 to Station 263+20 along northbound M-3 (Gratiot Avenue) in Chesterfield Township, Macomb County. The pipe had limited deterioration. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 5-1: Southeast Michigan Site 5-1 Pipe Condition Summary

Surface Observations	Bituminous pavement with cracks. Approximately 6' depth of cover.
Pipe Cracking	No cracking observed.
Wall Distress	No significant wall distress noted.
Mandrel	In 2011 mandrel passed 27% of pipe length. Mandrel stopped at approximately 10.2 feet from access MH A and 54.3 feet from access MH B. No mandrel test was done in 1994.
Deflection	Measureable maximum deflection was approximately 5.6 percent.
Sagging/Settlement	Sagging was noticed near the access MH at both ends of the pipe and at several locations throughout the barrel. Sagging at access MH A was approximately 1.4 inches.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 2.0 inches wide. The coupling design was apparently holding the ends of the pipe apart.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No mandrel testing was conducted in 1994. The 1994 inspection indicated several sags throughout the pipe.

The inspection showed minor changes of joint offset/separation (1 ea, construction issue) and minor sagging in the pipe. Sagging at the manholes and other locations throughout the barrel was probably due to poor backfill. In the 235 feet pipe run was observed 1 anomaly that averaged out to 1 anomaly per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 5-2

The research pipe was a 80 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 26738, CS 50052 approximately 20 years ago, from Station 141+72 to Station 140+92 along southbound M-3 (Gratiot Avenue) in Macomb Township, Macomb County. The continuing pipe deterioration is possibly due to the type of local soils and inadequate bedding. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 5-2: Southeast Michigan Site 5-2 Pipe Condition Summary

Surface Observations	Grass and gravel. Approximately 2' depth of cover.
Pipe Cracking	Numerous radial and longitudinal cracks were observed throughout the pipe. Several multiple cracks were observed. Largest measured crack width was 0.08 inches.
Exposed Reinforcing Steel	Rust/mineral staining was present in several areas, indicating potential corrosion of reinforcing steel at some
Sagging/Settlement	No significant sagging was observed within the pipe.
Joint Condition	Heavy roots were documented coming through joint.
Structural Rating	3824 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	It appeared that the structure had continued to degrade since the last inspection.

The crack with infiltration encrustation at 25-27 feet from access manhole A in the 1994 video and the crack at 61 feet from access manhole A in the 1994 video were determined to be skid marks in 2011/2013. The inspection showed moderate to severe changes of cracking (3 ea, construction issue) and root intrusion (1 ea, post construction issue). The roots coming through the joints will need to be monitored. In the 80 feet pipe run were observed 4 anomalies that averaged out to 5 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 5-3

The research pipe was a 68 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 26738, CS 50051 approximately 20 years ago, from Station 79+42 to Station 80+10 along southbound M-3 (Gratiot Avenue) in Clinton Township, Macomb County. There were stains and exposed aggregate observed, possibly due to scour. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 5-3: Southeast Michigan Site 5-3 Pipe Condition Summary

Surface Observations	Grass cover and gravel pavement. Approximately 1' depth of cover.
Pipe Cracking	Numerous radial and longitudinal cracks were observed throughout the pipe. The largest crack was at joint bell and was 0.58 inches wide.
Exposed Reinforcing Steel	Rust/mineral staining was present in several areas, indicating potential corrosion of reinforcement steel at some.
Sagging/Settlement	Two long areas holding water were observed in the laser profile data. Deepest sag was approximately 1 inch.
Joint Condition	Some fractured bells. Maximum joint separations were 1 to 2 inches wide.
Structural Rating	2316 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	It appeared that the pipe had continued to degrade since the last inspection. Several more cracks were observed that were not included or documented in the previous 1994 inspection.

The inspection showed moderate to severe changes of spalling (1 ea, considered production issue because was not associated with cracks or other structural damage), fracturing/multiple cracks (4 ea, construction issue), joint offset/separation (1 ea, construction issue) and minor sagging. Several of the cracks were larger than 0.10 inches in width. The largest crack was 0.58 inches wide. In the 68 feet pipe run were observed 6 anomalies that averaged out to 9 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 5-4

The research pipe was a 170 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 26738, CS 50051 approximately 20 years ago, from Station 55+30 to Station 57+00 along southbound M-3 (Gratiot Avenue) in Clinton Township, Macomb County. The pipe appears to have lost its shape, and a number of buckled areas have occurred, possibly due to the shallow installation under flexible pavement. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 5-4: Southeast Michigan Site 5-4 Pipe Condition Summary

Surface Observations	Bituminous pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	Cracking was observed in several locations with 0.75 inches maximum width, soil was visible at 46 feet from access MH A.
Wall Distress	Dimpling, puncture, radial and multiple cracking in areas of high deflection.
Mandrel	In 2011 mandrel passed 5% of pipe length. Mandrel stopped at approximately 1.5 feet from access MH A and 7.8 feet from access MH B.
Deflection	Measureable maximum deflection was approximately 11 to 12 percent
Sagging/Settlement	Sagging was noticed in several areas throughout the pipe, 1.3 inches max.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 2.0 inches wide, coupling design holding the ends of the pipe apart..
Structural Rating	3221 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Significant changes had occurred since 1994. Mandrel stopped from MH A at 25 ft in 1994, at 1.5 ft in 2011, from MH B went 4 ft further in the 2011. Significant cracking and dimpling not noted in 1994, were observed in 2011.

The inspection showed severe changes of buckling/dimpling (11 ea, construction issue), crack/fracture/puncture/hole (4 ea, constr. issue) and sagging. Pipe deflection was approximately 11 to 12% (2 ea, constr. issue). The mandrel stopped (1 ea, constr. issue) at pipe end A. The pipe should be monitored for additional signs of impending structural failure. In the 170 feet pipe run were observed 17 anomalies that averaged out to 11 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 5-5

The research pipe was a 253 feet long, 18 inch diameter **plastic** storm sewer installed under contract MDOT JN 26738, CS 50051 approximately 20 years ago, from Station 106+70 to Station 104+10 along northbound M-3 (Gratiot Avenue) in Clinton Township, Macomb County. The pipe appears to have further shape deformation since 1994 inspection. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 5-5: Southeast Michigan Site 5-5 Pipe Condition Summary

Surface Observations	Bituminous pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	No cracking was observed.
Wall Distress	No wall distress was observed.
Mandrel	In 2011 mandrel passed 1% of pipe length. Mandrel in 2011 correlated well with the laser profile data by stopping approximately 10 inches from MH A and 1'-2" from MH B. In 1994 mandrel stopped 5 feet from MH A and 58 feet from MH B. Significant invert flattening was observed.
Deflection	Measureable maximum deflection was approximately 10.8 percent.
Sagging/Settlement	Sagging was noticed in several areas throughout the pipe, max. 1.5" deep.
Joint Condition	Maximum joint separation (joint plastic band width) was approximately 3.5 inches wide, coupling design was apparently holding the ends of the pipe apart.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Mandrel test pull direction results appeared not to correlate between the 1994 and 2011 inspections. Additional deflection had occurred since the 1994 inspection.

The inspection of showed moderate changes of minor sagging, joint offset/separation (2 ea, construction issue) and deflections (3 ea, construction issue). The largest deflection was approximately 10.8 percent. The mandrel stopped (2 ea, construction issue) at pipe ends. In the 253 feet pipe run were observed 7 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-1

The research pipe was a 84 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 91+90 across westbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The blockage observed at mid pipe in 1994 had since been removed, as confirmed by the 2011 inspection. It appears that a catch basin had been constructed and then abandoned where the pipe crosses the curbline. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-1: Southeast Michigan Site 6-1 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with no cracks. Approximately 4' depth of cover.
Pipe Cracking	Two radial cracks were observed (0.03 inches and 0.11 inches wide).
Exposed Reinforcing Steel	No visible steel, rust staining was coming out of radial cracks.
Sagging/Settlement	Sagging was noted in both the 1994 and the 2011 inspections. Maximum sag depth was 1.1 inches in 2011.
Joint Condition	Vertical offsets at joints. Horizontal joint condition was not severe. Maximum joint separations were 1 to 2 inches wide.
Structural Rating	5112 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	3 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	A broken pipe section (confirmed as post installation contractor damage) at 40 feet from access MH A was documented in the 1994 inspection. Additional vertical offsets had occurred at some of the joints in addition to the documented two radial cracks. One of the cracks was at the damaged repaired section and appeared it could be the continuation of a saw cut.

The inspection showed moderate changes including vertical joint offset/separation (3 ea, construction issue) and cracks (1 ea larger than 0.06 inches, construction issue). There was a broken pipe section (1 ea, confirmed as post installation contractor damage). In the 84 feet pipe run were observed 5 anomalies that averaged out to 6 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 6-2

The research pipe was a 51 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 91+90 across eastbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had lost its original shape in vicinity of access MH A. A dip in the pipe grade is possibly due to improper bedding. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-2: Southeast Michigan Site 6-2 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with cracks. Approximately 4' depth of cover.
Pipe Cracking	None.
Wall Distress	Slight compression in inner liner near access MH B.
Mandrel	In 2011 mandrel passed 4% of pipe length, stopping approximately 6.5 feet shorter than in 1994 from MH A (at 1'-6" from A, & 0'-4" from MH B in 2011), indicating additional movement of the pipe. Mandrel did not pass in 1994.
Deflection	Measureable maximum deflection was approximately 8.3 percent. The pipe was deflecting in a uniform ring manner.
Sagging/Settlement	Significant signs of sagging, approximately 1.5 inches deep, were noticeable going into MH B. Slight buckle/inner liner compression was observed at 49 ft from MH A.
Joint Condition	Maximum joint separation was approximately 1 inch wide (not measured).
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Historical performance was indicating that the pipe has continued to sag/deflect outside of access MH B. Mandrel testing did not pass in 1994 or 2011. Pull distance in 2011 was approximately 6.5 feet shorter from MH A.

The inspection showed moderate changes of minor sagging, slight buckling (1 ea, construction issue) and deflection of approximately 8.3 percent (1 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. In the 51 feet pipe run were observed 4 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-3

The research pipe was a 161 feet long, 15 inch diameter **concrete** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, between Station 91+90 and Station 90+25 in the median of 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had generally retained its original condition. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-3: Southeast Michigan Site 6-3 Pipe Condition Summary

Surface Observations	Grass. Approximately 6' depth of cover.
Pipe Cracking	Two radial cracks were observed (0.03 inches and 0.09 inches wide).
Exposed Reinforcing Steel	Spacer ends were exposed. Rust/spacer/mineral staining was observed in different areas.
Sagging/Settlement	Sagging occurred at some of the joints, not noted in the 1994 inspection. Deepest sag area was approximately 0.7 inches.
Joint Condition	Several vertical offsets at joints, horizontal was not severe, water ponding on upstream side of joint. Max. separations were 0.5 to 1.0 inch wide.
Structural Rating	1200 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Limited cracking was mentioned in the 1994 inspection. Measurements in 2011 indicated a radial crack approximately 0.09 inches wide at 157.6 feet from access MH A. Sagging/vertical offset was apparent at some of the joints that were not mentioned in the 1994 inspection. Rust staining was observed in the 2011 inspection, but was not mentioned in the 1994 inspection.

The inspection showed moderate changes of cracks (1 ea, construction issue), minor sagging and minor vertical joint offset/separation. The observed cracks were less than 0.10 inches in width. In the 161 feet pipe run was observed 1 anomaly that averaged out to 1 anomaly per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 6-4

The research pipe was a 53 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 99+75 across westbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had limited deterioration. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-4: Southeast Michigan Site 6-4 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks. Approximately 3' depth of cover.
Pipe Cracking	Two radial cracks were observed (0.07 inches and 0.34 inches wide).
Exposed Reinforcing Steel	Rust staining was coming from one of the cracks.
Sagging/Settlement	Slight sagging, approximately 0.9 inches deep, was occurring at some of the joints. This was not observed in the 1994 inspection.
Joint Condition	A few joints were slightly offset vertically. Maximum joint separations were less than 0.5 inches.
Structural Rating	2111 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No defects were observed in the 1994 inspection. It was apparent the pipe had settled and cracked since the 1994 inspection. Radial cracks had occurred on both ends of the pipe, within 5 feet of each access MH.

The inspection showed moderate changes of fracturing/cracking (2 ea, construction issue). One of the cracks was 0.34 inches in width. In the 53 feet pipe run were observed 2 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 6-5

The research pipe was a 52 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 99+75 across eastbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had, for the most part, preserved its original shape. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-5: Southeast Michigan Site 6-5 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 4' depth of cover.
Pipe Cracking	None.
Wall Distress	No wall distress observed.
Mandrel	In 2011 mandrel passed 93% of pipe length. Mandrel testing passed in 1994, and did not pass in 2011. Mandrel stopped from access MH A at 20'-2", from access MH B at 28'-2".
Deflection	Measureable maximum deflection was approximately 6.0 percent. The pipe was deflecting in a uniform ring manner along its length.
Sagging/Settlement	Water was standing in the pipe, possibly due to a sag at 11 feet from access MH A, approximately 1.5 inches deep.
Joint Condition	Maximum joint separation appeared to be 0.5 inches wide, or less.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No distress was noted in 1994. In 2011, mandrel testing failed and sagging was apparent.

The inspection showed minor to moderate changes of minor deflection and sagging. The measured maximum pipe deflection was approximately 6 percent. In the 52 feet pipe run were observed zero anomalies that averaged out to zero anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 6-6

The research pipe was a 247 feet long, 15 inch diameter **plastic** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, from Station 99+75 to Station 102+25 in the median of 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe condition had continued to deteriorate from 1994, possibly due to bedding settlement. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-6: Southeast Michigan Site 6-6 Pipe Condition Summary

Surface Observations	Grass and gravel. Approximately 6' depth of cover.
Pipe Cracking	Maximum crack was 0.78 inches wide.
Wall Distress	Severe wall distress, cracking, dimpling, cracking, fracturing.
Mandrel	In 2011 mandrel passed 1% of pipe length. Mandrel testing did not pass in 1994 or 2011. Mandrel went approximately 5 ft from each MH in 1994, and approximately 0.5 feet from each MH in 2011.
Deflection	Measureable maximum deflection was approximately 18 percent.
Sagging/Settlement	Pipe contained several deep sags. Max. sag was approximately 1.5 inches.
Joint Condition	Maximum joint separations did not appear to be severe and were 0.5 to 1.0 inches, or less.
Structural Rating	2200 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (subject to downgrade due to excessive fractures) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe) (subject to downgrade due to excessive fractures)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (3 per review in 2013)
Historical Performance	Since 1994 pipe had continued to deflect and crack. Pipe will likely continue to degrade due to observed racking and unequally distributed loading.

The inspection showed moderate to severe changes including minor sagging, crack/fracture/tear (4 ea, construction issue), buckling/dimpling/racking (2 ea, construction issue) and deflections of up to approximately 18 percent.(4 ea, construction issue), some of which could be damage from nearby bridge construction. The mandrel stopped (2 ea, construction issues) at pipe ends. In the 247 feet pipe run were observed 12 anomalies that averaged out to 5 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-7

The research pipe was a 50 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 113+45 across eastbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had lost original shape, possibly due to the heavy traffic above. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-7: Southeast Michigan Site 6-7 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	Severe cracking and fracturing. Max. crack was approx. 0.2 inches wide, radial.
Wall Distress	Dimpling was observed near access MH B.
Mandrel	In 2011 mandrel passed 4% of pipe length. Mandrel testing did not pass in 1994 or 2011. The mandrel data indicated that the pipe has continued to deflect. In 1994, the mandrel went 5 feet from MH A, and 39 feet from MH B. In 2011 the mandrel went 8 inches from MH A and 14 inches from MH B.
Deflection	Measureable max. deflection was approximately 8.2 percent, uniform ring.
Sagging/Settlement	Severe sagging was observed at MH B. Sag depth was approx. 3.4 inches.
Joint Condition	Maximum joint separation was measured as 1.65 inches wide.
Structural Rating	4122 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	Mandrel pull distance has decreased. Fracturing and cracking had occurred that were not documented in 1994.

The inspection showed moderate to severe changes of sagging (2 ea, construction issue), joint offset/separation (2 ea, construction issue), cracking/fracturing (6 ea, construction issue) and buckling/dimpling (1 ea, construction issue). The measured maximum pipe deflection was approximately 8.2 percent (1 ea, construction issue). The mandrel stopped (2 ea, construction issues) at pipe ends. In the 50 feet pipe run were observed 14 anomalies that averaged out to 28 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-8

The research pipe was a 38 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 116+40 across westbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe generally had retained original condition. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-8: Southeast Michigan Site 6-8 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks. Approximately 3' depth of cover.
Pipe Cracking	One radial crack was observed, less than 0.01 inches wide.
Exposed Reinforcing Steel	Rust staining was coming from a radial crack near access MH A.
Sagging/Settlement	Slight sagging was occurring at some of the joints, 1 inch or less.
Joint Condition	Slight vertical offsets at some of the joints, horizontal offset was measured at 1.5 inches wide and 1.91 inches wide.
Structural Rating	1100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	No major defects had occurred since the 1994 inspection. A hairline radial crack was picked up in the 2011 inspection. Some slight sagging was observed at the joints in the 2011 inspection.

The inspection showed moderate changes of joint offset/separation (2 ea, construction issue), minor sagging and minor cracking. The observed crack was less than 0.01 inches in width and was considered to be minor. In the 38 feet pipe run were observed 2 anomalies that averaged out to 5 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-9

The research pipe was a 38 feet long, 12 inch diameter **plastic** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 116+40 across eastbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had lost its original shape, possibly due to the heavy traffic above. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-9: Southeast Michigan Site 6-9 Pipe Condition Summary

Surface Observations	Concrete pavement with no cracks. Approximately 4' depth of cover.
Pipe Cracking	Observed circumferential and longitudinal cracking, max. 0.19 inches wide.
Wall Distress	Severe fracturing was occurring near access MH A, cracking was observed near both access manholes, radial crease in pipe and longitudinal compression in liner were noted.
Mandrel	In 2011 mandrel passed 4% of pipe length. Mandrel testing did not pass in 1994 or 2011. Mandrel data indicated that the pipe has continued to deflect. In 1994, the mandrel went 25 feet from MH A. In 2011 the mandrel went 1.3 feet from MH A and 0 feet from MH B.
Deflection	Measureable maximum deflection was approximately 7.8 percent.
Sagging/Settlement	Maximum sag depth of 1.1 inches. Settlement at access manholes was likely causing the observed pipe distress.
Joint Condition	Maximum joint separations were close to normal <0.5 inches wide.
Structural Rating	3121 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The mandrel pull distance had decreased. Fracturing and cracking were occurring that were not documented in 1994.

The inspection showed moderate to severe changes of fracturing/cracking/crease (4 ea, construction issue) and minor sagging with deflections of up to approximately 7.8 percent (1 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. In the 38 feet pipe run were observed 7 anomalies that averaged out to 18 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 6-10

The research pipe was a 41 feet long, 12 inch diameter **concrete** storm sewer installed under contract MDOT JN 33147, CS 63192 approximately 20 years ago, at Station 113+45 across westbound 12 Mile Road near M-5 in the City of Novi, Oakland County. The pipe had generally retained its original condition. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 6-10: Southeast Michigan Site 6-10 Pipe Condition Summary

Surface Observations	Concrete pavement with cracks. Approximately 3' depth of cover.
Pipe Cracking	Radial crack near access MH A, 0.02 inches wide.
Exposed Reinforcing Steel	Rust staining was coming from a radial crack.
Sagging/Settlement	Maximum sag depth was approximately 1.4 inches.
Joint Condition	Joint offset was observed at 3 locations, at one of them severe (at 33.6 feet from access MH A) with backfill visible. Maximum horizontal separation was approximately 1 inch or less.
Structural Rating	2212 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	Cracking was observed in 2011 that was not noted in 1994. Backfill was now visible in an offset joint that was documented in 1994.

The inspection pipe showed moderate changes including joint offset/separation with visible soils (1 ea, construction issue) and minor sagging and cracking. In the 41 feet pipe run were observed 1 anomaly that averaged out to 2 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 7-1

The research pipe was a 195 feet long, 12 inch diameter **metal** culvert installed under contract MDOT JN 26738A, CS 50052. approximately 20 years ago, along northbound M-3 (Gratiot Ave) in Chesterfield Township, Macomb County. The pipe could not be inspected because it appears to have been removed by a reconstruction project. No sign of either the pipe end sections or the manholes were found at its former location. The 1994 overall condition was evaluated as good.

