

Evaluation of HDPE Pipe Performance
on
Kentucky DOT and Ohio DOT
Construction Projects

by Pipeline and Drainage Consultants
a subsidiary of Spartan Construction



American **Concrete Pipe** Association

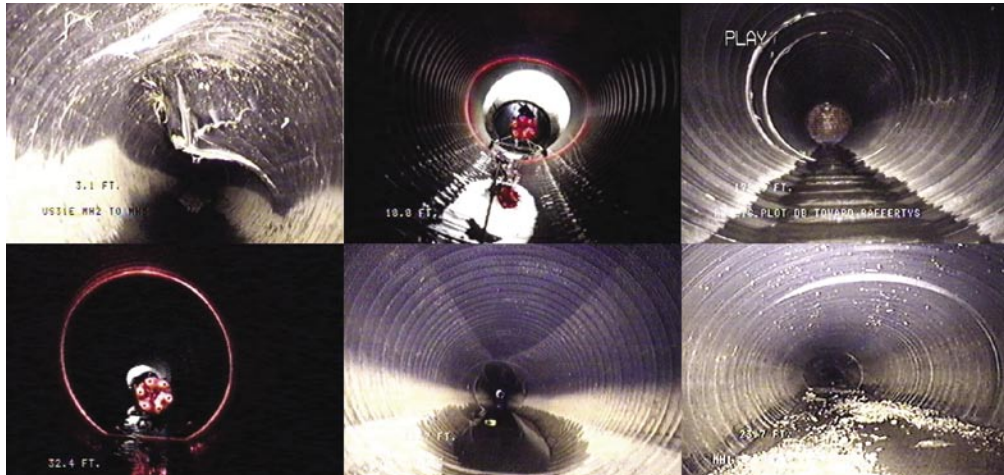
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EVALUATION OF HDPE PIPE PERFORMANCE ON KENTUCKY DOT CONSTRUCTION PROJECTS

Completed 9/12/05



Background:

This report is an independent study conducted by the KY Transportation Center and Pipeline and Drainage Consultants. It was partially sponsored by the American Concrete Pipe Association.

In May of 2005, the Kentucky Department of Transportation formed a task group to evaluate current specifications and the use of HDPE pipe on future KY DOT projects. It was decided to first evaluate the long-term performance on previous HDPE pipe installations before proceeding further.

KY DOT selected seven HDPE pipe sites to be evaluated. Field evaluations were performed in July, 2005 by the KY Transportation Center and Pipeline and Drainage Consultants. Long term performance was obtained from historical documentation¹ and compared to the field measurements taken in July of 2005.

Field Testing and Equipment:

A detailed video inspection was performed on selected pipes at each of the sites in three phases. Phase I and Phase II were conducted in conjunction with each other.

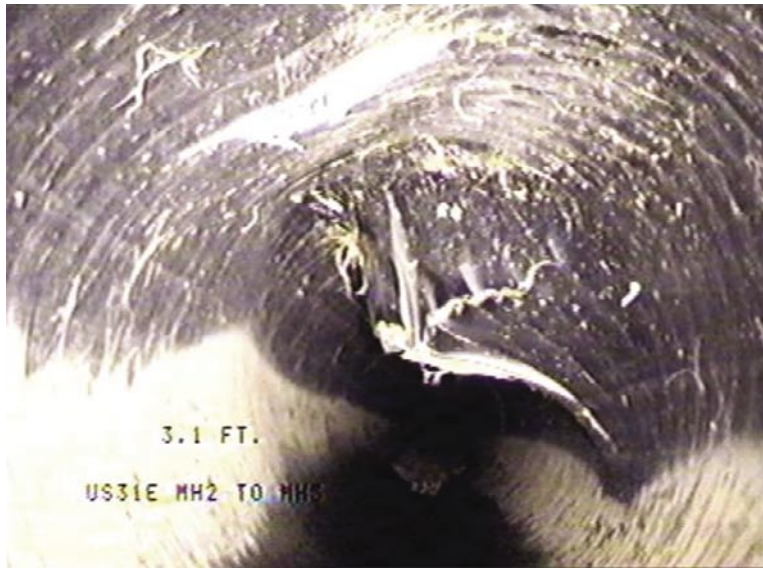
Phase I: a detailed video pipe inspection with high intensity lighting using a CUES OZ II pipe line inspection camera because its camera optics has little barrel distortion that could be mistaken for pipe deflection.

Phase II: a pipeline profiling laser ring was placed at the far end of the pipe and pulled through with little to no light in order to maximize the visibility of the red laser ring, which shows areas of pipe distortion (racking, crown flattening, vertical and horizontal deflection) that may not be observed by video inspection alone.

Phase III: a detailed post evaluation of the Phase I and Phase II data.

The project sites included inspection of 3,892 feet of HDPE pipe sections at the following locations:

- 1 US 27, Nicholasville Road, Lexington (983.6 feet)
- 2 US 68/KY 80, Bowling Green (658.0 feet)
- 3 KY 210, Hodgenville (130.0 feet)
- 4 US 31e, Hodgenville (239.5 feet)
- 5 US 150, Stanford (676.0 feet)
- 6 US 127, Owen County (300.0 feet)
- 7 KS 207, Flatwoods (905.0 feet)



Video image on Project 4, US 31e, Hodgenville, failure in 18 inch storm drain due to deflection of approximately 50%.

Findings

Project 1 - US 27, Nicholasville Road, Lexington

Information indicated that the pipe was backfilled with No. 9 crushed limestone and the entire project had been inspected Nov. 4, 1991. At that time, none of the pipe sections had over 5% deflection.

Current laser deflection measurement (July 2005) indicates that several of the line segments