Table SE 7-1: Southeast Michigan Site 7-1 Pipe Condition Summary

Surface Observations	not inspected in 2011.
Corrosion	not inspected in 2011
Deflection	not inspected in 2011
Sagging/Settlement	not inspected in 2011
Joint Condition	not inspected in 2011
Structural Rating	not inspected in 2011
Structural Rating Index	not inspected in 2011
Field Log Score	not inspected in 2011
Condition Rating	not inspected in 2011
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	not inspected in 2011

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SE Michigan Site 7-2

The research pipe was a 212 feet long (93 feet concrete and 119 feet metal), 12 inch diameter culvert. In 1994 the pipe consisted of two **concrete** segments surrounding a **metal** segment installed under contract MDOT JN 26738A, CS 50052 63192 approximately 20 years ago, from Station 226+20 to Station 224+10 along northbound M-3 (Gratiot Avenue) in Chesterfield Township, Macomb County. The 46 foot south segment has been replaced and extended with 51 feet metal and 43 feet concrete pipe. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 7-2: Southeast Michigan Site 7-2 Pipe Condition Summary

Surface Observations	Grass and concrete driveway pavement. Approximately 2' depth of cover.
Pipe Cracking	Several concrete pipe hairline cracks, most appeared crystallized, possibly the effect of repairs. Maximum concrete pipe crack width was less than 0.01 inches. Holes were observed in the metal pipe with 4.52 inches max. width.
Exposed Reinforcing Steel	Not observed.
Sagging/Settlement	Maximum sag depth was approximately 1 inch.
Joint Condition	Max. joint separation at metal pipe was 0.5 to 1 inches, and at concrete pipe was approximately 2.07 inches wide. Roots were noted in the inspection.
Structural Rating	5437 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (combination of the concrete and metal) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	3 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 (concrete) & 4 (metal) per rating scale from nine (excellent) to zero (failed)
1994 Assessment	3 per rating scale from five (good) to one (poor) (4 for concrete sector and 3 for metal sector per review in 2013)
Historical Performance	Holes in the metal pipe segment were observed both in 1994 and 2011. Aggregate debris was observed in 2011 that was not noted in 1994.

The inspection of the concrete pipe segment showed minor changes including joint offset/separation (2 ea, construction issue), minor sagging and minor cracks. The inspection of the metal pipe segment showed severe changes of puncture holes with visible soil (9 ea, construction issue), offset joints (3 ea, construction issue), deflection more than 10% (2 ea, construction issue) and minor sagging. In the 93 feet minus 3 feet concrete pipe run were observed 2 anomalies that averaged out to 2 anomalies per 100 feet of pipe. In the 119 feet plus 51 feet metal pipe run were observed 14 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 7-3

The research pipe was a 151 feet long, 12 inch diameter **metal** culvert installed under contract MDOT JN 26738A, CS 50052 approximately 20 years ago, along northbound M-3 (Gratiot Ave) in Chesterfield Township, Macomb County. The pipe could not be inspected because it appears to have been removed by a reconstruction project. No sign of either the pipe end sections or the manholes were found at its former location. The 1994 overall condition was evaluated as fair to good.

Table SE 7-3: Southeast Michigan Site 7-3 Pipe Condition Summary

Surface Observations	not inspected in 2011
Corrosion	not inspected in 2011
Deflection	not inspected in 2011
Sagging/Settlement	not inspected in 2011
Joint Condition	not inspected in 2011
Structural Rating	not inspected in 2011
Structural Rating Index	not inspected in 2011
Field Log Score	not inspected in 2011
Condition Rating	not inspected in 2011
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	not inspected in 2011

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 8-1

The research pipe was a 73 feet long, 18 inch diameter **concrete** culvert installed under contract MDOT JN 25576, CS 82022 approximately 20 years ago, at Station 233+40 across Ramp G from southbound Merriman Road to eastbound I-94 in the City of Romulus, Wayne County. The pipe condition had deteriorated since 1994, with cracks and joint separations showing up. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 8-1: Southeast Michigan Site 8-1 Pipe Condition Summary

Surface Observations	Grass and composite/concrete pavement with no cracks. Approximately 4' depth of cover.
Pipe Cracking	Small radial hairline crack at bell and longitudinal hairline crack in crown were observed. Maximum crack width was less than 0.01 inches.
Exposed Reinforcing Steel	No reinforcing steel was exposed.
Sagging/Settlement	Sagging could not be measured exactly because invert was full of water throughout the pipe, but was estimated to be 2.7 inches.
Joint Condition	Joints at both ends of the pipe were separated more than 4.2 inches. Daylight and soils were observed through the joint at one pipe end.
Structural Rating	2411 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The pipe was rated in good condition in 1994 with no mention of joint separation or cracking. Sagging, cracks and joint offsets have appeared since then.

The inspection showed severe changes of joint offset/separation (3 ea, construction issue), sagging (1 ea, construction issue) and cracks. The cracks were less than 0.01 inch in width and were considered to be minor. There were substantial joint separations at the culvert endings. In the 73 feet pipe run were observed 3 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 8-2

The research pipe was a 76 feet long, 18 inch diameter **concrete** culvert installed under contract MDOT JN 25576, CS 82022 approximately 20 years ago, at Station 236+40 across Ramp D from southbound Merriman Road to westbound I-94 in the City of Romulus, Wayne County. The pipe condition had deteriorated since 1994 with new cracks and joint separations showing up. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SE 8-2: Southeast Michigan Site 8-2 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with no cracks. Approximately 4' depth of cover.
Pipe Cracking	Radial cracks at the bell in several areas with some weeping. Longitudinal cracking in the crown. Largest measured crack width was 0.03 inches.
Exposed Reinforcing Steel	No reinforcing steel was exposed.
Sagging/Settlement	No significant sagging was noticed. Culvert end sections at the ends of the pipe were separating. Standing water was approximately 0.9 inches at 17 feet from culvert end A.
Joint Condition	The joints at both ends of the pipe were separated 2 to 4 inches. Daylight and soils were visible between the pipe and the culvert end section A.
Structural Rating	2A13 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	It was apparent that both of the culvert end sections had moved since the 1994 inspection. The largest measured crack width was 0.03 inches. Rust staining, infiltration, and weeping were observed in several areas.

The crack at 43 feet from access manhole A in the 1994 video was determined to be skid mark in 2011/2013. The inspection showed moderate to severe changes of joint offset/separation (2 ea, construction issue), cracks and minor sagging. The largest crack was less than 0.06 inches in width and was considered to be minor. In the 76 feet pipe run were observed 2 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SE Michigan Site 8-3

The research pipe was a 50 feet long, 15 inch diameter **concrete** culvert installed under contract MDOT JN 25576A, CS 82022 approximately 20 years ago, at an I-94 crossover located east of Middlebelt Road in the City of Romulus, Wayne County. The pipe could not be inspected because it appears to have been removed by a reconstruction project. No sign of either the pipe end sections or the manholes were found at its former location. There was no data in the 1994 report for the overall condition of this pipe.

Table SE 8-3: Southeast Michigan Site 8-3 Pipe Condition Summary

Surface Observations	Not inspected in 2011
Pipe Cracking	not inspected in 2011
Exposed Reinforcing Steel	not inspected in 2011
Sagging/Settlement	not inspected in 2011
Joint Condition	not inspected in 2011
Structural Rating	not inspected in 2011
Structural Rating Index	not inspected in 2011
Field Log Score	not inspected in 2011
Condition Rating	not inspected in 2011
1994 Assessment	good (no numerical assessment in the 1994 report) (5 per review in 2013)
Historical Performance	not inspected in 2011

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Bad Axe Site 9-1

The research pipe was a 44 feet long, 36 inch diameter **plastic** storm sewer installed under contract MDOT JN 38022, CS 32032 approximately 10 years ago, from Station 0+244.3 to Station 0+257.5 under the northbound lane of M-53 (North Port Crescent Street) in the City of Bad Axe, Huron County. The observed cracks at the top of the pipe and significant loss of shape are possibly due to bedding and backfill compaction problems. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table BA 9-1: City of Bad Axe Site 9-1 Pipe Condition Summary

Surface Observations	Bituminous pavement with cracks. Approximately 5' depth of cover.
Pipe Cracking	Significant cracking was observed in several areas within the pipe. Max. radial fracture at a joint was 1.53 inches, max. crack was 0.14 inches.
Wall Distress	Buckling/dimpling, cracks through buckled areas.
Mandrel	In 2011 mandrel passed 2% of pipe length. Mandrel stopped near the manholes on each pipe end at approximately 0.33 feet from access MH A and at 0.41 feet from access MH B.
Deflection	Measureable maximum deflection was approximately 9 percent. The area close to access MH A could not be completely profiled. The deflection at this location appeared to be 10 percent or greater.
Sagging/Settlement	Sagging was noticed near the MH at both ends of the pipe and at mid barrel. Maximum sag depth was approximately 3.5 inches.
Joint Condition	Maximum joint separation was 1.53 inches wide.
Structural Rating	4121 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/dimpling (3 ea, construction issue), cracks/fractures (3 ea, construction issue), sagging (1 ea, construction issue) and joint offset/separation (1 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. The deflection, with measured maximum of 9 percent (1 ea, construction issue) was probably result of poor bedding and backfill. The pipe should be monitored for additional signs of impending structural failure. In the 44 feet pipe run were observed 11 anomalies that averaged out to 25 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Bad Axe Site 9-2

The research pipe was a 143 feet long, 36 inch diameter **plastic** storm sewer installed under contract MDOT JN 38022, CS 32032 approximately 10 years ago, from Station 0+257.5 to Station 0+301.0 under the northbound lane of M-53 (North Port Crescent Street) in the City of Bad Axe, Huron County. The pipe was under heavy traffic and has experienced deterioration. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table BA 9-2: City of Bad Axe Site 9-2 Pipe Condition Summary

Surface Observations	Bituminous pavement with no cracks. Approximately 5' depth of cover.
Pipe Cracking	Significant diagonal cracking was observed at some of the joints, with max. width of 1.07 inches.
Wall Distress	Buckling/crease was observed.
Mandrel	In 2011 mandrel passed 4% of pipe length. Mandrel stopped near the manholes on each pipe end at approximately 4.5 feet from access MH A and 1.12 feet from access MH B.
Deflection	Measureable maximum deflection was approximately 7.4 percent.
Sagging/Settlement	Sagging was noticed near the access MH at both ends of the pipe. Sag was approximately 2.2 inches.
Joint Condition	Maximum joint separation was 1.87 inches wide.
Structural Rating	2111 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	2 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/dimpling/crease (1 ea, construction issue), crack/fractures (2 ea, construction issue), joint offset/separation (2 ea, construction issue) and sagging (2 ea, construction issue). The mandrel stopped (2 ea, construction issues) at pipe ends. The pipe should be monitored for additional signs of impending structural failure. In the 143 feet pipe run were observed 9 anomalies that averaged out to 6 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Bad Axe Site 9-3

The research pipe was a 257 feet long, 36 inch diameter **plastic** storm sewer installed under contract MDOT JN 38022, CS 32032 approximately 10 years ago, from Station 0+301.0 to Station 0+379.1 under the northbound lane of M-53 (North Port Crescent Street) in the City of Bad Axe, Huron County. The pipe was under heavy traffic and has experienced deterioration. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table BA 9-3: City of Bad Axe Site 9-3 Pipe Condition Summary

Surface Observations	Bituminous pavement with no cracks. Approximately 6' depth of cover.
Pipe Cracking	Diagonal and multiple cracking were noted at several of the joints. Radial cracking was observed at mid barrel, 0.3 inches wide.
Wall Distress	Racking and buckling/dimpling were observed.
Mandrel	In 2011 mandrel passed 1% of pipe length. Mandrel stopped near the manholes on each pipe end at approximately 1.5 feet from access MH A and at approximately 1.5 feet from access MH B.
Deflection	Measureable maximum deflection was approximately 8.3 percent.
Sagging/Settlement	Sagging was noticed near the MH at both ends of the pipe. Maximum sag depth was 2.1 inches.
Joint Condition	Maximum joint separation was 1.91 inches wide.
Structural Rating	4231 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	3 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/dimpling/crease (2 ea, construction issue), crack/fractures (6 ea, construction issue), joint offset/separation (5 ea, construction issue) and sagging (1 ea, construction issue). The pipe deflection was approximately 8.3 percent (4 ea, construction issue). The mandrel stopped (2 ea, construction issue) at pipe ends. The pipe should be monitored for additional signs of impending structural failure. In the 257 feet pipe run were observed 20 anomalies that averaged out to 8 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

City of Munising Site 10-1

The research pipe was a 60 feet long, 15 inch diameter **plastic** storm sewer installed under contract MDOT JN 11349, CS 02042 approximately 30 years ago, from Station 48+90 to Station 49+50 along northbound of M-28 (Munising Street) in the City of Munising, Alger County. The pipe appears to be an old smooth wall spiral design and the inspection observed punched holes through the pipe walls with the soil visible. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table MU 10-1: City of Munising Site 10-1 Pipe Condition Summary.

Surface Observations	Grass, gravel and bituminous pavement. Approximately 2' depth of cover.
Pipe Cracking	Cracks and fractures in the crown were observed where the crown was starting to invert. Maximum hole size was 1.31 inches.
Wall Distress	The crown was flattened, starting to invert, buckled and cracked. Staining and leakage through the pipe wall were observed in several areas. The pipe appeared to be of the old single wall corrugated profile spiral pipe design.
Mandrel	In 2011 mandrel passed 25% of pipe length. 2011 mandrel data indicated overdeflected pipe at approximately 13 ft from MH A, and at 2 ft from MH B.
Deflection	Measureable maximum deflection was approximately 15 percent or greater.
Sagging/Settlement	Sagging was noticed close to both access manholes. Maximum sag depth was approximately 2.8 inches.
Joint Condition	No major joint separations were observed with 0.5- inches maximum width.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/dimpling (2 ea, construction issue), crack/fracture/hole (4 ea, construction issue) and sagging (2 ea, construction issue). The pipe deflection was approximately 15 percent (1 ea, construction issue). The mandrel stopped (1 ea, construction issue) close to MH B. The pipe should be monitored for additional signs of impending structural failure. In the 60 feet pipe run were observed 10 anomalies that averaged out to 17 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Munising Site 10-2

The research pipe was a 300 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 11349, CS 02042 approximately 30 years ago, from Station 52+50 to Station 49+50 along northbound M-28 (Munising Street) in the City of Munising, Alger County. The pipe appears to be an old smooth wall spiral design and had a substantial amount of hardened sand deposits with signs of significant degradation. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table MU 10-2: City of Munising Site 10-2 Pipe Condition Summary.

Surface Observations	Grass and bituminous pavement. Approximately 2' depth of cover.
Pipe Cracking	Radial cracks and fractures were documented throughout the pipe with visible leakage through walls in several areas & max. hole size of 1 inch.
Wall Distress	Severe cracking and tearing was occurring near MH B with severe grade change. The pipe appeared to be of the old single wall corrugated profile spiral pipe design. Gushing infiltration and soil visible were witnessed.
Mandrel	Mandrel tests could not be conducted because the pipe was not accessible due to narrow access manholes and a pipe end extending into the MH.
Deflection	Max. deflection was approx. 14 percent close to MH B. Significant grade change of the pipe invert there caused non-standard positioning between camera and laser device and possibly affected laser data accuracy.
Sagging/Settlement	Severe sagging near the far access MH B. Sag of approximately 4.6 inches.
Joint Condition	Maximum joint separation was approximately 3.03 inches.
Structural Rating	4321 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	3 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/dimpling (1 ea, construction issue), crack/fracture/holes (7 ea, construction issue), joint offset/separation (6 ea, construction issue), sagging (1 ea, construction issue) and deflections of up to approximately 14 percent (5 ea, construction issues), probably due to poor bedding and backfill. The pipe should be monitored for additional signs of impending structural failure. In the 300 feet pipe run were observed 20 anomalies that averaged out to 7 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

City of Munising Site 10-3

The research pipe was a 208 feet long, 24 inch diameter **concrete** storm sewer consisting of two segments connected by a catch basin. The concrete pipe replaced the original 24 inch diameter plastic pipe that was installed under contract MDOT JN 11349, CS 02042 from Station 52+50 to Station 54+60 along northbound M-28 (Munising Street) in the City of Munising, Alger County. The original plastic pipe was installed approximately 30 years ago. The time of replacement of the plastic pipe with the concrete pipe is not known. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table MU 10-3: City of Munising Site 10-3 Pipe Condition Summary

Surface Observations	Grass and bituminous and concrete pavement with no cracks. Approximately 2' depth of cover.
Pipe Cracking	Hairline cracking with staining, maximum crack width less than 0.01 inches.
Exposed Reinforcing Steel	Not observed, significant rust/mineral staining on sidewalls.
Sagging/Settlement	Sagging could not be measured exactly due to standing water and debris but was estimated to be 3.9 inches deep.
Joint Condition	Maximum joint separation was approximately 1.35 inches wide. Weeping joints were observed. Water/moisture/rust staining was present on the side walls. Three chipped joints were noted.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous performance data was available.

The inspection showed infiltration staining, small chips at joints (3 ea, construction issue), joint offset/separation (2 ea, construction issue) and sagging (1 ea, construction issue). The observed extensive infiltration staining is probably related to the high groundwater table in the area. The accumulation of debris in the drainage system is causing standing water in the pipe. The freeze/thaw effects to the sagging of the shallow installed pipe could not be assessed because of standing water in the pipe. In the 208 feet pipe run were observed 6 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Munising Site 10-4

The research pipe was a 97 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 11349, CS 02042 approximately 30 years ago, from Station 54+60 to Station 55+60 along northbound M-28 (Munising Street) in the City of Munising, Alger County. The pipe appears to an old smooth wall spiral design. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table MU 10-4: City of Munising Site 10-4 Pipe Condition Summary.

Surface Observations	Grass. Approximately 2' depth of cover.
Pipe Cracking	Buckling/fracture was observed at 16.5 feet from access MH A.
Wall Distress	Wall was severely compressed and faulted at 16.5 feet from MH A with the fault/fracture not apparent at the time of the field inspection. The pipe appeared to be of the old single wall corrugated profile spiral pipe design.
Mandrel	In 2011 mandrel passed 0% of pipe length. Mandrel tests could not be conducted from MH A because access was restricted due to small size MH and pipe that extended inside the MH. Mandrel went 0 feet from MH B.
Deflection	Measureable maximum deflection was approximately 7 to 9 percent. Debris, water and the spiral design were affecting the accuracy of the laser data.
Sagging/Settlement	Debris and water in invert in several areas. Sag was approximately 1.8 inches.
Joint Condition	Joint separation less than 2 inches wide & no major distress were observed.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed buckling/fracture (1 ea, post construction damage), sagging (1 ea, construction issue), joint offset/separation (1 ea, construction issue) and deflections of approximately 7 to 9 percent (1 ea, construction issue) that were probably due to poor bedding and backfill, and possibly facilitated by the high groundwater table and the freeze/thaw cycles related to the shallow installation. The mandrel stopped (1 ea, construction issue) at MH B. The pipe should be monitored for additional signs of impending structural failure. In the 97 feet pipe run were observed 5 anomalies that averaged out to 5 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

City of Munising Site 10-5

The research pipe was a 183 feet long, 24 inch diameter **plastic** storm sewer installed under contract MDOT JN 11349, CS 02042 approximately 30 years ago, from Station 55+60 to Station 57+60 along northbound M-28 (Munising Street) in the City of Munising, Alger County. The pipe appears to be an old smooth wall spiral design. The pipe had three segments connected by drainage manholes. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table MU 10-5: Munising Site 10-5 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with cracks. Approximately 2' depth of cover.
Pipe Cracking	Several stained areas throughout the pipe were observed that appear to be material washing through cracks in the pipe wall. Fractures and holes with max. size of 4 inches in the pipe wall and gushers were also identified.
Wall Distress	A hole in the wall of the pipe near MH A was observed. Several cracks and fractures, weeper/gusher infiltration, and soil visible were witnessed.
Mandrel	In 2011 mandrel passed 3% of pipe length. Mandrel test went approx. 3.3 feet from MH A and 2.7 feet from MH B.
Deflection	Measureable maximum deflection was approximately 7 to 9 percent, uniform ring, but pipe slightly racked in some areas. Debris, water and the spiral design were affecting the accuracy of the laser data.
Sagging/Settlement	Debris and water in invert of the pipe with depth of approximately 4.3 inches were observed.
Joint Condition	No major joint separation or distress was observed with max. width of less than 1.0 inch.
Structural Rating	5121 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	4 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	3 per rating scale from nine (excellent) to zero (failed)
Historical Performance	No previous data was available.

The inspection showed infiltration, fractures/cracks/holes (3 ea, construction issue), sagging (1 ea, construction issue) and deflections of approximately 7 to 9 percent (2 ea, construction issue). The mandrel tests stopped (2 ea, construction issues) at pipe ends. The pipe should be monitored for additional signs of impending structural failure. In the 183 feet pipe run were observed 8 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 7-1

The research pipe was a 119 feet long, 18 inch diameter **metal** culvert installed under contract MDOT JN 30894, CS 70023 approximately 20 years ago, from Station 532+75 to Station 531+50 across a crossover in the median of Old M-21 (Chicago Drive) east of Port Sheldon Road in Georgetown Township, Ottawa County. Punching was observed at one location, possibly caused by the installation of a sign pole that has been later removed. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 7-1: Southwest Michigan Site 7-1 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 4' depth of cover.
Corrosion	Moderate corrosion below the springline was observed. Bituminous invert coating is recommended.
Deflection	Pipe was less than 5 percent deflected.
Sagging/Settlement	Maximum sag depth was approximately 1.6 inches. The standing water at the outlet was due to accumulated debris and lack of proper ditching at the outlet.
Joint Condition	Joints appeared to be in good condition with maximum separation of less than 0.5 inches.
Structural Rating	5100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	5 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	5 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	It was apparent that there was damage to the pipe wall - a hole with 4 inches maximum width - possibly due to sign post installation, and moderate corrosion below the springline, which both have occurred since 1994.

The inspection showed moderate to severe changes of sagging (1 ea, construction issue), corrosion (1 ea, considered production issue because not associated with structural damage) and a holes with soils visible (2 ea, post-construction damage). Polymer coating is recommended to control the present corrosion (1 ea, considered production issue because not associated with structural damage). In the 119 feet pipe run were observed 5 anomalies that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SW Michigan Site 7-2

The research pipe was a 142 feet long, 18 inch diameter **metal** culvert installed under contract MDOT JN 30894, CS 70023 approximately 20 years ago, from Station 545+65 to Station 544+30 across a crossover in the median of Old M-21 (Chicago Drive) west of Port Sheldon Road in Georgetown Township, Ottawa County. A dent was observed, possibly caused by a sign pole installation. In the opinion of the field assessment, the test pipe was in overall poor but acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 7-2: Southwest Michigan Site 7-2 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 4' depth of cover.
Corrosion	Moderate to significant corrosion below the springline was observed.
Deflection	Pipe was deflected approximately 10.3 percent at an isolated point load/dent, while the rest of the pipe had not deflected excessively.
Sagging/Settlement	Maximum sag depth of approximately 1.7 inches.
Joint Condition	Joints appeared to be in good condition except for one joint separation. Maximum joint separation was 1.66 inches.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	4 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	It was evident that the dent and sags were in the pipe in 1994, but it appears that corrosion had occurred below the springline since the 1994 inspection.

The inspection showed moderate changes of sagging (1 ea, construction issue), corrosion (1 ea, considered production issue because not associated with structural damage) and joint separation (1 ea, construction issue). Pipe was deflected approximately 10.3 percent (1 ea, post-construction damage) at an isolated point load/dent while the rest of the pipe had not deflected excessively. Moderate to significant corrosion below the springline was observed. Polymer coating is recommended. In the 142 feet pipe run were observed 4 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 10-1

The research pipe was a 35 feet long, 12 inch diameter **metal** culvert installed under a driveway under contract MDOT JN 31083, CS 80041 approximately 20 years ago, at Station 91+49 along westbound M-43 in Arlington Township just east of the City of Bangor, Van Buren County. The pipe had no significant degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 10-1: Southwest Michigan Site 10-1 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 2' depth of cover.
Corrosion	No corrosion was observed.
Deflection	The pipe was less than 5 percent deflected, uniform ring.
Sagging/Settlement	Maximum sag depth or standing water was 0.8 inches.
Joint Condition	Joints appeared to be in good condition, maximum joint separation was 1.17 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	8 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The 1994 inspection documented a sag close to access point B. The 2011 inspection documented standing water/possible sagging being observed close to access point A. The sag data appears to be reversed between the 1994 and 2011 inspections. In 1994 dip was recorded close to access point B. In 2011 sagging was observed in vicinity of access point A only. Minor changes have occurred since the 1994 inspection.

The inspection showed minor changes and that the pipe was in good condition with a joint offset/separation (1 ea, construction issue). In the 35 feet pipe run were observed 1 anomaly that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 10-2

The research pipe was a 35 feet long, 12 inch diameter **metal** culvert installed under a driveway under contract MDOT JN 31083, CS 80041 approximately 20 years ago, at Station 92+43 along westbound M-43 in Arlington Township just east of the City of Bangor, Van Buren County. The pipe had no significant degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 10-2: Southwest Michigan Site 10-2 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 2' depth of cover.
Corrosion	No corrosion was observed.
Deflection	Pipe was less than 5 percent deflected, uniform ring.
Sagging/Settlement	Maximum sag depth or standing water was 1.4 inches.
Joint Condition	Joints appeared to be in good condition. The maximum joint separation was 0.86 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	8 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The pipe appeared to be in good condition. No distress was observed in the 1994 inspection. Slight sagging/standing water was observed in the 2011 inspection.

The inspection showed minor changes and that the pipe was in good condition. In the 35 feet pipe run were observed zero anomalies that averaged out to zero anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 10-3

The research pipe was a 36 feet long, 12 inch diameter **metal** culvert installed under a driveway under contract MDOT JN 31083, CS 80041 approximately 20 years ago, at Station 93+75 along westbound M-43 in Arlington Township just east of the City of Bangor, Van Buren County. The pipe had no significant degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 10-3: Southwest Michigan Site 10-3 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with no cracks. Approximately 2' depth of cover.
Corrosion	No corrosion was observed.
Deflection	The pipe was less than 5 percent deflected, uniform ring.
Sagging/Settlement	Maximum sag depth or standing water was 1.1 inches.
Joint Condition	Joints appeared to be in good condition, maximum joint separation was 0.96 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	8 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The pipe appeared to be in good condition. No distress was observed in the 1994 inspection. Slight sagging was observed in the 2011 inspection.

The inspection showed minor changes and that the pipe was in good condition. In the 36 feet pipe run were observed zero anomalies that averaged out to zero anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 10-4

The research pipe was a 35 feet long, 12 inch diameter **metal** culvert installed under a driveway under contract MDOT JN 31083, CS 80041 approximately 20 years ago, at Station 95+20 along westbound M-43 in Arlington Township just east of the City of Bangor, Van Buren County. The pipe had limited degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 10-4: Southwest Michigan Site 10-4 Pipe Condition Summary

Surface Observations	Grass and concrete pavement with no cracks. Approximately 2' depth of cover.
Corrosion	Corrosion was visible along the edge of the waterline.
Deflection	The pipe had less than 5 percent uniform ring deflection.
Sagging/Settlement	Maximum sag depth or standing water was 1.4 inches.
Joint Condition	Joints appeared to be in good condition. Maximum joint separation was 1.08 inches wide.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No distress was noted during the 1994 inspection. Some slight sagging/standing water was observed in the 2011 inspection, in addition to early signs of corrosion along the lower haunches of the pipe.

The inspection showed moderate changes and that the pipe was in good condition with minor corrosion (1 ea, considered production issue because not associated with structural damage) and a joint offset/separation (1 ea, construction issue). In the 35 feet pipe run was observed 2 anomalies that averaged out to 6 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SW Michigan Site 10-5

The research pipe was a 26 feet long, 12 inch diameter **metal** culvert installed under a driveway under contract MDOT JN 31083, CS 80041 approximately 20 years ago, at Station 112+35 along westbound M-43 in Arlington Township just east of the City of Bangor, Van Buren County. The pipe had limited degradation. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 10-5: Southwest Michigan Site 10-5 Pipe Condition Summary

Surface Observations	Grass and gravel. Approximately 2' depth of cover.
Corrosion	No corrosion noted.
Deflection	Pipe had a rack and flat crown spot and was deflected approximately 7.3 percent.
Sagging/Settlement	Slight sagging that was approximately 0.5 inches deep was noted at 13 feet from pipe end A.
Joint Condition	No joints, one piece of pipe.
Structural Rating	5200 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (Pipe has poor score by this rating system, but actually it appears to be stable, and not severely deflected. This leads to a conclusion that further review and improvements of the NASSCO coding for deflection is needed to better represent pipe condition. (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	5 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	2 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	6 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	Pipe had moderate deflection but should remain stable. No distress was noted in the 1994 inspection. Possibly the pipe had been damaged by a mower and had excessive loads since the 1994 inspection. The 2011 inspection documented damage to a pipe end and two deflected areas that appeared to correlate with above ground wheel tracks.

The inspection showed moderate changes and that the pipe was in good condition. One of the pipe's ends appeared to have been damaged (1 ea, post construction damage) by a mower since the 1994 inspection. The assigned NASSCO Structural Rating of 5200 was a poor score, but the pipe looked stable and not severely deflected. The deflection appeared correlated with the observed aboveground wheel tracks. In the 26 feet pipe run was observed 1 anomaly that averaged out to 4 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various
Pipe Types, Sizes and Depths

SW Michigan Site 11-1

The research pipe was a 98 feet long, 18 inch diameter **metal** culvert installed under contract MDOT JN 29443, CS 61074 approximately 20 years ago, at Station 7+90 across Ramp A from Sternberg Road to northbound US-31 in the City of Norton Shores, Muskegon County. The pipe had limited degradation. The measured pipe length in 1994 was about 20 feet shorter than in 2011 because of distance counter slippage. In the opinion of the field assessment, the test pipe was in overall fair and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW 11-1: Southwest Michigan Site 11-1 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 20' depth of cover.
Corrosion	A few isolated areas of point corrosion/pitting, and a larger area of corrosion in/near the crown were observed.
Deflection	The pipe was deflected less than 5 percent, uniform ring. The end of pipe was crushed.
Sagging/Settlement	Minimal sagging that was less than 0.5 inches deep was observed.
Joint Condition	Joint separations were minor with a maximum width of 0.5 to 1.0 inches.
Structural Rating	5100 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	5 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	3 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	The 1994 data indicated some sagging of the pipe. The 2011 inspection indicated some minor corrosion, sagging, and joint separation. The largest observed change was the damage to the end of the pipe.

The inspection showed moderate changes of pipe end dent (1 ea, post-construction damage), corrosion (2 ea, considered production issue because not associated with structural damage) and minor sagging, but that the pipe was in good condition. In the 98 feet plus 20 feet pipe run were observed 3 anomalies that averaged out to 3 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SW Michigan Site 11-2

The research pipe was a 62 feet long, 18 inch diameter **metal** culvert installed under contract MDOT JN 29443, CS 61074 approximately 20 years ago, at Station 8+00 across Ramp D from southbound US-31 to westbound Sternberg Road in the City of Norton Shores, Muskegon County. The pipe had no significant degradation. The measured pipe length in 1994 was 8 feet shorter than in 2011 because of distance counter slippage. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW MI 11-2: Southwest Michigan Site 11-2 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 5' depth of cover.
Corrosion	No significant corrosion was observed during the inspection.
Deflection	The pipe was deflected less than 5 percent, uniform ring.
Sagging/Settlement	Maximum sag depth was approximately 1.6 inches.
Joint Condition	Joints appeared to be in good condition with less than 0.5 inches wide maximum joint separation.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	4 per rating scale from five (good) to one (poor) (4 per review in 2013)
Historical Performance	There were no observations of distress noted in the 1994 inspection. Some sagging/standing water and minor corrosion was observed in the 2011 inspection.

The inspection showed minor to moderate changes with sagging (1 ea, construction issue), but that the pipe was in good condition. In the 62 feet plus 8 feet pipe run was observed one anomaly that averaged out to 2 anomalies per 100 feet of pipe.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

SW Michigan Site 11-3

The research pipe was a 52 feet long, 18 inch diameter **metal** culvert installed under contract MDOT JN 29443, CS 61074 approximately 20 years ago, at Station 30+25 across Ramp C from Sternberg Road to southbound US-31 in the City of Norton Shores, Muskegon County. The pipe had no significant degradation. The measured pipe length in 1994 was 20 feet shorter than in 2011 2011 because of distance counter slippage. In the opinion of the field assessment, the test pipe was in overall good and acceptable condition for future research. The following table summarizes the inspection findings:

Table SW MI 11-3: Southwest Michigan Site 11-3 Pipe Condition Summary

Surface Observations	Grass and bituminous pavement with no cracks. Approximately 5' depth of cover.
Corrosion	Noticeable corrosion in invert and lower haunch were observed throughout the pipe.
Deflection	The pipe was deflected less than 5 percent, uniform ring.
Sagging/Settlement	Maximum sag depth was approximately 1.3 inches.
Joint Condition	Joints appeared to be in good condition with less than 0.5 inches wide maximum joint separation.
Structural Rating	0000 (max-distress, max-occurrences, 2 nd -max-distress, 2 nd -max-occurrences) (no NASSCO coding for deflection, no rating for deflection and buckling)
Structural Rating Index	1 per rating scale from one (no/minor anomalies) to five (failing/failed pipe)
Field Log Score	1 per rating scale from one (unlikely failure) to five (failure likely in 5 years)
Condition Rating	7 per rating scale from nine (excellent) to zero (failed)
1994 Assessment	5 per rating scale from five (good) to one (poor) (5 per review in 2013)
Historical Performance	No distress was noted in the 1994 inspection. Moderate corrosion and sagging was documented in the 2011 inspection. Application of bituminous liner could help control corrosion.

The inspection showed minor to moderate changes of corrosion in the invert and the lower haunch (1 ea, considered production issue because not associated with structural damage), but the remaining part of the pipe was in good condition. In the 52 feet plus 20 feet pipe run was observed one anomaly that averaged out to 2 anomalies per 100 feet of pipe.

5.3 DISCUSSION BY TEST SITE

5.3.1 Southeast Michigan Site 1 (Waterford and Independence Townships)

A total of three of the four targeted concrete pipe runs were inspected. One pipe run could not be inspected because dewatering was not feasible. The depth of cover was approximately 4 to 6 feet from top of pipe to the surface above. The surface consisted of composite pavement that had settled and cracked at some locations. Sagging in isolated areas was observed at one of the pipe runs. Longitudinal cracking of the road pavement was observed over the sewer trenches. All inspected test pipes showed signs of reinforcement ghosting, possibly due to the spacers that were used for centering the reinforcement cages. Joint separation was not excessive in any of the pipes. Radial hairline cracking was observed at some of the joints and/or at center of pipe barrels in isolated locations. All cracks were less than 0.01 inches wide. Missing joint mastic was noted at some of the joints and hanging mastic was observed at one pipe run. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.2 Southeast Michigan Site 2 (Cities of Pontiac and Auburn Hills)

A total of three concrete pipe runs were inspected. The depth of cover was approximately 3 to 5 feet from top of pipe to the surface above. The surface was grass over some areas and bituminous and concrete pavement over other areas. There was an undergoing reconstruction to bituminous, concrete and composite pavement at the time of the inspection. All of the test pipes had significant cracking, some of which had deteriorated to severe circumferential fracturing. Each pipe had cracks equal to or greater than 0.10 inches. Joint damage, either vertical offset and/or cracking or fracturing was noted at all pipes. Lack of support at the bells or the haunches appeared to be the leading cause of damage of all pipe runs at this site. The site 2-1 and 2-3 pipes showed significant changes compared to data included in the 1994 inspection report. Site 2-3 pipe in 2011 showed signs of significant fracture, slabbing and missing material. On-site photos at the time of the 2011 inspection indicated the roadway at the site 2-3 pipe had been patched, and was overlaid with new bituminous and concrete surface. The observed pipe condition confirmed the necessity that all sewers and culverts be inspected prior to major surface rehabilitation work in order to find out about the needs for pipe repair or replacement. All test pipes at this site were ruled acceptable to be kept in place for future research.

Re-Examination of the 1994 and Subsequent Sewer and Culvert Installations of Various Pipe Types, Sizes and Depths

5.3.3. Southeast Michigan Site 3 (Ypsilanti Township)

A total of five plastic and one concrete pipe runs were inspected. The depth of cover was approximately 3 to 5 feet from top of pipe to the surface above. The surface consisted of grass and composite pavement which had cracked at some locations. For the plastic pipe, from comparison of the mandrel test data of 1994 and 2011, it was apparent that deflections have continued near the manhole (MH) structures. In 1994, four of the five plastic pipes passed the mandrel tests. In 2011, at all five plastic pipes the mandrels stopped at specific deflected points along the pipe runs. For 20 year old installations, the deflections were not considered excessive at 7 percent or less. Wall compression and tension due to settlement and sagging was visible at the inner pipe wall on several of the pipes. Severe change had occurred in the site 3-2 pipe where ripping/tearing and several cracks were observed near MH B. The concrete pipe has shown little change, except an open joint with flowing water was observed. Several of the plastic pipes were showing signs of wrinkling/buckling in the crown, where there was settlement near the access manholes. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.4 Southeast Michigan Site 4 (Macomb & Clinton Townships)

A total of nine plastic pipe runs were inspected. The depth of cover was approximately from 4 to 6 feet from top of pipe to the surface above. The surface consisted of concrete pavement that had cracked at 4 of the 9 locations. The laser profiler data indicated that all of the pipes were deflected in excess of 5 percent. Approximately 70 percent of the pipes did not pass the mandrel test when the mandrel stopped at specific deflected points along the pipe runs. Deflection levels at the site 4-2, 4-3, and 4-4 pipes were 7.6 percent or less. Water at the invert at site 4-1, 4-6, 4-8, and 4-9 pipes affected the laser accuracy when determining the deflection percentage. This was caused by laser light reflected not from pipe invert, but from the present water surface. The 9 point mandrel did not have enough points to capture all of the deflection that the laser did. Sagging was noted in several of the pipe runs, with significant sagging near some of the MH structures. Cracking was reported in some pipe runs. Minor to significant dimpling and/or minor buckling was noted in approximately 60 percent of the pipe runs. The mandrel test data indicated that some of the pipe continued to deflect since the 1994 inspection. All test pipes at this site were ruled acceptable to be kept in place for future research.

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5.3.5 Southeast Michigan Site 5 (Macomb, Clinton & Chesterfield Townships)

A total of three plastic and two concrete pipe runs were inspected. The depth of cover from top of pipe to the surface above was approximately 1 to 2 feet at the concrete pipes, and 3 to 6 feet at the plastic pipes. The surface consisted of grass, gravel and bituminous pavement that had cracked at some locations. Two of the three plastic pipes were over 10 percent deflected, with the third deflected approximately 5.6 percent. The two concrete pipes had a significant number of cracks, with multiple cracks in some locations. Cracks were significantly larger than hairline cracking. The site 5-2 concrete pipe had a maximum crack width of 0.08 inches and the site 5-3 concrete pipe had a 0.58 inches crack at a joint bell. Significant increases to the amount of distress had occurred in most of the pipes since the 1994 inspection. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.6 Southeast Michigan Site 6 (City of Novi)

A total of five plastic and five concrete pipe runs were inspected. The depth of cover was approximately 3 to 6 feet from top of pipe to the surface above. The surface consisted of grass and concrete pavement that had cracked at some locations. A comparison of the mandrel test data between 1994 and 2011 indicated the plastic pipes have continued to deflect near the MH structures. The observed deflections in plastic pipe were as high as 18 percent. Cracking was noted in both the plastic and concrete pipes. Cracks in the concrete pipes were as large as 0.34 inches wide and located in the mid-pipe section, at pipe invert, sidewalls and crown. It appears that most of the distress in both concrete and plastic pipes was due to settlement issues caused by improper bedding and backfill during construction. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.7 Southeast Michigan Site 7 (Chesterfield Township)

One pipe run consisting of both concrete and metal sections along its length was inspected at this site. Two pipes at this site that were previously included in the 1994 study have since been removed. The depth of cover of the remaining pipe at site 7-2 was approximately 2 feet from top of pipe to the surface above. The surface consisted of grass and concrete driveway pavement. It is shown in the 1994 inspection that several defects were noted in both the concrete and metal pipe sections at that time. Based on the number of punctures through the wall of the metal pipe section, it is apparent the pipe was not installed correctly with adequate bedding and backfill and that depth of cover was not enough to protect it from errant vehicles passing through the grass area. The 2011 inspection identified additional punctures in the metal pipe. Two of the joints in the

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concrete pipe had over 2 inches of separation. The separated joints were located in sag areas, likely indicating improper bedding at the time of installation. Corrosion does not appear to have been the major factor in the performance of the metal pipe. The most significant factor appears to be the punctures through the metal pipe wall due to improper installation including insufficient depth of backfill for the site conditions, and improper compaction. It appears the concrete portion of the pipe had several joints that were pulled apart approximately 2 inches due to sagging, in addition to some hairline radial cracking. The inspected test pipe run was ruled acceptable to be kept in place for future research.

5.3.8 Southeast Michigan Site 8 (City of Romulus)

A total of two concrete pipe runs were inspected. A third pipe that was previously included in the 1994 study has since been removed. The depth of cover was approximately 4 feet from top of pipe to the surface above. The surface consisted of grass, concrete and composite pavement. Significant movement had occurred at the pipe end sections of both pipes since the 1994 inspection. The inlet ends of both pipe sites had the largest joint separations, with separations wide enough to allow light visible at the crown of each of the joints. Cracking was more pronounced at the site 8-2 pipe, and was also noted in the 1994 inspection. It appears that rust staining, leakage and infiltration have occurred since the last inspection. The maximum observed crack width was approximately 0.03 inches. It is surmised that water flow had undermined the culvert ends, and the undermining was to continue and cause wider joint gaps. Possible slope creep may be causing the settlement and separation of the pipe from the pipe end sections. The inspected test pipes were ruled acceptable to be kept in place for future research preferably after repair of the culvert end connections.

5.3.9 Central Michigan Site 9 (City of Bad Axe)

A total of three plastic pipe runs were inspected. The depth of cover was approximately 5 to 6 feet from top of pipe to the surface above. The surface consisted of bituminous pavement that had cracked at some locations. All of the pipes had diameter of 36 inches and were deflected 7 percent or more. Early signs of rupturing was observed at the site 9-1 pipe. Radial cracking was observed in some of the barrels, and radial, linear and diagonal cracking was observed at several of the joints. A total of ten cracks were noted in the three pipes. All of the pipes did not allow the mandrel to pass. The mandrel stopped at, or in vicinity of the access manholes. Sagging of pipe was evident near several of the manholes. A longitudinal crease was observed in the wall of all the pipes. All test pipes were ruled acceptable to be kept in place for future research.

5.3.10 Upper Peninsula Site 10 (City of Munising)

A total of four plastic and one concrete pipe runs were inspected. The depth of cover was approximately 2 feet from top of pipe to surface above. The surface consisted of grass, gravel, bituminous pavement with no cracks and concrete pavement with cracks. The plastic pipes appeared to be of the old single wall corrugated profile spiral pipe design. The inspection confirmed this type of pipe profile's tendency to crack over time. The observed staining and leakages on the pipe walls indicated the pipe walls were beginning to crack. At some locations cracks, fractures and holes were allowing sediment to pass through. The plastic pipes at sites 10-1, 10-2 and 10-5 were in poor condition. Two of them had exhibited inverse curvature and the third was damaged, with site 10-2 pipe having severe settlement and cracking/fracturing. Site 10-4 pipe was in better condition than the other plastic pipes, but appeared to have a large buckling/fracture through the wall at 16 feet from manhole A. The observed deflections ranged from 7 percent to 15 percent. Deflections could not be measured precisely because the water present in the sag areas prevented exact laser measurements. All of the pipes at the Munising Site 10, including the concrete pipe, showed signs of infiltration. Spongy grass cover and water gushing with pressure through some of the fractures in the pipe walls made apparent to the research team that the surrounding area had high water table. The concrete pipe had several chipped joints, and signs of infiltration rust/mineral staining at the pipe walls and joints was observed in several of the pipe sections. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.11 Southwest Michigan Site 7 (Georgetown Township)

A total of two metal pipe runs were inspected. The depth of cover was approximately 4 feet from top of pipe to surface above. The surface consisted of grass and bituminous pavement with no visible cracks. Both pipes showed signs of moderate to significant corrosion below the springline, indicating the need for polymer coating. Both pipes were damaged, likely due to construction or post construction activities. The site 7-2 pipe had buckle/dent at a point in the crown that was deflected over 10 percent. The site 7-1 pipe had punctures through the crown of the pipe. The observed damage may have been caused by sign post installation work. The test pipes were ruled acceptable to be kept in place for future research preferably after repair of the dented culvert end section at the site 7-1 test pipe.

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5.3.12 Southwest Michigan Site 10 (Arlington Township, east of City of Bangor)

A total of five short metal pipe runs were inspected. The depth of cover was approximately 2 feet from top of pipe to surface above. The surface consisted of grass and gravel (at 10-5), bituminous pavement (at 10-1 & 10-2) and concrete pavement (at 10-3 & 10-4) with no cracks. Four of the five pipes had less than 5 percent deflection. The site 10-5 pipe was deflected approximately 7.3 percent and had a rack, flat spot, and a crushed end. The deflection in the site 10-5 pipe appeared to coincide with the above ground wheel tracks in the gravel driveway area. Corrosion was noted in one pipe and appeared to be present along the edge of the waterline mark. The pipes are approximately 20 years old, and appear to be in good condition. Protective concrete inlet and outlet end sections, each estimated to cost \$400, could be added to prevent damage to the 12 inch diameter pipe ends. The inspected pipes at this site were all shallow driveway/entrance pipe culverts. It is suggested that future pipe studies to include deeper cross drain culverts that carry heavy bed loads and debris (consisting of sand and stone particles that roll and slide along the stream bed) to explore further pipe condition deterioration. All test pipes at this site were ruled acceptable to be kept in place for future research.

5.3.13 Southwest Michigan Site 11 (City of Norton Shores)

A total of three metal pipe runs were inspected. The depth of cover from top of pipe to surface above was approximately 5 feet for two of the pipes, and 20 feet for the site 11-1 pipe. The surface consisted of grass and bituminous pavement with no cracks. All of the pipes had less than 5 percent deflection except the damaged end of the site 11-1 pipe, which had been crushed. The pipes had metal inlet and outlet end sections that were not able to protect them from maintenance and construction vehicles. A replacement metal end for an 18 inch diameter pipe is estimated to cost about \$200. A replacement concrete end for an 18 inch diameter pipe is estimated to cost about \$500. Minor corrosion was observed at the haunches down to the invert at site 11-3 pipe and at some isolated areas of site 11-2 pipe. Limited to no distress was noted in the previous 1994 inspection. Since the 1994 inspection minor to moderate corrosion and some residual settlement had occurred in some of the pipe. Damage to the end of the site 11-1 pipe was not noted in the 1994 inspection. Application of bituminous coating to the metal culverts can reduce corrosion damage. All test pipes at this site were ruled acceptable to be kept in place for future research, preferably after repair of the dented culvert end section at the site 11-1 test pipe.

5.4 DISCUSSION BY ANOMALY

The observed pipe anomalies can be divided into structural and operational/maintenance anomalies.

5.4.1 Structural and Construction Anomalies

The observed structural and construction anomalies at the “concrete test pipe” were as follows:

- circumferential (radial) cracks – possibly caused by inadequate bedding and/or traffic loads
- longitudinal and spiral cracks – possibly caused by improper bedding and/or heavy traffic loads
- multiple cracks – cracks in close vicinity, possibly caused by heavy traffic loads and improper bedding and backfill at the specific location
- fracture cracks – possibly caused by improper bedding and/or heavy traffic loads
- surface damage on pipe interior – possibly caused by corrosive environment, inadequate mix design and/or insufficient concrete cover over the reinforcement during pipe production
- joint offset/separation – possibly caused by inadequate installation and/or improper bedding technique
- deviations in the vertical alignment - possibly caused by inadequate installation and/or improper bedding technique

The observed structural and construction anomalies at the “metal test pipe” were as follows:

- holes – possibly caused by corrosion, perforation caused by sign pole installation work, or improper backfill
- dents - possibly caused by sign pole installation work, heavy traffic or insufficient backfill cover
- uniform ring shape deformation, racking, invert and crown flattening – possibly caused by inadequate bedding, backfill and/or heavy traffic loads
- pipe end damage – possibly caused by passing construction or maintenance equipment and/or errant vehicles driving over the unprotected pipe ends joint offset/separation – possibly caused by inadequate installation and/or improper bedding and backfill
- deviations in the vertical alignment - possibly caused by inadequate installation and/or improper bedding and backfill technique

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The observed structural and construction anomalies at the “*plastic test pipe*” were as follows:

- wall buckling – reverse curvature or deformation that reduces the structural capability, possibly caused by inadequate bedding and backfill, and/or excessive shape deformation
- crease – indentation associated with wall buckling
- dimpling – local distortion related to wall buckling, or inner liner non-structural response to deflection, possibly caused by inadequate bedding and backfill
- uniform ring shape deformation, racking, invert and crown flattening – possibly caused by inadequate bedding, backfill and/or heavy traffic loads
- cracks – possibly caused by inadequate bedding and/or heavy traffic loads
- holes – possibly caused by significant point loads and/or improper bedding and backfill
- joint separation – possibly caused by improper construction methods
- deviations in the vertical alignment - possibly caused by inadequate installation and/or improper bedding technique

Because of use of salt for roadway deicing in Michigan, it was assumed that all pipe included in the study conveyed liquids that are corrosive for the unprotected metal.

When inspecting for joint separation anomalies the research team considered the following:

Subsection 909.03 of the 2012 MDOT's Standard Specifications for Construction require watertight joints to be used for sewer and culvert installations as per *American Society for Testing and Materials (ASTM) C 443* for concrete pipe, *ASTM F 477* for plastic pipe and *AASHTO M 36* for metal pipe.

Article 7.1.5 of the current ASTM C 443 Standard Specification for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets states that joint design shall provide for opening one side of the outside perimeter of the joint 0.50 inches wider than the assembled position. If proper installation efforts and techniques are used on normal straight lines for newly installed pipe there is no reason to for the joints to be open more than 0.50 inches, similar to offsets observed at the Southeast Michigan Site 1 pipe. This study recommends that MDOT establish for newly installed concrete pipe joint offset within 0.25 inches, with required maximum of 0.75 inches, for watertight gasket performance in accordance with *ASTM C 443* and *Michigan Test Method (MTM) 723* (that references *ASTM C 924M* and *ASTM C969M*).

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Other new concrete pipe maximum joint gaps for curved and other installations can be determined by the manufacturer on an individual pipe joint/size basis, and as allowed by the standards, with the potential use of exterior wrapping filter fabric to prevent infiltration of bedding and backfill fines.

Since the above listed plastic and metal pipe standards do not set a maximum for the joint separations, the various manufactures of flexible pipe can have different allowances. The *MDOT Qualified Products List* includes joints that were confirmed for new flexible pipe installations in accordance with the *Michigan Testing Methods* that reference *ASTM* methods.

In order to place the joint separation issue for the existing test pipe on a common ground, the research considered joint separation allowances that were similar to the concrete pipe joint separation allowances. Joints with visible non-uniform gap around the perimeter and joint separations that are wider than 0.50 inches were measured for all pipe types. Existing pipe joint separations that were wider than 1 inch were considered excessive. The plastic band type joints at southeast Michigan sites 3, 4 and 5 were assumed to be within design limits with an extra 1 inch width for a total of up to 2 inches.

For metal pipe this consideration was in agreement with *Article 26.4.2.4. of the AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update)* that requires new pipe joint opening to not exceed 1.0 inch.

It is suggested a separate study to investigate the allowance for maximum joint separation of different manufactures for different materials of newly installed and existing pipe. The study could be expanded by investigating maximum joint separation allowances for different backfill materials, with and without filter fabric wrapping, as well as proper methods for repairing of leaking and misaligned joints.

AASHTO is currently working on the joint definition issues as stated in the comments of *Article 30.4.2. of the AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update)*. The construction industry will benefit from the results of this work that could set the standard for allowable joint separations.

The deviations in vertical alignment were mostly observed beneath lanes with heavy traffic and in vicinity of drainage structures.

5.4.2 Operational and Maintenance Anomalies

The observed operational and maintenance anomalies were primarily related to sand and gravel accumulations that were clogging the pipe. Probable reasons for such accumulations were sags in the pipeline and holes/voids in the pipe walls allowing backfill infiltration. Often accumulations of sediment occur when the pipe does not have sufficient slope. Corrugations inside the plastic pipe at the Munising site were the reason for significant sand/gravel accumulation that was reducing pipe capacity.

Another observed anomaly was liquid infiltration. While the liquid infiltration stains are not necessarily related to structural anomalies, the observed stream-like infiltrations were often related to structural anomalies like cracks, fractures or holes in pipe walls.

Stainings with possible association to structural anomalies were specifically noted for review and consideration. The “rust” appearance of some stains should not necessarily be associated to steel corrosion, but possibly to presence of lignite aggregates or groundwater iron settlement. Other noted stains could have been due to groundwater discoloring or various dissolved mineral and floating particle settlements.

The corrugation appearance and reinforcement ghosting at some 12 and 15 inch diameter concrete pipe was assumed not to be an anomaly, but a production process outcome that could be within the *AASHTO M-170 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe* standard required by the *MDOT Standard Specifications for Construction*. *AASHTO M-170 (ASTM C-76) Article 8.1.1.* requires minimum 0.75 inches concrete cover over the circumferential reinforcement. *AASHTO M-170 (ASTM C-76) Article 12.1* allows pipe diameter variations up to 0.20 inches. *AASHTO M-170 (ASTM C-76) Article 12.2* allows wall thickness variations up to 5% or 0.20 inches, whichever is greater, which for a 15 inch pipe is 0.75 inches. A study that includes obtaining core samples of the inspected pipe walls is necessary to prove if the production requirements of minimum concrete cover over the reinforcement and of diameter and wall thickness variations had been followed.

5.5 PIPE PERFORMANCE

Most of the test pipe included in the study was installed about 20 years ago, but there was some 10 year old and some 30 year old installed pipe, as presented in **Figure 1**. This range in age provided an opportunity to investigate pipe performance at different service stages.

5.5.1 Pipe Condition Observations

The evaluations from the 2011 study, combined with the information from the study carried out in 1994, provided an opportunity to investigate the change in conditions for the same installations. The observed changes are presented in **Figure 4**.

No observed changes were noted for the following test pipe:

- Three test pipes in City of Bad Axe and five test pipes in City of Munising that were not in the 1994 research.
- Two SE Michigan site 7 test pipes and one SE Michigan site 8 test pipe that were in the 1994 study, but had been subsequently removed by reconstruction projects.
- One SE Michigan site 1 test pipe that could not be inspected in 2011 due to high groundwater levels in the sewer system.

A significant number of the observed anomalies could be traced back to issues arising from the original construction, with the most typical suspected cause being inappropriate bedding and backfilling.

A total of 17 concrete test pipes were compared, and 14 of them (or approximately 82%) had moderate and severe condition change. The 2011 study was able to observe, measure and record in more detail the present-day concrete pipe anomalies than in 1994. This included observations of hairline cracks that were recorded in the 2011 field logs as “too small to measure”. Most of the studied concrete pipe was under commercial roadways, with part of it under highways, highway ramps, driveways and grass roadside.

The primary factor for concrete pipe performance was assessed to be the proper bedding and backfill along the barrel, especially in vicinity of the pipe joints.

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A total of 22 plastic test pipes were compared, and 21 of them (or approximately 95%) had moderate and severe condition change. The 2011 study was able to observe, measure and record in detail the shape deformations changes, in addition to performing the traditional mandrel tests. As shown later in the report, at 5 out of 8, or approximately at 60%, of the plastic test pipes where comparison was possible, the mandrel passed in 1994 but did not pass in 2011. Most of the studied plastic pipe was under commercial roadways, with part of it under driveways and grass roadside.

The primary factor for plastic pipe performance was assessed to be the proper bedding and backfill. Use of proper pipe installation methods and bedding and backfill materials is suggested for adequate distribution of the surface loads, controlling deflection, and limiting development of local anomalies like cracks and buckling .

A total of 11 metal test pipes were compared, and 8 of them (or approximately 73%) had moderate and severe condition change. Part of the studied metal pipe was under residential driveways and the rest was under commercial road crossovers, highway ramps and grass roadside.

For the most part the observed metal pipe performance was deemed not to be directly related with installation issues. The SW Michigan site 10-5 test pipe was probably damaged by a mower and excessive loads since the 1994 inspection. The SW Michigan site 11-1 test pipe was probably damaged by maintenance machinery.

Some metal test pipe was probably damaged by sign installation work performed after 1994. In order to avoid similar damage, it is recommended that sign crews to always have as built plans on hand to see possible culvert and sewer conflicts, and to field stake the exact culvert and sewer locations before sign installation or re-installation work.

5.5.2 Minimum Depth of Cover for Pipe Performance

There has been widespread debate on whether pipe installation depths influence pipe performance. This study provided an opportunity to investigate how pipe performance is influenced by the installation depth. The pipe installation depths recorded during the field inspections are presented in **Figure 6**. The listed depths there are approximate average depths from the surface to the “as constructed” inverts of the pipe ends.

The study observed that nearly all the test pipe had been installed in accordance with the *AASHTO* and *MDOT* minimum required installation depths. Two plastic storm sewer test pipes under driveways in the City of Munising, installed in the early 1980's, did not meet the current *MDOT* minimum depth of cover requirement of 3 feet. Before 1996 the *MDOT Standard Specifications for Construction* did not include directions for use of plastic pipe for application as storm sewers that state requirements for minimum depth of cover.

Article 12.6.6.3 of Section 12: Buried Structures and Tunnel Liners of the AASHTO LRFD Bridge Design Specifications (Spring 2012 Edition) specifies minimum cover for pipe of different size and material type. The minimum cover is measured (see **Figure 5.**) from the top of rigid pavement for metal and plastic pipe, from bottom of rigid pavement for concrete pipe, from top of flexible pavement for concrete pipe and from bottom of flexible pavement for plastic and metal pipe. The minimum cover for structural requirements needs to be calculated by following directions of *Section 12 of the AASHTO LRFD Bridge Design Specifications*, and is dependent on the pipe type characteristics, soil material used in the trench, traffic loads and other listed factors.

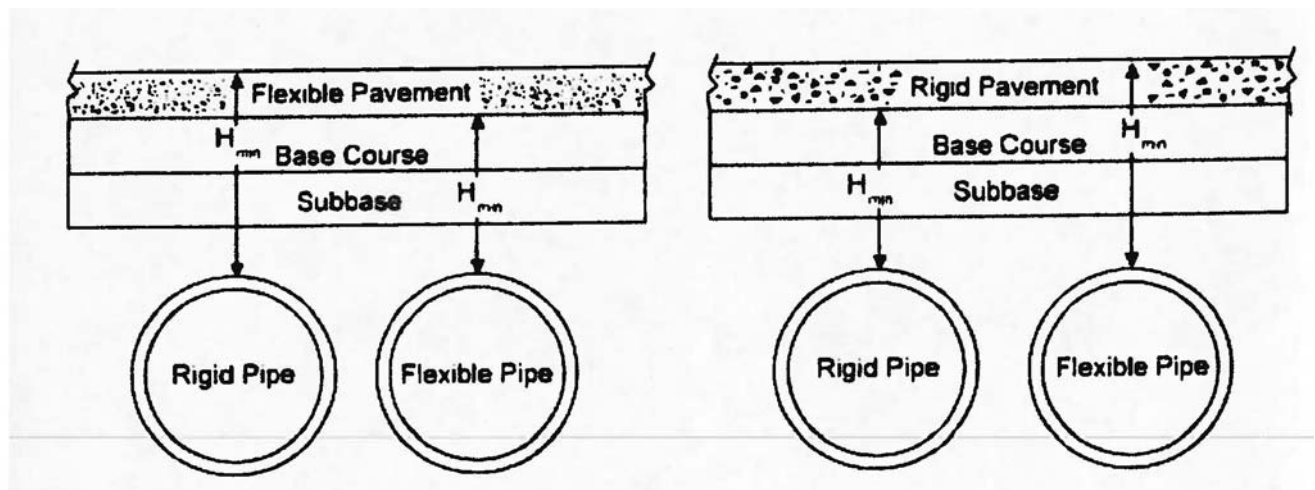


Figure 5 Minimum Cover Orientation

(from *AASHTO LRFD Bridge Design Specifications, Spring 2012 Edition*)

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For the 12 to 36 inch diameter pipe included in the 2011 research, the *AASHTO LRFD Bridge Design Specifications (Spring 2012 Edition)* minimum cover for various pipe installations is as follows:

- for reinforced concrete pipe under unpaved areas – 12 inches
- for reinforced concrete pipe under flexible pavement – 12 inches under top of pavement
- for reinforced concrete pipe under rigid pavement – 9 inches under bottom of pavement
- for plastic pipe under unpaved areas and not subject to traffic loads – 12 inches
- for plastic pipe under rigid pavement – 24 inches under top of pavement
- for plastic pipe under flexible pavement – 24 inches under bottom of pavement
- for metal pipe under unpaved areas – 12 inches
- for metal pipe under flexible pavement – 12 inches under bottom of pavement
- for metal pipe under rigid pavement – 12 inches under top of pavement

All pipe included in the research appeared to have cover that is approximately equal to, or more than, the *AASHTO* minimum requirements indicated above, with exception of two plastic test pipes located under bituminous driveways in the City of Munising and one concrete test pipe under unpaved area in Clinton Township.

It is possible that some of the pipes may require more cover if structural calculations are performed for their specific diameter, material, soil and compaction conditions, and other parameters that are described in detail in *Section 12: Buried Structures and Tunnel Liners of the AASHTO LRFD Bridge Design Specifications (Spring 2012 Edition)*, like installation factor, resistance factors, flexibility factors, crown soil cover factor, axle load correction factor, concrete strength correction factor, bedding factor, vertical load distribution factor, horizontal load distribution factor, etc. Additional cover may also be necessary to avoid the thaw/freeze ground layers.

The 2012 MDOT Standard Specifications for Construction require in *Subsection 401.03.D* that at least 3 feet of cover over the pipe be maintained during construction. Minimum cover is measured from top of pipe to top of the maintained construction roadway surface.

The *AASHTO* minimum cover requirements during construction are specified in the *AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update)* - in *Article 26.6* for metal pipe, in *Article 27.5.4.4* for concrete pipe, and in *Article 30.6* for plastic pipe. For flexible pipe with diameter up to 36 inches the *AASHTO*

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minimum depth of cover is 2 feet before allowing vehicles or construction equipment with maximum 50 kips axle loads to cross the trench surface on the condition that the backfill material is installed to the required density. *AASHTO* requires minimum depth of cover of 3 feet if construction equipment with up to 150 kips axle loads is used on the site. For pipe with diameter up to 36 inches that is included in the study the *AASHTO* minimum depth of cover for concrete pipe is 3 feet, with an option to adjust the minimum required depth of cover after structural evaluation that proves that the construction equipment loads on the pipe do not exceed the pipe design strength.

Except for the driveway culvert installations, the current *MDOT Standard Specifications for Construction* allow only Class IV Reinforced Concrete Pipe beneath influence of pavement when the depth of cover is no greater than three feet. It is recommended that *MDOT* include in their specifications the *AASHTO* requirement listed above, namely, that this pipe have a minimum cover of 9 inches to the bottom of concrete pavement, and a minimum of 12 inches of cover to the surface of the flexible pavement.

The current *MDOT Standard Specifications for Construction* do not specify minimum cover for driveway culverts. It is recommended that *MDOT* include in their specifications the minimum *AASHTO* pipe covers as requirements for driveway culverts, at least for culverts at commercial driveways that are subject to heavy traffic loads.

The 2011 study did not find conclusive evidence for pipe performance problems directly related to depth of cover, but rather possibly related to the lack of proper bedding and backfill. However, the greater depth of cover over the pipe allows for better distribution of traffic loads and thus reducing the problems related to improper bedding and backfill. On the other hand, greater installation depth results in larger static loads from backfill over the pipe. To obtain conclusions regarding the influence of greater installation depth on pipe performance it is recommended that pipe with deeper installations be included in a future study.

One observation that was noted in the 2011 study regarding plastic pipe depth of cover was that limited pavement cracking had occurred at locations with more than 5 feet depth of cover under concrete pavement and with more than 6 feet depth of cover under bituminous pavement.

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No similar observation could be noted for the concrete pipe installations. The composite pavement had cracks at all SE Mi site 1 test pipes, although these concrete pipes had 4 to 6 feet depth of cover.

Considering that both presence of cracks and no cracks were observed in the concrete pavement above the SE Michigan site 6 plastic pipe installations with 4 feet of cover, and the concrete pipe installations with 3 feet of cover, it can be speculated that the dominant factor for pavement performance above sewer and culvert installations is not the depth of cover over the pipe, but rather the quality of the bedding and backfill material installation.

No pavement cracks were observed at the metal test pipe sites. An explanation for that is that these were driveway, crossover and highway ramp installations possibly constructed with bedding, backfill and depth of cover that were adequate for the local soil conditions and traffic loads.

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		CONCRETE PIPE (RCP)			PLASTIC (POLYETHYLENE) PIPE (HDPE)					METAL (CSP)			
		Nominal Diameter	12"	15"	18"	12"	15"	18"	24"	36"	12"	18"	
		Location	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	
1	STORM SEWERS	20 YEARS +/- OLD PIPE											
2		SE	5.9										
3		SE			5.9								
4		SE	7.3										
5		SE		6.6									
6		SE			6.8								
7		SE	4.4										
8		SE	3.9										
9		SE					6.7						
10		SE				4.3							
11		SE				4.5							
12		SE				3.5							
13		SE				5.1							
14		SE	4.5										
15		SE				6.4							
16		SE				5.6							
17		SE						6.9					
18		SE				6.6							
19		SE				6.9							
20		SE				5.7							
21		SE				5.4							
22		SE							7.3				
23		SE							6.6				
24		SE							8.1				
25		SE	3.0										
26		SE	1.7										
27		SE				4.4							
28		SE						6.9					
29	SE	5.7											
30	SE				6.1								
31	SE		7.8										
32	SE	4.2											
33	SE				4.9								
34	SE					7.1							
35	SE				4.6								
36	SE	4.7											
37	SE				5.2								
38	SE	4.3											
39	CULVERTS	SE									N/A		
40		SE	3.3								3.3		
41		SE									N/A		
42		SE			5								
43		SE			5								
44	STORMS SEWERS	30 YEARS +/- OLD											
45		BA								8.7			
46		BA								8.3			
47		BA								9.3			
48		MUN					3.3						
49	MUN						4.3						
50	MUN						4.1						
51	MUN						4.1						
52	MUN						4.4						
53	CULVERTS	20 YEARS +/- OLD											
54		SW										5	
55		SW										5	
56		SW										3	
57		SW										3	
58		SW										3	
59		SW										3	
60		SW										21	
61	SW										6		
		Average installation depths (ft):	4.4	7.2	5.7	5.3	5.7	6.9	5.6	8.8	3.1	8.6	
		Average depth by pipe type (ft):	5.0			5.8					5.6		
		Average depth by pipe size (ft):	12"=	4.6	15"=	6.3	18"=	7.2	24"=	5.6	36"=	8.8	
		TOTAL AVERAGE DEPTH (ft):	5.6										

Figure 6 Installation Depths from Surface to Invert of Pipe



5.5.3 Bedding and Backfill for Pipe Performance

Proper pipe bedding and backfill play major role in achieving acceptable long term pipe performance. Improper bedding and backfill are suspected to be the cause for the majority of anomaly issues exhibited by the test pipes. Suspected improper practices include use of bedding/backfill material with high clay content and inadequate gradation, pipe installation within the thaw/freeze zone, inadequate bedding/backfill structural envelope around the pipe and insufficient compaction.

The MDOT requirements for pipe bedding and backfill are presented in sections 401 and 402 of the *Standard Specifications for Construction* and R-82 and R-83 series of the *Standard Plans*. The AASHTO requirements are presented in Sections 26, 27 & 30 of the *AASHTO LRFD Bridge Construction Specifications* and Section 12 of the *AASHTO LRFD Bridge Design Specifications*.

The AASHTO and MDOT pipe installation requirements were compared for differences in pipe bedding, backfill and installation methods. The following is a list of differences:

- *AASHTO LRFD Bridge Construction Specifications* Articles 26.5.4.1, 27.5.4.3 & 30.5.8.3 specify trench fill material is to be placed in 8 inch layers.
MDOT Standard Specification for Construction subsection 401.03.D specifies that backfill material be placed in layers no greater than 10 inches or half the pipe diameter, whichever is less. It is recommended that MDOT further review if specifying layers no greater than 8 inches or half the pipe diameter, whichever is less, would be beneficial. This review should include a separate study about the cost with detailed analysis based on construction practice data in Michigan provided by major state contractors.
- *AASHTO LRFD Bridge Construction Specifications Article 30.5.8.2* specifies that plastic pipe haunch bedding is to be placed in 6 inch layers.
Neither the *MDOT Standard Specification for Construction* nor the *MDOT Standard Plans* provide direction specifically about the thickness of the layers at the plastic pipe haunch backfill. It is suggested that an additional separate study investigate the effectiveness of this specification. The study should include cost analysis and how the AASHTO recommendations are to be followed.

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- *AASHTO LRFD Bridge Construction Specifications Article 30.3.2.1* specifies plastic pipe backfill material to be free of rock fragments larger than 1.5 inches and a maximum bedding particle size of 1 inch.

MDOT Standard Plans R-83, Details A, B & C specify backfill material Class III, which allows fragments up to 6 inches, and *Detail D* specifies backfill material Class II, which allows fragments up to 3 inches. It is suggested that modified backfill material that excludes large fragments be specified for the details based on additional separate study. That study should recommend bedding and backfill details, reveal contractor issues, make cost evaluations, and provide information about the relation of cost of recommended changes versus pipe longevity.

- *AASHTO LRFD Bridge Construction Specifications Article 26.3.8* specifies metal pipe bedding material to have maximum particle size less than one-half the corrugation depth, and backfill material to be free of rock fragments larger than 3 inches.

MDOT Standard Plans R-83, Details A, B & C specify backfill material Class III, which allows fragments up to 6 inches. It is suggested that modified backfill material that excludes large fragments be specified for the details based on additional separate study. That study should recommend bedding and backfill details, reveal contractor issues, make cost evaluations, and provide information about the relation of cost of recommended changes versus pipe longevity.

- *AASHTO LRFD Bridge Construction Specifications Article 30.5.4* requires plastic pipe trench widths to be not less than 1.5 times the outside diameter plus 12 inches.

Plastic pipe trench width is of importance because it is related both to providing adequate working room and haunch compaction space, and to providing that the backfill bears substantial part of the surface loads, part of which are distributed to trench walls through friction.

AASHTO LRFD Bridge Construction Specifications Article 27.5.2.2 specifies concrete pipe trench widths to be greater than 1.33 times outside diameter or outside diameter plus 24 inches, whichever is greater, or wider if required for adequate space to attain the specified compaction in the haunch and bedding zones.

It is suggested that *MDOT* review through additional separate study if modifications to the current *Standard Plans R-83* trench widths will be beneficial. That study should recommend trench details,

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reveal contractor issues, make cost evaluations, and provide information about the relation of cost of recommended changes versus pipe longevity.

Some of the worst anomalies were observed at the City of Bad Axe test site, which included three 36 inch diameter plastic test pipes installed approximately ten years ago. The research team contacted the MDOT Engineer who oversaw the installation for further information. The Engineer recalled how easy it was for the workers to carry around the 20 foot long 36 inch diameter pipe. As far as he remembered, all the MDOT pipe installation procedures and methods were followed. Still, it can be suspected, that likely inadequate trench compaction played large role in the overall condition of the pipe.

It should be noted that sewer installations of plastic pipe were permitted only for pipe with diameter equal or less than 24 inches by *subsection 402.01 Table 402.1 note (c)* of the *1996 MDOT Standard Specifications for Construction*, current at the time of construction of the Bad Axe test pipes. *Subsection 402.01 Table 402.1 note (e)* of the *1996 MDOT Standard Specifications for Construction* states that 36 inch diameter pipe is approved only for selected state projects and is to be installed according to special provisions. No data was available to the research team about how the 36 inch diameter pipe was allowed and what, if any, special provisions, materials and construction methods were applied for its installation.

The shape deformation of the plastic pipe in the City of Bad Axe could be investigated in the future, together with the other observed anomalies, for more facts about large diameter plastic pipe performance.

5.6 MANDREL TESTING COMPARISON BETWEEN 1994 AND 2011 RESEARCH

Subsection 402.03.C.1 of the 2012 MDOT Standard Specifications for Construction require at least 50 percent installed length of each size plastic pipe be tested for deformation, using a 9 point mandrel sized at 95 percent nominal pipe diameter, after installation, trench backfill and compaction, but before paving.

In the 2011 study 95 percent mandrel (5 percent deflection) nominal pipe diameter evaluations were performed on all plastic pipes included from the 1994 research. The mandrel test results from the 1994 study are presented in **Figure 7**. The mandrel test results for the pipes inspected in the 2011 research are presented in **Figure 8**.

A comparison review between the 2011 and the 1994 mandrel test results indicated that during the 17 year period, most plastic pipes have deflected above the *MDOT* maximum allowed shape deformation for new pipe installation of 5 percent of the nominal pipe diameter. However, the laser profiler data (see **Figure 4**) indicates that most of the shape deformations are below the 90 percent mandrel (10 percent deflection), which is considered by the *Ohio DOT* pipe evaluation system a threshold for satisfactory performance of existing plastic pipe. There is currently no practice in Michigan to allow for the use of a 90 percent mandrel (10% deflection), or other size mandrels, except 95 percent mandrel (5 percent deflection) based on the nominal pipe diameter. However, currently available laser profiler technology can be used to measure various ranges of shape deformations, including a deformation equivalent to 90 percent mandrel (10 percent deflection) of nominal pipe diameter.

Article 30.7.1 of the AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update) specifies a minimum 30 day period after pipe installation, trench backfill and compaction, before the pipe may be inspected. The *MDOT Standard Specifications for Construction* do not have such a requirement. According to *AASHTO*, the 30 day period allows for settlement and deflection development. It is recommended that *MDOT* review the benefits of introducing this *AASHTO* requirement into their specification. The review should include cost analysis based on collected data from the common practice in Michigan, define the expected benefits, review problems and costs associated with additional time constraints on the construction process, and evaluation of the likely response from the motoring public.

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Article 30.7.1 of the AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update) also specifies that all newly installed plastic pipe be inspected to ensure long term performance. Article 30.7.2 then requires that all areas in which deflection was detected visually to be inspected for deflection. This means that if all visually inspected pipe show signs of deflection, then 100 percent of the pipe will need to have separate detailed inspection that proves if the deflection is within the allowable limits.

The current MDOT Standard Specifications for Construction in Subsection 401.03.C.1 require that at least 50 percent of the installed plastic pipe length for each pipe size on a project be tested for shape deformation. This is a greater percentage than what Article 30.7.2 of the AASHTO LRFD Bridge Construction Specifications (2010 Interim, 2011 Update) specifies for inspection that requires at least 10 percent randomly selected pipes of the total number of pipe runs representing at least 10 percent of the total pipe footage on the project to be inspected. In some cases though, if a large part of the installed plastic pipe is visibly deflected, the MDOT at least 50 percent requirement will be less than what AASHTO requires, which could be as high as 100 percent, if all the pipes are reported deflected by the mandatory 100 percent visual inspection.

A separate study could clarify the benefits and potential performance increase if 100% of installed plastic pipe was mandrel or laser tested when new. The study should include information regarding cost increase due to 100% testing instead of the current MDOT practice versus the increase in pipe performance.

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n/a=pipe not accessible for mandrel test		PLASTIC (POLYETHYLENE) PIPE						
		Nominal Diameter	12"	15"	18"	24"	36"	
Location		Total Pipe Length,	Mandrel Test Results in 1994:	Starting from Pipe End A,	Starting from Pipe End B	or	OK = Full Mandrel Pass	
1	STORM SEWERS 20+/- YR OLD	Southwest Michigan Site 3-1	308'	40' from A	20' from B			
2		Southwest Michigan Site 3-2	65'	Mandrel - OK				
3		Southwest Michigan Site 3-3	67'	Mandrel - OK				
4		Southwest Michigan Site 3-4	72'	Mandrel - OK				
5		Southwest Michigan Site 3-5	69'	Mandrel - OK				
6		Southwest Michigan Site 4-1	52'	(no mandrel test)				
7		Southwest Michigan Site 4-2	53'	Mandrel - OK				
8		Southwest Michigan Site 4-3						
9		Southwest Michigan Site 4-4	53'	Mandrel - OK		153'	Mandrel - OK	
10		Southwest Michigan Site 4-5	55'	5' from A	10' from B			
11		Southwest Michigan Site 4-6	65'	(no mandrel test)				
12		Southwest Michigan Site 4-7	51'	(no mandrel test)				
13		Southwest Michigan Site 4-8					262' (no mandrel test)	
14		Southwest Michigan Site 4-9					250' (no mandrel test)	
15		Southwest Michigan Site 5-1					235' (no mandrel test)	
16		Southwest Michigan Site 5-4	170'	3' from A	25' from B			
17		Southwest Michigan Site 5-5						
18		Southwest Michigan Site 6-2	51'	8' from A	n/a from B	253'	5' from A	
19		Southwest Michigan Site 6-5	52'	Mandrel - OK				
20		Southwest Michigan Site 6-6						
21		Southwest Michigan Site 6-7	50'	5' from A,	39' from B			
22		Southwest Michigan Site 6-9	38'	25' from A	0' from B			
23	City of Bad Axe Site 9-1					44' (not in 1994 research)		
24	City of Bad Axe Site 9-2					143' (not in 1994 research)		
25	City of Bad Axe Site 9-3					257' (not in 1994 research)		
26	City of Munising Site 10-1			65'	(not in 1994 research)			
27	City of Munising Site 10-2					296' (not in 1994 research)		
28	City of Munising Site 10-4					112' (not in 1994 research)		
29	City of Munising Site 10-5					68' (not in 1994 research)		

Figure 7 Mandrel Test Results from 1994 Study

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n/a= pipe not accessible for mandrel test		PLASTIC (POLYETHYLENE) PIPE					
	Nominal Diameter	12"	15"	18"	24"	36"	
	Location	Total Pipe Length, Mandrel Test Results in 2011 Starting from Pipe End A, Mandrel Test Results in 2011 Starting from Pipe End B					
1	SE	306' A=12'-4" B=89'-4"					
2	SE	65' A=1'-10" B=3'-2"					
3	SE	67' A=1'-3" B=2'-7"					
4	SE	72' A=2'-0" B=2'-10"					
5	SE	69' A=66'-6" B=1'-9"					
6	SE	52' A=1'-5" B=7'-1"					
7	SE	53' all way pass from A					
8	SE	153' A=28' B=full length of pipe					
9	SE	53' all way pass					
10	SE	55' A=0'-2" B=1'-3"					
11	SE	65' A=3'-4" B=54'-1"					
12	SE	51' A=0'-4" B=1'-1"					
13	SE				262' A=157' B=N/a		
14	SE				250' A=3'-1" B=39'-7"		
15	SE				235' A=10'-2" B=54'-4"		
16	SE	170' A=1'-6" B=7'-10"					
17	SE			253' A=0'-10" B=1'-2"			
18	SE						
19	SE	51' A=1'-8" B=0'-4"					
20	SE	52' A=20'-2" B=28'-2"					
21	SE	50' A=0'-8" B=1'-2"					
22	SE	38' A=1'-4" B=0'-0"	247' A=0'-4" B=0'-7"				
23	City of Bad Axe Site 9-1					44' A=0'-4" B=0'-5"	
24	City of Bad Axe Site 9-2					143' A=4'-6" B=1'-1.5"	
25	City of Bad Axe Site 9-3					257' A=1'-6" B=1'-6"	
26	City of Munising Site 10-1		65' A=12'-11" B=2'-1"				
27	City of Munising Site 10-2				296' A=N/a B=N/a		
28	City of Munising Site 10-4				112' A=N/a B=0'-0"		
29	City of Munising Site 10-5				68' A=3'-3" B=2'-7"		

Figure 8 Mandrel Test Results from 2011 Study

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The following is a comparison list, in percentages, between the mandrel tests performed in 1994 and 2011:

- for site SE Mi 3-1: 306 ft long, mandrel pulled 20 percent of total length in 1994, 33 percent in 2011
- for site SE Mi 3-2: 65 ft long, mandrel pulled 100 percent of total length in 1994, 8 percent in 2011
- for site SE Mi 3-3: 67 ft long, mandrel pulled 100 percent of total length in 1994, 6 percent in 2011
- for site SE Mi 3-4: 72 ft long, mandrel pulled 100 percent of total length in 1994, 7 percent in 2011
- for site SE Mi 3-5: 69 ft long, mandrel pulled 100 percent of total length in 1994, 99 percent in 2011
- for site SE Mi 4-2: 53 ft long, mandrel pulled 100 percent of total length in 1994, 100 percent in 2011
- for site SE Mi 4-3: 153 ft long, mandrel pulled 100 percent of total length in 1994, 100 percent in 2011
- for site SE Mi 4-4: 53 ft long, mandrel pulled 100 percent of total length in 1994, 100 percent in 2011
- for site SE Mi 4-5: 55 ft long, mandrel pulled 27 percent of total length in 1994, 2 percent in 2011
- for site SE Mi 5-4: 170 ft long, mandrel pulled 16 percent of total length in 1994, 5 percent in 2011
- for site SE Mi 5-5: 253 ft long, mandrel pulled 25 percent of total length in 1994, 1 percent in 2011
- for site SE Mi 6-2: 51 ft long, mandrel pulled 16 percent of total length in 1994, 4 percent in 2011
- for site SE Mi 6-5: 52 ft long, mandrel pulled 100 percent of total length in 1994, 93 percent in 2011
- for site SE Mi 6-6: 247 ft long, mandrel pulled 4 percent of total length in 1994, 1 percent in 2011
- for site SE Mi 6-7: 50 ft long, mandrel pulled 88 percent of total length in 1994, 4 percent in 2011
- for site SE Mi 6-9: 38 ft long, mandrel pulled 36 percent of total length in 1994, 4 percent in 2011

The sample size comprising 1994 and 2011 mandrel data consisted of sixteen pipe runs. In 1994, eight of the pipe runs, or 50 percent, passed the mandrel test, while in 2011, only 3 of the pipe runs, or 20 percent passed the test. Note that the three pipes (4-2, 4-3 & 4-4) that retained their shape were located at westbound M-59 in Macomb Township (Southeast Michigan Site 4) and were all installed beneath concrete pavement with 4 to 5 feet depth of cover. It can also be noted that another group of 3 pipes (3-2, 3-3 & 3-4) that cross US-12 (Michigan Avenue) in Ypsilanti Township (Southeast Michigan Site 3) showed a large drop in the mandrel pull lengths from 100 percent in 1994 to single digit percentage mandrel pull lengths in 2011, and were all installed under composite pavement with 3 feet depth of cover.

Soil conditions, bedding, backfill, compaction, type of pavement and traffic loading are all factors that may have contributed to the difference in pipe shape performance at the M-59 (Southeast Michigan Site 4) and US-12 (Southeast Michigan Site 3).

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The percentage changes between the 1994 and 2011 inspections of the pull distances in the mandrel tests derived from data included in **Figures 7 and 8** are presented on **Figure 9** and **Figure 10**.

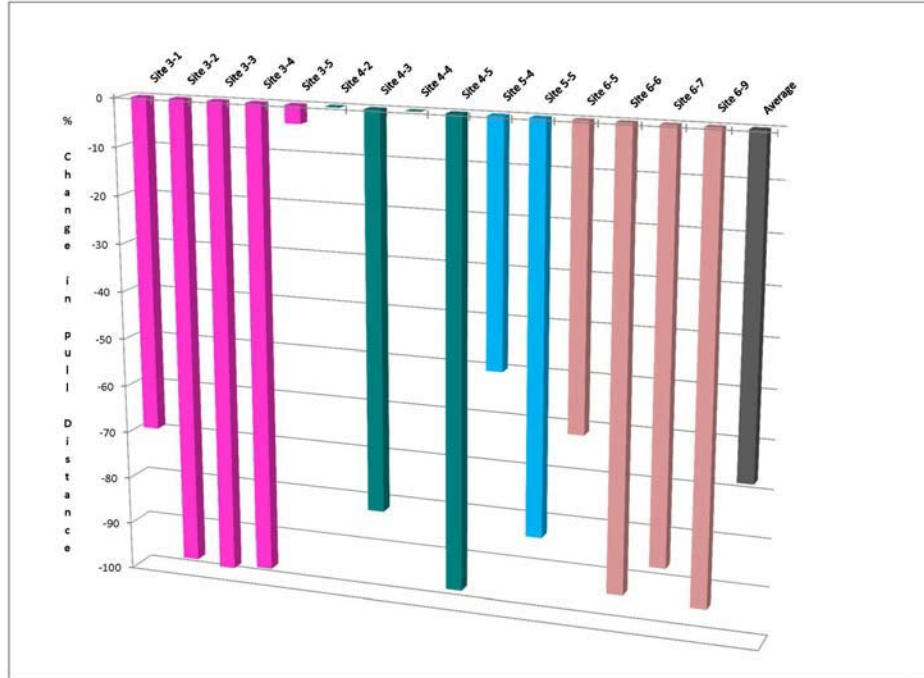


Figure 9 1994 vs 2011 Study Mandrel Pull from MH A Percent Change

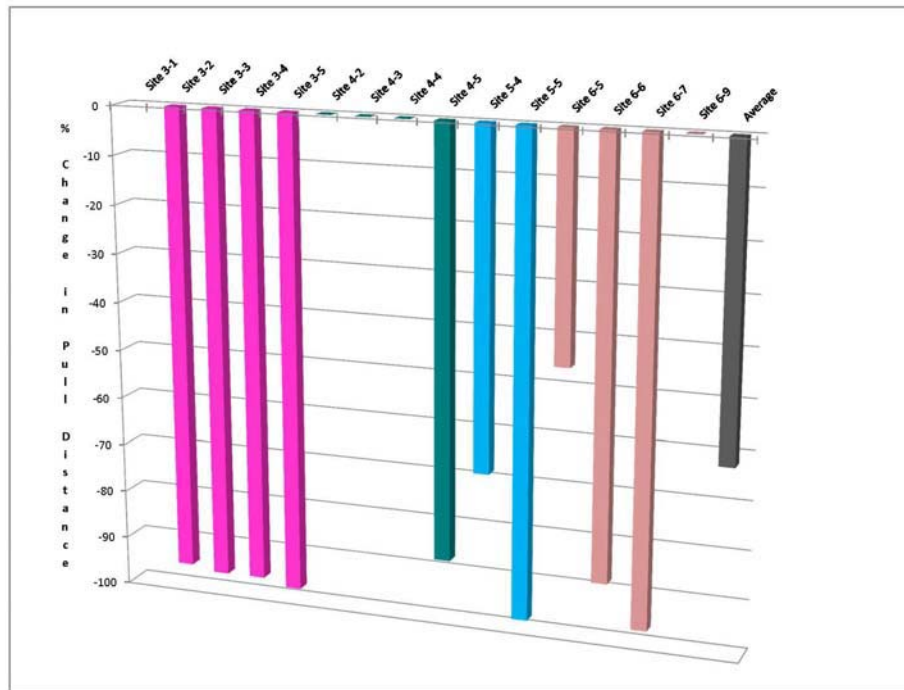


Figure 10 1994 vs 2011 Study Mandrel Pull from MH B Percent Change

5.7 LASER PROFILER SYSTEM

The use of laser profiling allows for remote pipe inspection of anomalies, such as pipe shape deformation, which otherwise cannot be determined with traditional CCTV camera inspections. Currently, there is limited experience in the State of Michigan with the relatively new technology. This research investigates the performance of laser profiler technology using a number of approaches, as discussed below.

The laser profiling system consists of a laser profiling device, data collection and processing software and a camera. Typically, the system is supplemented with a laser micrometer measuring device and an inclinometer.

The laser profiling device emits a laser beam in the form of either a continuous ring or spinning beams that reflects on the inside of the pipe wall. The reflection is recorded by a camera. Currently, analog cameras are used for laser profiling, although it is widely expected that digital cameras will take their place in the future.

The continuous ring laser technology utilizes either one or a series of fixed laser diode heads in a 360 degree configuration that all emit laser beams to create the ring. The number of laser heads is increased for 18 inch diameter and larger pipe to ensure that sufficient laser intensity is created. For 12 and 15 inch diameter pipes, one laser diode head may be sufficient. Where more than one diode head is required, the diode heads are equally spaced around a common holding frame. A ten head laser was necessary for the inspection of the 36 inch diameter plastic pipe located in the City of Bad Axe (see **Figure 2**). Most of the laser ring devices are not mounted on camera transporters. They have their own transporter or slide that is attached to the camera transporter (see **Figure 11**). The continuous ring laser profilers are typically moved through the pipe with speed of 30 feet per minute. The speed is reduced at problem locations where more detailed laser profiling is deemed necessary for better inspection detail.

The spinning beam laser technology utilizes laser diodes that rotate 360 degrees around an axis parallel to the pipe to emit spiraling laser beams. The laser beam projections are recorded by a camera. Although the beam projection is uninterrupted, the camera captures the pipe wall reflection image as dots due to the built in frames per minute limitations. The spinning beam laser diodes are usually attached as a pair, along with the camera, to a common head. They are also used as a micrometer device when performing the video inspection. Although the spinning beam laser profilers can be moved through the pipe with speed of 30 feet per minute in a similar way as the continuous ring lasers, in order to have more data points and increase their

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precision, the speed is often reduced as directed by the Engineer. A discussion of what maximum speed the spinning lasers should have when applied in Michigan is presented in **Appendix G**.

The current practice for performing laser profiling is to insert a camera at one end of the pipe and conduct a traditional CCTV video inspection until the unit reaches the other end of the pipe. Then, on the way back, the camera is utilized to perform the laser profiling by recording the pipe wall reflected light from the laser emitting device.

The current laser profiler systems cannot gather information at beginning and end of the pipe runs. This is due to need for set up space and offset distance between camera and laser device, because of viewing angle limitations of the continuous ring lasers. **Figure 11** and **Figure 12** present the approximate zone that will lack in information.

It should be noted that the Cues, IBAK, and other systems that utilize Cleanflow lasers, have variable areas lacking laser information depending on the inspected pipe diameter. The RST, Aries, and other systems that utilize Coolvision, and the Rausch lasers have information lacking zones that are constant and do not depend on the inspected pipe diameter.

The inclinometer can be a standalone device that can be attached to the camera transporter, or integrated with the camera or laser profiler. Verification of the desired inclinometer accuracy of +/-0.1 percent of the different devices available on the market was outside the scope of this study.

The micrometer device is connected to two laser diodes that are used with the video camera to measure, onscreen over the image, the anomaly dimensions. The micrometer laser diodes are typically integrated with the camera head. The micrometer can be a standalone device connected to the diodes, or a software add on that can be calibrated and measure the dimensions onscreen over the projected image of the anomaly. The accuracy claimed by micro measurement laser vendors was +/-0.01 inches, as listed in **Appendix F**.

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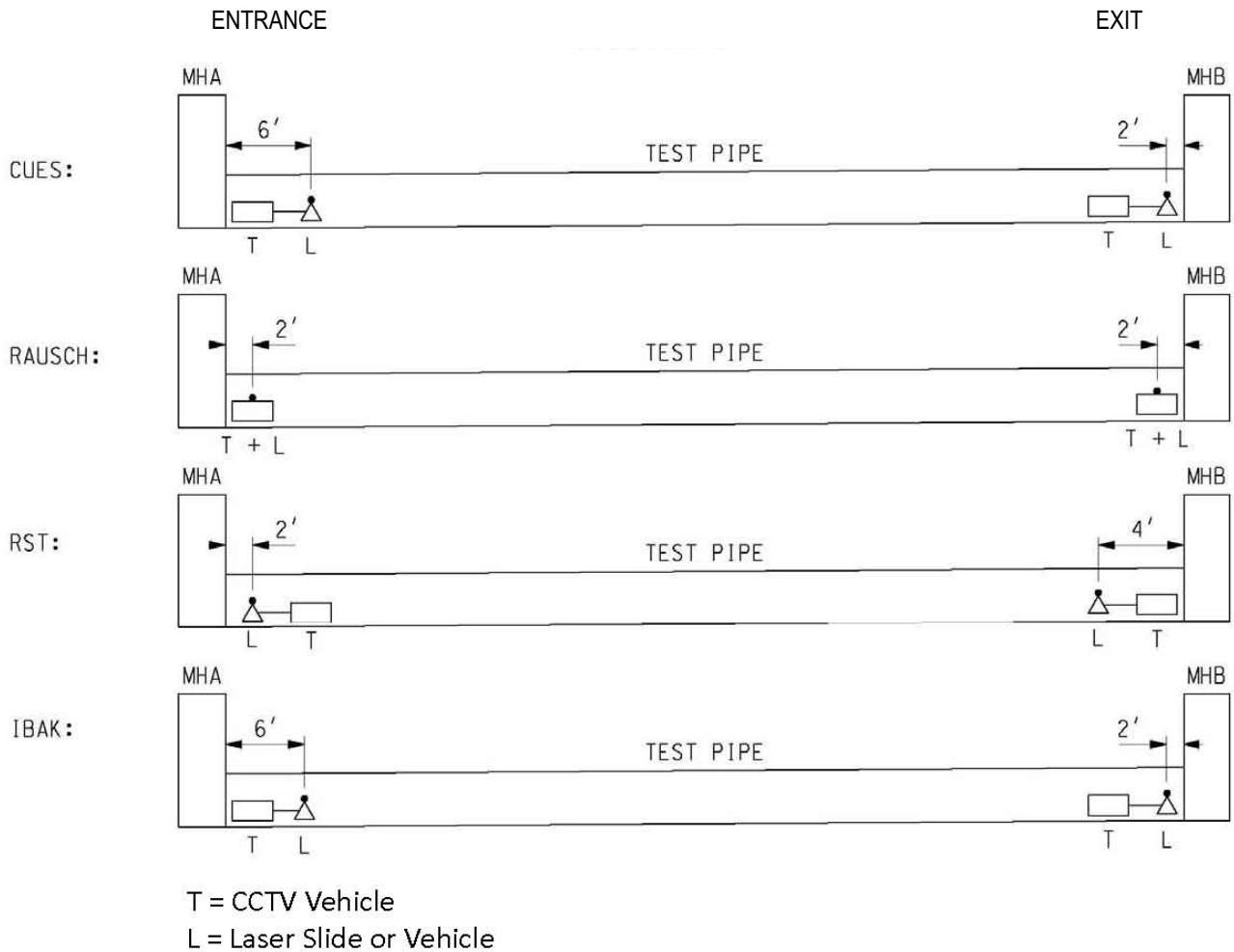


Figure 11 Approximate Zone Lacking Laser Information

- **Cues** – loses 6 feet (+/-) at entrance, 2 feet (+/-) at end of pipe
- **Rausch** – loses 2 feet (+/-) at entrance, 2 feet (+/-) at end of pipe
- **RST** – loses 2 feet (+/-) at entrance, 4 feet (+/-) at end of pipe
- **IBAK** – loses 6 feet (+/-) at entrance, 2 feet (+/-) at end of pipe

Figure 12 Laser Ability to Measure Whole Pipe Run

5.7.1 Laser Profiler Comparison to Mandrel Testing

A Cues/Cleanflow laser profiler system that included CCTV was utilized for inspection of all the test pipes in the 2011 research. Mandrel tests were then performed, when physically possible, on all the plastic pipes in the 2011 research. This provided an opportunity to compare the laser profile pipe deflection results against the mandrel test data.

The comparison details are as follows (“**match**” indicates that both sets of data show pipe shape deformation greater than 5 percent, “**no match**” indicates that the two sets of deflection data differ and do not both show pipe shape deformation greater than 5 percent, A and B designate the points at each end of the pipe, “no laser data” refers to the no laser zones at end of pipes, as presented on **Figure 11** and **Figure 12**):

- for site SE Mi 3-1: laser/mandrel **match** at end A , laser deflection/mandrel **no match** at end B
- for site SE Mi 3-2: no laser data at mandrel stop points*
- for site SE Mi 3-3: no laser data at mandrel stop points*
- for site SE Mi 3-4: no laser data at mandrel stop points*
- for site SE Mi 3-5: laser/mandrel **match** at end A , no laser data at mandrel stop point near end B*
- for site SE Mi 4-1: no laser data at mandrel stop point near end A* , laser/mandrel **match** at end B*
- for site SE Mi 4-2: full mandrel pass, approximate laser **no match** of maximum 5.7 percent deflection
- for site SE Mi 4-3: laser/mandrel **match** at end A, laser/mandrel **no match** from end B
- for site SE Mi 4-4: full mandrel pass, laser/mandrel **no match** (6.1 percent deflection)
- for site SE Mi 4-5: no laser data at mandrel stop points*
- for site SE Mi 4-6: no laser data at mandrel stop point near end A* , laser/mandrel **match** at end B
- for site SE Mi 4-7: no laser data at mandrel stop points*
- for site SE Mi 4-8: laser/mandrel **no match** from end A, no mandrel data from end B*
- for site SE Mi 4-9: no laser data at mandrel stop point near end A* , laser/mandrel **match** at end B
- for site SE Mi 5-1: laser/mandrel **match** from end A, laser/mandrel **match** from end B
- for site SE Mi 5-4: no laser data at mandrel stop point near end A* , laser/mandrel **match** at end B
- for site SE Mi 5-5: no laser data at mandrel stop points*
- for site SE Mi 6-2: no laser data at mandrel stop points*
- for site SE Mi 6-5: laser/mandrel **match** from end A, laser/mandrel **match** from end B

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- for site SE Mi 6-6: no laser data at mandrel stop points*
- for site SE Mi 6-7: no laser data at mandrel stop points*
- for site SE Mi 6-9: no laser data at mandrel stop points*
- for site Bad Axe 9-1: no laser data at mandrel stop points*
- for site Bad Axe 9-2: no laser data at mandrel stop points*
- for site Bad Axe 9-3: no laser data at mandrel stop points*
- for site Munising 10-1: laser/mandrel **match** from end A, no laser data at mandrel stop near end B*
- for site Munising 10-2: no mandrel data**
- for site Munising 10-4: no laser data at mandrel stop points*
- for site Munising 10-5: no laser data at mandrel stop points*

* laser profiling was not possible adjacent to the access manholes due to technology limitations as presented on **Figure 11** and **Figure 12**, see paragraph below:

** mandrel testing was not possible because end of pipe was not accessible to the mandrel shape due to the narrow access manholes

At 20 of the 28 (70 percent) locations with available mandrel data, a comparison with the laser data was not possible because the type of laser technology used in the study was not able to capture the last few feet at the ends of the pipe. It should also be noted that a significant number of the plastic pipe shape deformations were observed in the vicinity of the drainage structures that the pipes were connected to. Thus, the use of laser profiling should be carefully weighed against its inability to collect data at the pipe ends. This is discussed, for the available laser profiler technologies, in the presentation located in **Appendix F** and the laser profiler recommendation provided in **Appendix G**.

When the mandrel stop point data and laser data were both available, there was a match between the two methods in 80 percent of the locations (14 out of 17). It should be pointed out that these were relative matches because the two sets of data had a slightly different basis as explained below:

The nine point mandrels were unable to pass through the pipe where the 5 percent nominal pipe diameter shape deformation was exceeded. The pipe diameter used by the laser profiler to determine pipe shape

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deformations in excess of 5 percent was calculated internally by the laser profiler software. This diameter is not necessarily equal to the nominal pipe diameter.

5.7.2 Laser Profiler System Demonstration, Evaluation and Recommendation

There are currently three laser profiler technologies on the market. Two of them utilize a continuous ring laser technology, while the third utilizes spinning laser beams.

The New Zealand company, CleanFlow Systems, manufactures a continuous ring laser profiler named CLEANFLOW. The Cleanflow software provides both office and onsite data processing capability for the laser operator. More recently, the company was acquired by the U.S. company RedZone Robotics, that has currently retained the laser profiler trademark name, CLEANFLOW.

The Canadian company, C-Tec, makes another type of continuous ring laser profiler named COOLVISION. Currently, all collected laser profiler data from the Coolvision system is required to be sent to the company headquarters for processing. The company plans to introduce onsite operator data processing in the future. However, only 10 percent of the collected Coolvision data would be utilized for this on-site processing even in the future. For complete processing that utilizes 100 percent of the collected Coolvision data, the data will still need to be sent to the Canadian headquarters for processing.

The sole spinning beam laser profiler, named RAUSCH, is made by the German company Wolfgang Rausch, and is distributed and serviced in the United States by its subsidiary, Rausch Electronics USA. The spinning laser profiler is integrated with the Rausch CCTV camera inspection system into one common unit that uses one common transporter. The collected data can be processed onsite.

A laser profiler demonstration event, that included the three available laser profiling technologies, was held at the MDOT garage near the City of Williamston, Michigan. The following laser profiler vendors were invited:

- **Cues, Inc.** of Orlando, Florida, that uses Cleanflow Laser Profiler plus Cues CCTV (presenting on Monday, June 13, 2011)
- **Rausch Electronics USA, LLC** of Chambersburg, Pennsylvania, that uses Rausch Laser Profiler plus Rausch CCTV (presenting on Tuesday, June 14, 2011)

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- **RS Technical Services, Inc.** of Petaluma, California, that uses Coolvision Laser Profiler plus RST CCTV (presenting on Tuesday, June 14, 2011)
- **IBAK Helmut Hunger GmbH & Co./Rapidview, LLC** of Rochester, Indiana, that uses Cleanflow Laser Profiler plus IBAK CCTV (presenting on Wednesday, June 15, 2011)
- **Aries Industries, Inc.** of Waukesha, Wisconsin was invited, but declined to participate in the planned June 2011 testing demonstration. Their technology is similar to that of RS Technical Services, Inc., and uses Coolvision Laser Profiler plus Aries CCTV camera.
- **Envirosight, LLC** of Randolph, New Jersey was invited, but declined to participate in the planned June 2011 testing demonstration. Their technology is similar to that of Cues and that of IBAK, and uses Cleanflow Laser Profiler plus Envirosight CCTV camera.

The event included testing of the devices in concrete, metal and plastic pipes. The vendor test results were compared against physical pipe data collected manually by the research team. The results from each vendor were also compared to the results of the other vendors. A comparative analysis was prepared and presented to *MDOT*. The presentation is provided in **Appendix F**.

The comparative analysis between the different laser profiler technologies provided a basis for a recommendation to be prepared to assist *MDOT* with the decision on which laser profiler to purchase. The recommendation was also based on past and present experience in the use of laser profilers, and on the information learned about each device through the vendor supplied information. The laser profiler recommendation is included in **Appendix G**.

The following basic criteria considerations were included in the comparative analysis:

- Ability to measure pipe diameter deviations, pipe cracks and other pipe anomalies
- Quality and expediency of results/reports, quality of analog CCTV
- Precision and necessary calibrations
- Laser device technology, field operation procedures and safety issues
- Resolving laser profiling issues related to presence of pipe corrugations
- Pipe size ranges and approximate no-laser data zones at end of pipe runs
- Measuring slope with inclinometer
- Option for documenting speed of the crawler when laser profiling

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- Equipment pricing and possibility for upgrade to digital camera
- Optical zoom (min 10:1) and combined digital/optical zoom (min 40:1)
- Adjustable transporter speed and adjustable camera height
- Distance counter
- Inclinator
- CCTV Camera ability to rotate 360 degrees and to pan and tilt 90 degrees
- Camera ability to pan and zoom 360 degrees at every joint and pipe anomaly
- Minimum size of cracks able to be measured (0.01")
- Profiler accuracy (0.5%)
- Profiler repeatability (0.12%)

During the demonstration event, it became apparent that the report output of the different vendor systems varied significantly in format and content. For example: some reports show maximum and minimum diameter graphs; some show only horizontal and vertical plane graphs of the shape deformation; some show a flatout color presentation of the different percentage deformations, while others show an "ovality" graph; which is a summary graph of the maximum deflection registered at different clock positions around the pipe perimeter along the pipe length.

None of the report presentations showed plane graphs that resemble the shape deformations that the edges of a 9 point mandrel encounter during the traditional mandrel test required by the *MDOT Standard Specifications for Construction*. Such graphs would have facilitated the results comparison between the different types of equipment and the mandrel testing.

In order to unify and simplify the differing vendor laser profiling report output, it was suggested that *MDOT* require the reports to contain graphs of diameter deviations in at least six planes, and preferably at eight equally spaced planes; one of which must be vertical, and another horizontal. These graphs would then correspond to a virtual 12 edge, or a virtual 16 edge adjustable mandrel, and thus register the shape deformations in a similar way as a physical 12 edge or 16 edge mandrel.

The six or eight plane shape deformation graphs would then be easy to understand by all participants in the construction process and readily able to compare to the results of a traditional mandrel test. The vendors

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representing the three currently available laser profiler technologies all expressed willingness to introduce this approach in their reporting if it became an *MDOT* requirement.

5.7.3 Laser Profiler Special Provision

The current *MDOT* Special Provision for laser profiler application is 03DS401(D305) “*Laser Inspection of Sewer and Culvert Pipe*”, and is presented in **Appendix H**. It was used as a blueprint to prepare the proposed laser profiler special provision, 12DS402(xxxx) “*Laser Inspection of Sewer and Culvert Pipe*”, also included in **Appendix H**.

The following sources were reviewed during the development of the suggested special provision:

- the *Florida DOT* laser profiler requirements
- the *Ohio DOT* laser profiler requirements
- the *Pennsylvania DOT* laser profiler requirements
- the *Kentucky Transportation Cabinet* laser profiler requirements

In addition, the information obtained from the laser profiler demonstration event was considered during the development of the suggested special provision.

The laser profiling process is a tool to provide benefit to all construction stakeholders. In order to achieve that benefit, the timing of submittal requirements and documents should be well defined. The protocol for laser profiling should be similar to the *MDOT* protocol for video post-installation/pre-paving pipe inspections, except with additional recommended requirements pertaining to the laser profiling. The suggested revisions and additions are presented in the proposed laser profiler specification, and included in the conclusions section of this report.

5.7.4 Laser Profiler, CCTV and Operator Certification

Past experience and comparison with other states was used to determine the suggested vendor certification process for *MDOT* laser profiling implementation. Florida DOT requires an independent laboratory certification, while the Kentucky Transportation Cabinet requires a signed certification by the equipment manufacturer.

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It was determined that neither of the above certifications could be recommended for implementation in Michigan without revisions. A middle ground approach was then explored, that took into account some preliminary discussions with *MDOT* that centered on having an *MDOT* controlled certification process.

The approach discussed was to utilize an *MDOT* controlled and prepared pipe test facility, with parameters and anomaly dimensions that could be measured manually. If the results of the collected laser profiler data meet certain measurement tolerances, in a repeatable way, then the laser profiler system could be *MDOT* certified, and allowed for use on *MDOT* projects. The suggested protocol is presented in the conclusions section of this report.

It is suggested that the operators that run laser profiling equipment be also certified by *MDOT*. The certification process initially could be based on the operator resume, list of laser profiling jobs and client references, similarly to what is currently done in the states of Florida and Kentucky. This certification process could later be supplemented or replaced by written and field technical exams that verify operator knowledge and skills.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The listed conclusions and recommendations pertain to concrete, plastic and metal pipe with the same 12 to 36 inch diameters as the pipe included in the this 2011 study.

6.1 CONCLUSIONS

The research analysis and discussions lead to the following conclusions:

6.1.1 Crack and Shape Deformation Anomalies

- For **new concrete** pipe installations – Based on *Article 27.6.4 of AASHTO LRFD Bridge Construction Specifications, MDOT Standard Specifications of Construction that reference AASHTO M-170 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (ASTM C-76), FHWA Culvert Inspection Manual and Ohio DOT Culvert Management Manual* perform the following: Identify and take measurements of pipe cracks that are 0.01 inches or wider. Prior to installation, reject pipe for any continuous crack having a surface width of 0.01 inches or more and extending for a length of 12 inches or more, regardless of position in the wall of the pipe. As approved by the Engineer, evaluate structurally, repair and seal installed pipe with crack widths from 0.02 to 0.10 inches. Replace pipe with any crack that is more than 0.10 inches wide.

- For **new plastic** pipe installations – Based on *Article 30.7.2 of AASHTO LRFD Bridge Construction Specifications and MDOT Standard Specifications for Construction and Ohio DOT Culvert Management Manual* perform the following: Remove and reinstall, or replace, pipe with nominal diameter reduced by more than 5%. Only reinstall undamaged pipe. Replace pipe with any visible signs of buckling, delamination, cracks or splits.

- For **new metal** pipe installations – Based on *Article 26.5.7 of AASHTO LRFD Bridge Construction Specifications, FHWA Culvert Inspection Manual and Ohio DOT Culvert Management Manual* perform the following: Conduct visual inspection to check for dents or other construction damage. Remove and reinstall, or replace, pipe with nominal diameter reduced by more than 7.5% determined by mandrel test or laser profiling. Only reinstall undamaged pipe. Replace metal pipe with any visible signs of corrosion, cracks or dents.

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- For **existing concrete** pipe installations - Based on *AASHTO LRFD Bridge Construction Specifications*, *FHWA Culvert Inspection Manual*, *Ohio DOT Culvert Management Manual*, and observations of this study, perform the following: Identify and take measurements of pipe cracks that are 0.01 inches or wider. Evaluate structurally, repair and seal pipe with crack widths from 0.02 to 0.06 inches. Evaluate structurally, repair and inspect in 30 years pipe with crack widths from 0.07 to 0.12 inches. Evaluate structurally, repair and inspect in 20 years pipe with crack widths from 0.13 to 0.25 inches. Evaluate structurally, repair and inspect in 10 years pipe with crack widths from 0.25 to 0.50 inches. Unless otherwise approved by the Engineer, consider replacement of pipe with if crack widths greater than 0.50 inches, soil infiltration and loss of bedding and backfill material are observed.

- For **existing plastic** pipe installations – Based on *Ohio DOT Culvert Management Manual* and observations of this study perform the following: Identify and take measurements of any buckling, dimpling, crease, racking, inverse curvature and cracks (splits, cuts, rips, ruptures, fractures, tears, punctures, holes). Inspect the pipe in 20 years if non-structural buckling and dimpling, or cracks (splits, cuts, rips, ruptures, fractures, tears, punctures, holes) less than 0.25 inches wide and up to 6 inches long (with no soil infiltration) are observed. Inspect the pipe in 10 years if minor structural buckling, dimpling, crease and racking, or cracks (splits, cuts, rips, ruptures, fractures, tears, punctures, holes) less than 0.25 inches wide and longer than 6 inches (with no soil infiltration) and cracks (splits, cuts, rips, ruptures, fractures, tears, punctures, holes) from 0.26 to 0.50 inches wide (with no soil infiltration) are observed. Unless otherwise directed by the Engineer, consider replacement of pipe if structural buckling, dimpling, crease and racking, or cracks (splits, cuts, rips, ruptures, fractures, tears, holes) wider than 0.50 inches, soil infiltration and loss of bedding and backfill material are observed.

- For **existing metal** pipe installations – Based on *FHWA Culvert Inspection Manual*, *Ohio DOT Culvert Management Manual* and observations of this study perform the following: Identify and take measurements of any dents and cracks (pitting, pinholes, punctures, holes). Inspect the pipe in 20 years or sooner as directed by the Engineer, if inner surface discoloration is observed. Consider replacement of the pipe, or inspect in 10 years or sooner as directed by the Engineer, if inner surface corrosion or cracks (pitting, pinholes, punctures, holes) are observed. Unless otherwise directed by the Engineer, consider replacement of pipe with cracks (pitting, pinholes, punctures, holes) causing loss of bedding and backfill material or any amount of corrosion with probable cause corrosive soils.

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- For **existing plastic** pipe installations – Based on *AASHTO LRFD Bridge Construction Specifications*, *Ohio DOT Culvert Management Manual* and observations of this study perform the following: Evaluate structurally and inspect in 20 years pipe with nominal diameter shape deformation from 5.1% to 7.5% when subject to traffic loads, and from 7.6% to 10.0% when not subject to traffic loads. Evaluate structurally and inspect in 10 years plastic pipe with nominal diameter shape deformation from 7.6% to 10.0% when subject to traffic loads, and from 10.0% to 15.0% when not subject to traffic loads. Unless otherwise directed by the Engineer, consider for replacement plastic pipe with nominal diameter shape deformation above 10.0% when subject to traffic loads , and above 15.0% when not subject to traffic loads.

- For **existing metal** pipe installations – Based on *AASHTO LRFD Bridge Construction Specifications*, *FHWA Culvert Inspection Manual*, *Ohio DOT Culvert Management Manual* and observations of this study perform the following: Evaluate structurally and inspect in 20 years pipe with nominal diameter shape deformation from 7.6% to 10.0% when subject to traffic loads, and from 10.1% to 15.0% when not subject to traffic loads. Evaluate structurally and inspect in 10 years pipe with nominal diameter shape deformation from 10.1% to 15.0% when subject to traffic loads, and from 15.1% to 20.0% when not subject to traffic loads. Unless otherwise directed by the Engineer, consider for replacement metal pipe with nominal diameter shape deformations above 15.0% when subject to traffic loads, and above 20.0% when not subject to traffic loads.

6.1.2 Joint Separation Anomalies

Measure all joint separations that are wider than 0.50 inches and the separation of all joints with visible non-uniform gap around the perimeter. Consider as excessive joint separations of newly installed concrete pipe that are wider than 0.75 inches, and unless otherwise directed by the Engineer, remove and re-install the pipe. Verify the separation requirements for the flexible pipe joints included in the *MDOT Qualified Products List* as established after testing by the *MDOT MTM-723 Michigan Test Method for Watertightness Testing of Culvert and Sewer Joints Up to 24 inches (600 mm) in diameter*, and by other *MDOT* approved method for the 36 inch diameter pipe included in the study. Unless otherwise approved by the Engineer, replace pipe with signs of soil migration at the joints.

6.1.3 Pipe Performance and Inspection Frequency

Monitor cracking, holes and joint separations, concrete pipe slabbing, plastic pipe deflection, racking, buckling and dimpling, metal pipe deflection and corrosion, and other anomalies occurring in all pipe types, through inspections

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every 10, 20 and 30 years, or other frequency, as determined by the Engineer, and advise for timely replacement before failure.

6.1.4 Laser Profiling and Mandrel Testing

The first few feet at each end of a flexible pipe that cannot be investigated by the laser profiler should be checked with a mandrel. For the remaining length of a flexible pipe run, laser profiling can replace the *MDOT* mandrel tests for plastic pipes and used to determine the shape deformation of metal pipe. It is recommended the laser profiler equipment be certified by *MDOT* prior to use. If a laser profiler system is able to test the entire pipe run, then the laser profiling test can fully replace the mandrel test, as long as the equipment is *MDOT* certified.

Mandrel test verification should be allowed if the laser profiler results are questioned. Mandrel test verification for newly installed metal pipe should follow same procedures as specified for newly installed plastic pipe, except allowing maximum deflection as recommended by this research. The verification testing should be at the expense of the party that has questioned the laser profiler results, as described in the suggested laser profiling special provision presented in **Appendix H**.

Mandrels utilized in Michigan only have the ability to measure a fixed percent of pipe shape deformation that has been exceeded based on the nominal diameter. The laser profiling has the ability to measure varying deformation percentages and can be based on measured diameters, diameters provided by the pipe manufacturer, or the pipe nominal diameters. The precise measurements provided by laser profiling can prove very useful when making conclusions regarding condition and functionality of the inspected pipe, and when considering the difference in cost between repair and replacement.

6.1.5 Laser Profiler Technology Accuracy

The currently available laser profiler technologies can provide practical accuracy and reliability. The calibration of the laser profilers, micrometers and inclinometers should be initially and periodically (recommend annually) tested. After a successful initial test, any of the available laser profiling technologies can be utilized for a period of time defined by *MDOT*. Appropriate training and certification of the laser profiling operators should be established and made a requirement, and confirmed periodically (recommend every 5 years).

6.1.6 Protocol for Laser Profiler & CCTV Post-Installation/Pre-Paving Inspections

Once the pipe is in place and backfill density has been achieved:

- Conduct inspections a minimum of 30 days after pipe installation, backfill and trench compaction
- Conduct the inspection for pipe beneath traffic pavement 5 to 10 working days before pavement surfacing or completion of final grade
- Clean, dewater and divert flow from the pipe that will be inspected
- Use maximum speed of 30 feet per minute for the CCTV camera, the speed must be shown on the screen and recorded
- Use laser profiler to supplement all CCTV camera inspections of all pipe types – concrete, metal and plastic. The potential cost increases are shown at end of this subsection.
- Inspect 100 percent of the length of all newly installed pipes - concrete, metal and plastic
- Utilize for the inspections both a laser profiling special provision and a pipe installation testing form. See examples in **Appendix H** and **Appendix J**.
- Record the inspection results of the project on a Sewer and Culvert Inspection Summary Sheet. See example in **Appendix J**.
- Inspect every joint of every pipe type over 360 degrees around the joint with the camera
- Stop the camera at every anomaly and record its parameters
- Use distance counter measuring device to record the longitudinal location of the anomalies
- Use an inclinometer device to measure and record pipe slope
- Use a laser micrometer device to record crack widths, joint separation widths and other anomalies
- Document the degree of magnification of the camera when utilizing the micrometer device
- Laser profile all pipe types (concrete, metal and plastic) when pulling the camera back
- Use a maximum of 30 feet per minute speed when using a continuous ring laser, with the speed to be shown on the screen and recorded
- Use a maximum of 10 feet per minute speed when using a spinning ring laser, with the speed to be shown on the screen and recorded
- Use mandrel to verify maximum allowable shape deformation at flexible pipe ends that the laser profiler was not able to cover due to equipment capability limitations

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The laser profile inspection is expected to add \$3.00 to the \$1.50 per lineal foot cost of traditional culvert and sewer video inspections, as of recent contracts in Michigan in 2011 and 2012, to a total of \$4.50 per lineal foot, which is similar to the 2012 average unit price of \$4.70 per lineal foot in Kentucky.

The increase covers the laser profiling and micrometer measuring intended to better evaluate pipe condition. The expected lasering add on cost should be doubled to \$6.00 per lineal foot for inspecting isolated pipe runs, and tripled to \$9.00 per lineal foot when dewatering or extensive cleaning are necessary.

For cost estimating purposes we calculated the present worth of laser profiling inspections. The 4% annual discount rate present worth factor costs of \$4.50 per lineal foot pipe inspection are 0.68(10 year present worth factor)x\$4.50=\$3.10 per lineal foot if done in 10 years, 0.46(20 year present worth factor)x\$4.50=\$2.10 per lineal foot if done in 20 years and 0.31(30 year present worth factor)x\$4.50=\$1.40 per lineal foot if done in 30 years.

6.1.7 Protocol for Laser Profiler and CCTV Certification System

- Establish a permanent laser profiler, micrometer, inclinometer, and CCTV camera system test site at an *MDOT* facility
- The test site is to have at least two 40 feet long runs of concrete pipe (one 15 inch diameter run and one 36 inch diameter run), two 40 feet long runs of plastic pipe (one 15 inch diameter run and one 36 inch diameter run) and two 40 feet long runs of metal pipe (one 15 inch diameter run and one 36 inch diameter run).
- Each pipe run shall have at least one pipe joint present to be checked.
- Pipe runs are to have production and/or artificially created test control anomalies
- Manually measure, with appropriate precision, each test control anomaly
- CCTV inspect and laser profile the test pipes with the equipment that is to be certified that needs to be operated by technicians approved in advance by *MDOT* to perform laser profiling work based on resumes, list of past projects and performance references
- Repeat the inspection from the other side of each pipe run
- Compare the results of the two tests to check if they are both within allowable tolerances, and that there is consistency between them

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6.1.8 Laser Profiler Equipment

All three currently available laser profiler technologies can be utilized by *MDOT* certified vendors as long as they meet the *MDOT* equipment certification process. The following is a list of vendors that can potentially supply equipment for performing laser profiling work on *MDOT* projects:

- Cues, Inc. of Orlando, Florida (Cleanflow Laser Profiler)
- Rausch Electronics USA, LLC of Chambersburg, Pennsylvania (Rausch Laser Profiler)
- RS Technical Services, Inc. of Petaluma, California (Coolvision Laser Profiler)
- IBAK Helmut Hunger GmbH & Co./Rapidview, LLC of Rochester, Indiana (Cleanflow Laser Profiler)
- Aries Industries, Inc. of Waukesha, Wisconsin (Coolvision Laser Profiler)
- Envirosight, LLC of Randolph, New Jersey (Cleanflow Laser Profiler)

Any of the listed vendors could replace the current analog cameras with digital cameras as long as the current *MDOT* laser profiling requirements are met.

6.1.9 Laser Profiler Reporting

All laser profiler systems are recommended to include a minimum of six plane shape deformation reporting. One of the planes must be horizontal and another one must be vertical. The reports are also to include micrometer measurements of excessive joint separations, cracks and other anomalies and pipe slope determined with an inclinometer. The micrometers and inclinometers can be integrated in the CCTV or laser systems, or can be standalone devices that will operate in tandem with the other equipment.

6.1.10 Sewer and Culvert Inspection before Major Rehabilitations

Prior to any major road rehabilitation work, during the pre-design or design process, we recommend that *MDOT* inspect all drainage pipes beneath the roadway to identify pipes that require replacement or repair. Inspection costs to check pipes during the design phase could be partially offset by savings from eventually necessary pipe and pavement repair or replacement. It is also recommended that all test pipes used in this research be labeled and mapped, and that the *MDOT* staff be informed that the pipes should be kept intact for future research.

6.1.11 Sewer and Culvert Sagging Control

Pipes can fail due to sagging that once started can continue over time. Laser profiling and inclinometer measurements can be used to detect and show sags. The *MDOT Standard Specifications for Construction* could be

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strengthened to address specific measures regarding pipe sagging and grade changes. The approach utilized by other states can be investigated to provide guidance on how to address the issue.

6.1.12 Bedding and Backfill at Sewer Manholes under Traffic

The study found that significant amount of pipe settlement and deflection problems appear in sewer manhole vicinity. Pipe and pavement performance at sewer manholes located under traffic can be improved by compaction of the underlying native soils to minimum 95 percent of maximum unit weight and placing crushed stone bedding and backfill compacted to minimum 95 percent of maximum unit weight within the sewer manhole excavation limits instead of Class II and III material, as required in *subsections 401.03.D and 403.02 of the MDOT Standard Specifications for Construction and Standard Plans R-1*.

In order to provide the recommended single crushed stone backfill gradation for all bedding and backfill conditions, the selection of the gradation should consider the worst case condition that is to include unstable soils and high groundwater table. The gradation should prevent soil migration into the bedding and backfill, and should be in accordance with *AASHTO LRFD Bridge Design Specifications Article 12.4 Soil and Material Properties, AASHTO M-145 Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes and ASTM D 2321 Standard Practice for Underground Installation of Thermoplastic Pipe Sewers and Other Gravity-Flow Applications*. Detailed investigation and design should be performed for the proposed crushed stone bedding and backfill so that they are constructed to achieve maximum effectiveness.

Preliminary assessments suggest that this change is cost neutral but may eliminate traffic disruptions caused by future repairs. Three cubic yards of crushed stone installed under and around the sewer manhole will cost an additional \$84.00. This is approximately equivalent in cost to a \$76.00 6 feet long by 6 feet wide pavement repair patch around the sewer manhole made 25 years after the initial construction, not including traffic control and other miscellaneous costs that are case specific. The estimate was based on the following assumptions:

- Approximately 6 cubic yards sewer manhole excavation volume of 6 feet average length by 6 feet average width by 4.5 feet average depth at bottom of excavation
- Approximately 3 cubic yards volume occupied by a 4 foot diameter sewer manhole at 4.5 feet average depth
- \$39.00/cubic yard crushed stone cost, equal to the average unit price of 6A aggregate utilized in recent contracts in Michigan in 2011 and 2012

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- \$11.00/cubic yard Class III trench backfill cost based on the average unit price of compacted structural backfill used for backfill at sewer manholes under traffic in recent contracts in Michigan in 2011 and 2012
- \$50.00/square yard pavement patch removal and repair cost based on recent contracts in Michigan in 2011 and 2012
- Necessity for pavement repair in 25 years caused by sewer manhole settlement
- Use of the 25 year present worth factor of 0.38 that corresponds to 4% annual discount rate
- Use of the following additional cost equation: 3 cubic yards of backfill 6A aggregate x (\$39.00/cubic yard - \$11.00/cubic yard)=\$84.00
- Use of the following pavement patch repair cost equation: 4 square yards x \$50.00/square yard = \$200 per sewer manhole location
- Use of the following 25 year present worth pavement repair cost equation: = \$200 x 0.38 (present worth factor) = \$76.00 per sewer manhole location

The study observed cracks in the pavement or the curb and gutter at 29 of 58 (or 50%) inspected sewer manholes that were located within influence of traffic. Some of the sewer manholes had the pavement around them repaired in the past with new cracking showing at and around the repairs.

If an assumption is made that pavement repairs at sewer manholes are needed 25 years after the initial construction, the total repair cost at a manhole will be the \$76.00 direct cost plus assumed another \$76.00 for maintaining of traffic and other miscellaneous costs related to repairs of damage caused to vehicles by substandard pavement, public relations management, scoping, design and construction engineering. The total additional cost will then be \$76.00+\$76.00=\$152.00 per manhole.

For a sample of 10 arbitrary manholes like these included in the study, the additional bedding and backfill cost will be $10 \times \$84.00 = \840.00 . If it is assumed that the pavement at 50% of them will need repairs in 25 years, then the total repair cost will be $0.50 \times 10 \times \$152.00 = \760.00 , i.e. similar cost to what the additional bedding and backfill will cost.

The estimation calculations above show that the additional \$84.00 per manhole for improved bedding and backfill will be cost neutral when pavement restoration would have been necessary within 25 years if traditional manhole

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installation is applied and pavement at 50% of the manholes cracks to the point that repairs become necessary. The validity of the assumptions above needs to be confirmed by a separate statewide study.

No parallel cost effectiveness conclusion can be made for manholes that are not located under pavement because similar calculation that involves pavement restoration cannot be applied, and unless there is failure, the manholes remain in operation.

6.1.13 Pipe Bedding and Backfill

Concrete, metal and plastic pipe performance can be improved by use of modified *MDOT 2012 Standard Specifications for Construction* Class I bedding and backfill material compacted to minimum 95 percent maximum unit weight. The gradation modification of the *MDOT* Class I material should include maximum particle size as required by *AASHTO LRFD Bridge Construction Specifications Article 26.3.8 Bedding and Backfill Materials, Article 27.3 Materials* and *Article 27.5 Installation*, and *ASTM D 2321 Standard Practice for Underground Installation of Thermoplastic Pipe Sewers and Other Gravity-Flow Applications*. The maximum recommended particle size is 1 inch.

The use of modified Class I aggregate material is expected to add approximately \$2.00 per lineal foot to the pipe installation cost. This estimate was based on the following assumptions:

- \$15.00/cubic yard modified Class I material cost. There is no average unit price data from recent Michigan contracts for Class I material because it is not a separate pay item in the recent *MDOT Standard Specifications for Construction*. The price estimate is based on extrapolation of the difference in price between Class III (\$11.00/cubic yard) and Class II (\$14.00/cubic yard) structural backfills considering the difference of the “Loss by Washing” percentages of the Class I, Class II and Class III material
- \$11.00/cubic yard Class III trench backfill cost based on average unit price of compacted structural backfill of recent contracts in Michigan in 2011 and 2012
- \$14.00/cyd Class II trench backfill cost based on the average unit price of compacted structural backfill of recent contracts in Michigan in 2011 and 2012
- 0.5 cubic yards/lineal foot of pipe bedding and backfill material based on 3.5 feet by 4 feet average bedding and backfill structural envelope in the trench around the pipe

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Class I material has 5 percent maximum, Class II material has 7 percent maximum, and Class III material has 15 percent maximum Loss by Washing requirement according to Table 902.3 of the 2012 MDOT Standard Specifications for Construction.

No notable savings are expected through reduction in inspection cost during construction. A separate detailed investigation is necessary to determine if savings could be realized with less periodic pipe inspections than the current practice. Detailed studies are necessary to evaluate if any lifespan cost savings can be realized because structural failures that necessitate replacement are rare, and unless there is structural failure, drainage pipe typically is not replaced.

The practical and visible advantage of improved pipe bedding and backfill is likely reduced pavement cracking above the pipe. Detailed life cycle studies could evaluate how pipe performance influences pavement condition.

We estimate that pavement repair necessitated by notable pavement cracks or sags instigated by underlying pipe will cost approximately \$12.50 per lineal foot of pipe. This estimate is based on the following assumptions:

- 6 foot wide pavement replacement patch x 1 foot length = 0.66 square yards repair area per lineal foot of pipe
- \$50.00/square yard pavement patch removal and repair cost based on recent contracts in Michigan in 2011 and 2012
- Necessity for pavement restoration caused by settlement 25 years after pipe installation
- Use of 25 year present worth factor of 0.38 that corresponds to 4% annual discount rate
- Use of the following pavement repair cost equation: = \$50.00/square yard x 0.38 (present worth factor) x 0.66 square yards repair patch per lineal foot of pipe = \$12.50 per lineal foot of pipe

The estimated direct cost to repair cracked pavement above a sample of 100 feet pipe run 25 years after pipe installation is: 100 lineal feet x \$12.50/lineal foot = \$1250. If an assumption is made that maintaining of traffic and other miscellaneous costs related to repairs of damage caused to vehicles by substandard pavement, public relations management, scoping, design and construction engineering is equal to the direct repair cost, the total repair cost will be 2x\$1250=\$2500.

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The pavement at about 600 feet of the approximately 3700 feet of the study test pipe length under traffic was cracked. This is approximately 16% of the pipe length. We assume that half of it, or 8%, will necessitate pavement repairs in 25 years of service. For every 100 feet installed pipe length the total repair cost will be $\$2500 \times 0.08 = \200 . This amount is similar to the additional installation cost of a 100 foot pipe run, i.e. $100 \text{ lineal feet of pipe} \times \$2.00/\text{lineal foot} = \200 additional cost.

The estimation calculations above show that the additional \$2.00 per lineal foot spent for improved pipe bedding and backfill will be cost neutral when pavement restoration would have been necessary within 25 years if traditional pipe installation is applied and 8% of pavement along the pipe cracks to the point that repairs become necessary. The validity of the assumptions above needs to be confirmed by a separate statewide study.

No parallel cost effectiveness conclusion can be made for pipes that are not located under pavement because similar calculation that involves pavement restoration cannot be applied, and unless there is failure, these pipes remain in operation. Reduced inspection cost of properly installed pipe could offset the additional \$2.00 per lineal foot. For example the present worth inspection cost as presented at end of *subsection 6.1.6* of this report is \$2.10 if performed 20 years after installation.

6.1.14 Compaction Depth

The research team considers that the maximum depth of compaction layers no greater than 10 inches or half the pipe diameter, whichever is less, currently specified by the *2012 MDOT Standard Specifications for Construction*, is adequate from a practical point of view, as long as the quality of the bedding and backfill material is improved as suggested above. In the opinion of the research team, further investigation is necessary to prove the effectiveness of reduced depth compaction layers of 8 inches and 6 inches for backfill and bedding currently specified by *AASHTO*.

6.1.15 Minimum Depth of Cover

The current *MDOT* depth of cover specifications are within the *AASHTO* requirements when the depth of cover is more than 2 feet. Additional notes can be placed in the *MDOT Standard Specifications for Construction* for complete compliance with *AASHTO* for depths of cover from 0 to 2 feet. Refer to *Subsection 5.5.2 Minimum Depth of Cover* of this report for the *AASHTO* requirements listing various pipe types and surface conditions.

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6.1.16 Pipe Inspection Timing

Pipe installation inspections should be conducted no sooner than 30 days after completion of installation and final fill that excludes the pavement in accordance with *AASHTO LRFD Bridge Construction Specifications Article 26.5.7 Inspection Requirements for CMP* (for metal pipe), *Article 27.6 Field Inspection* (for concrete pipe) and *Article 30.7 Inspection Requirements* (for plastic pipe). If this is incorporated in the 2012 or subsequent *MDOT Standard Specifications for Construction*, the specifications should also state “Unless otherwise approved by the Engineer” so that the 30 days can be waived when necessary. Cost impact (i.e. user delay costs and increased construction duration causing higher construction cost) may negatively outweigh the benefit where traffic impacts may justify less time between installation and inspection. Unless otherwise approved by the Engineer, the 30 day backfill consolidation period should also be applied when pipe replacement becomes necessary.

6.1.17 Visual Shape Deformation Inspection of Flexible Pipe

Follow requirements of *Article 26.5.7* (for metal pipe) and *Article 30.7.2* (for plastic pipe) of the *AASHTO LRFD Bridge Construction Specifications* and inspect visually all newly installed flexible pipe for shape deformation based on nominal pipe diameter. If the visual inspection indicated excessive shape deformation, verify the shape of the pipe with mandrel or laser profiling testing. The pipe that the visual inspection identifies as having deflection shall be inspected with mandrel in addition to the minimum required percentage for mandrel inspection.

It appeared that excessive deflection at metal pipe included in the research, in the form of mostly dent damage, had occurred post installation due to sign post installation and maintenance work. Therefore, we suggest that *MDOT* not change the current policy of not requiring a minimum percentage of the newly installed 12 to 18 inch diameter metal pipe total length to be tested with mandrel for shape deformation.

6.2 RECOMMENDATIONS FOR MDOT IMPLEMENTATION

At present, laser profiling is not part of the *2012 MDOT Standard Specifications for Construction*. The following actions are recommended for implementation by MDOT:

- ***Approve a Modified Laser Profiler Specification***

Review and consider to use with the *2012 MDOT Standard Specifications for Construction* a modified version of the current laser profiler specification *03DS401(D305) Laser Inspection of Sewer and Culvert Pipe* that includes suggestions from this research. The modified version *12DS402(xxxx) Laser Inspection of Sewer and Culvert Pipe* is presented in **Appendix H**.

- ***Approve Sewer and Culvert Installation Testing Forms***

Suggested Pipe Installation Testing Form for Sewers and Culverts and Sewer and Culvert Pipe Inspection Summary Sheet are presented in **Appendix J**. If approved, they could be used to summarize results of pipe installation inspections that utilize laser profilers, micrometers and inclinometers.

- ***Allow Laser Profiler Inspection to Supplement Mandrel Tests***

Apply laser profiler equipment that is certified for use by MDOT. The current laser profiler technology is not able to provide data at the pipe ends. Allow laser profiling to replace mandrel testing for the part of the pipe runs that it can cover. For the pipe end zones, where no laser data is collected, require mandrel testing or, if possible and allowed by the Engineer and the applicable Local, State and Federal safety regulations, take manual deflection measurements, as detailed in specification *12DS402(xxxx) Laser Inspection of Sewer and Culvert Pipe* suggested by this study.

- ***Create a Laser Profiler Certification Program***

Minimum requirements for laser profiler equipment certification are to be clearly stated, documented and enforced.

- ***Create a Laser Profiler Equipment Testing and Certification Facility***

Establish a site at MDOT facility to perform laser profiler tests for certification. As a minimum, the site should have two 40 foot long segments of concrete, two 40 foot long segments of plastic and two 40 foot long segments of metal

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pipe, each with a 15 inch and a 36 inch diameter test specimen. It is recommended that all pipe materials allowed in MDOT projects be represented in a similar way.

- **Create a Laser Profiling Operator Certification Program**

The minimum requirements for laser profiler operator certification are to be clearly stated, documented and enforced.

- **Organize a Periodical Laser Workshop**

The workshops may be an annual event at the MDOT laser profiling test site. This could become a useful forum for the different laser profiler vendors and contractors to share experience and to show new technology. These workshops could also be utilized by the general or specialty contractors to familiarize themselves with the different available laser profiler technologies.

- **Create a Laser Profiler Pipe Inspection Database**

We recommend creating an online, statewide, laser profiler results database. This will improve transparency in the laser profiling practice and become a pipe inventory and pipe condition information source . This database could also be utilized for future laser profiler and pipe performance research.

- **Establish a Rule for Maximum Laser to Camera Distance**

We recommend establishing rules for the maximum laser to camera distance. This may minimize the need to use mandrel testing and manual deflection measurements at the end of the pipe runs. We also recommend specifying a timeframe in which all laser profiler vendors need to comply with the rules. The maximum offset distance can be determined by a separate study.

- **Revise Subsection 401.03.C.1 of MDOT Standard Specifications for Construction**

From current language "...Unless otherwise approved by the Engineer, perform the mandrel test from 5 to 10 working days before pavement surfacing or completion of final grade." to "...Unless otherwise approved by the Engineer, perform the mandrel test a minimum of 30 days after pipe installation with completion of final fill height to bottom of pavement or unpaved surface grades and from 5 to 10 working days before pavement surfacing or completion of final grade." Implication of change can be found in *subsection 6.1.16. Pipe Inspection Timing* of this report.

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- **Revise Subsection 402.03.K of MDOT Standard Specifications for Construction**

From current language "...After backfilling and compacting the trench, and from 5 to 10 working days before pavement surfacing or completion of final grade, conduct the inspection of sewers under pavement, unless otherwise approved by the Engineer." to "...Unless otherwise approved by the Engineer, for sewers under pavement, conduct the inspection after backfilling and compacting the trench a minimum of 30 days after pipe installation with completion of final fill height to bottom of pavement grades and from 5 to 10 working days before pavement surfacing." Implication of change can be found in *subsection 6.1.16. Pipe Inspection Timing* of this report.

- **Revise Subsection 402.03.K of MDOT Standard Specifications for Construction**

From current language "...For sewers not under pavement, conduct the inspection as close to project completion as possible, but allow time for corrective action determined by the video inspection and directed by the Engineer" to "...Unless otherwise approved by the Engineer, for sewers not under pavement, conduct the inspection a minimum of 30 days after pipe installation with completion of final fill height to unpaved surface and as close to project completion as possible, but allow time for corrective action determined by the inspection and directed by the Engineer. Implication of change can be found in *subsection 6.1.16. Pipe Inspection Timing* of this report.

- **Train Contractors and Inspectors in Pipe Installation**

We recommend that MDOT organize annual courses for Contractor and Inspector training in the recommended pipe installation procedures. The courses should emphasize proper manhole and pipe installation and should include manhole and pipe installation certificates that are valid for a period of time determined appropriate. An advanced form of this course could include both classroom and construction site "hands on" training.

- **Revise MDOT Standard Details and Specifications for Bedding & Backfill of Manholes & Pipe**

Revise the *Standard Details R-82 & R-83 MDOT* and the *MDOT Standard Specifications for Construction, Subsections 401 & 402* to reflect the suggested bedding and backfill material modification for storm manholes under traffic to use crushed stone, and for storm sewers and culverts to use Class I material, modified as suggested by this study. Consider specifying Class II material, modified as suggested by this study, instead of the recommended Class I, if the Class I material production in Michigan is not practical.

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- **Revise MDOT Specifications to include visual inspection for flexible pipe shape deformation**

Revise the *MDOT Standard Specifications for Construction, Subsections 401 & 402* to include visual shape deformation inspection of the total installed flexible pipe. The areas that the visual inspection identifies as having deflection shall be inspected with mandrel in addition to the minimum required percentage for mandrel inspection.

6.3 RECOMMENDATIONS FOR FUTURE STUDY

The following is a list of suggestions for future pipe research:

- ***Pipe Condition Research on the 2011 Test Pipe in 2021***

Notable and recordable structural condition changes of the pipe included in this research are expected to occur in the next ten years. Laser profiler technology may be fully supplemented by digital camera technology, or replaced by the laser scanning technology. The data collected, and the conclusions reached in the 2011 research, can be used as a basis for a research project, of a similar scope, in 2021. The research may then be repeated every ten years. All test pipe participating in the current research should be properly marked and/or flagged every year so that it is not removed or replaced, but left in place for future research where practical. If a complete failure, or close to complete failure of the research pipe is registered, only local repair should be allowed, and the repair records added as a supplement to this research.

- ***Applying a Nationwide Pipe Assessment System in Michigan***

Base the *MDOT* pipe condition assessment practice on the *FHWA* pipe inspection classifications. Consider using the results of an ongoing 2012-2015 *FHWA* study aiming to evaluate and update the 1986 *FHWA Culvert Inspection Manual*. When completed in 2015, it may become a valuable resource for the *MDOT* pipe inspection and evaluation methods.

- ***Accuracy of Pipe Condition Assessment***

The accuracy and applicability of different pipe condition classification systems should be further investigated. Each system has its weaknesses, along with positive features. The study should include review of the *FHWA/Ohio DOT* and the *NASSCO PACP* coding utilized by this research.

- ***Accuracy of Pipe Performance Evaluation***

The current research highlighted that pipe performance estimating is difficult, and subject to a number of factors, some of them not well defined, including rating system applicability and completeness, and experience and education of inspection staff. An evaluation database for pipe inspected in Michigan can be created to compile and unify inspection efforts and pipe performance estimates.

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- ***Plastic Pipe Performance when installed with 10 to 16 feet Depth of Cover***

A study involving deeper plastic pipe installation could investigate whether excessive shape deformation and other anomalies are avoided through utilizing greater installation depths.

- ***Use of Digital Cameras in conjunction with Laser Profilers***

The digital camera technology has not been linked with the laser profiling at present. Its use can improve both video and laser profiling inspections. A study could investigate the advantages to the laser profiling associated with the digital technology and recommend whether or not all laser profiling on state projects should switch to digital, and how long the transition period for such a switch should be.

- ***Use of Inclinometers in Pipe Inspections***

The use of inclinometers can substantially improve inspection results. At present, dimensions of vertical variations within a pipe run (i.e. heaves, dips and “bellies”) can be roughly assessed by the inspections, and sometimes remain completely undetected. The accuracy of different inclinometers needs to be investigated in detail. A separate inclinometer certification process can be established.

- ***Application of GPS in Pipe Alignment Assessments***

Horizontal pipe deviations are rarely registered and coded in field inspections. An accurate GPS device, which can operate underground when mounted on the CCTV/Laser profiler system, could provide the ability to register such deviations

- ***Laser Scanning versus Laser Profiling in Pipe Condition Assessment***

Laser scanning, an alternative to laser profiling, may eventually replace profiling. The scanning probe has an advantage over the laser profiler technology, which depends on a camera to be the data receiver. The current spinning beam laser technology resembles the laser scanning, but is still dependent on a camera with limited resolution, and consequently limited data points. The current continuous laser ring technologies have the laser device and the camera separated, which prevents data collection when corrugations, joint protractions or other object edges are in-between the laser ring and the camera. Laser scanning should be studied for pipe inspections once the technology is sufficiently evolved and available on the market.

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- ***Optimal Set Up of a Test Site for MDOT Laser Profiler Certifications***

The recommended Laser Profiler Certification Process requires the use of a properly established equipment test site. A separate study can determine what the certification criteria should be, and what testing should be undertaken to confirm the selected parameters. The study may then recommend an adequate test site.

- ***Optimal Requirements for Laser Profiler Operator Certification***

The operators performing laser profiler work in Michigan should have detailed knowledge of what the laser profiling criteria and results are expected to be, and how to follow the requirements of the laser profiler specification in a consistent manner. An annual operator certification process can become an useful tool for *MDOT* to unify the laser profiler operations statewide. This can also be an opportunity for the different laser profiler operators to meet and share experiences. The implementation of an operator certification process, that covers all of *MDOT* certified laser profiling technologies, can be investigated in a separate study.

- ***Review of the Application of Laser Profilers in MDOT Inspections***

If laser profiling becomes routine in the State of Michigan, a requirement can be implemented that requires documentation from laser profiling of pipe in state right-of-way to be submitted to *MDOT* and stored in a common database. This will eventually provide a laser profiling results database that could be reviewed to develop conclusions regarding applicability, accuracy, etc. A study could summarize the conclusions of the review.

- ***Recommended Maximum offset from Laser Profiler to CCTV camera***

Two out of the three current laser profiling technologies physically cannot allow laser profiling close to the ends of the inspected pipe due to necessity for an offset between the laser and the camera. For the Coolvision system, this distance is constant, while for the Cleanflow system, the distance varies depending on pipe diameter. The Rausch system does not have an offset. If a maximum offset is set, *MDOT* will be able to codify the maximum length adjacent to pipe ends that will have no laser profile data.

- ***Re-evaluation of the MDOT geometry allowances in pipe installation and minimum pipe slopes***

Precise survey instruments could be used to measure the exact vertical and horizontal alignment of the pipe included in the 2011 research. This could allow *MDOT* to evaluate and analyze how pipe geometry impacts pipe operations and maintenance. Separate conclusions could be made if the structural capacity is affected by pipe

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geometry, and how pipe layout deviations can be included in the pipe inspection coding and practice. Then the current MDOT requirements for minimum pipe slopes can be compared and evaluated against the observed test pipe vertical geometry.

- **Consistent Interpretation of Video and Laser Inspection Data**

A common issue is the inconsistency in interpretation of anomalies in pipe inspections. There is a necessity for simplicity and completeness of interpretation criteria, as well as common statewide training. A study can help to consolidate the interpretations.

- **Use of nominal, manufacturer supplied, physically measured or laser profiler calculated pipe diameter in laser profiling shape deformation calculations**

The MDOT specifications for plastic pipe require a mandrel size to be 95 percent of the nominal pipe diameter and currently do not require metal pipe shape verification. Other government and industry entities and standards have differing requirements for allowable pipe diameter deviations and deflections. A separate study on how the MDOT requirements compares with other current practices will clarify their applicability.

- **Adopting Pipe Installation Practice and Bedding and Backfill Materials of Neighbor States**

An investigation into specifications, procedures, types of bedding and backfill material, and lessons learned in the neighboring Great Lakes States could bring useful conclusions, that if implemented, may improve pipe performance in Michigan. The study should include cost efficacy estimates of suggested improvements.

- **Applying alternative pipe materials in Michigan**

Consider advantages of pipe made of alternative or modified materials like application of metal pipe with heavier gauges and protective coating, optimal PVC pipe use in drainage, utilization of plastic pipe with different resins, wall structure and joints, and introduction of steel reinforced thermoplastic and fiberglass pipe.

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7.0 ACCRONYMS, ABBREVIATIONS & SYMBOLS

AASHTO.....	American Association of State Highway and Transportation Officials
ASTM.....	American Society for Testing and Materials
CCTV	Closed Circuit Television
CS	Control Section
DOT	Department of Transportation
FHWA	Federal Highway Administration
fpm	feet per minute
ft	feet
JN	Job Number
LRFD	Load and Resistance Factor Design
MDOT	Michigan Department of Transportation
MH	Manhole
MI	Michigan
MTM	Michigan Test Methods
NASSCO	National Association of Sewer Service Companies
PACP	Pipeline Assessment and Certification Program
POSM	Pipeline Observation System Management
QPL	Qualified Products List
SE.....	southeast
SW.....	southwest
vs.....	versus

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8.0 APPENDIX

Appendix A	2011 Research Pipe Plans
Appendix B	2011 Inspection Report Field Logs
Appendix C	1994 Inspection Data
Appendix D1	FHWA & Ohio DOT Culvert Condition Coding
Appendix D2	NASSCO PACP Coding, Rating and Certificates
Appendix D3	1994 Report Coding
Appendix E1	Southeast Michigan Site 1 Detail Report
Appendix E2	Southeast Michigan Site 2 Detail Report
Appendix E3	Southeast Michigan Site 3 Detail Report
Appendix E4	Southeast Michigan Site 4 Detail Report
Appendix E5	Southeast Michigan Site 5 Detail Report
Appendix E6	Southeast Michigan Site 6 Detail Report
Appendix E7	Southeast Michigan Site 7 Detail Report
Appendix E8	Southeast Michigan Site 8 Detail Report
Appendix E9	City of Bad Axe Site 9 Detail Report
Appendix E10	City of Munising Site 10 Detail Report
Appendix E11	Southwest Michigan Site 7 Detail Report
Appendix E12	Southwest Michigan Site 10 Detail Report
Appendix E13	Southwest Michigan Site 11 Detail Report
Appendix F	Laser Profiler Presentation
Appendix G	Laser Profiler Recommendation
Appendix H	Laser Inspection Special Provisions
Appendix I	2011 Research Permits

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- Appendix J Sewer and Culvert Pipe Installation Testing Forms
- Appendix K1 ND94-1761 and ND94-1762 Research Reports
- Appendix K2 2013 Reassessment of ND94-1761 & ND94-1762 Evaluations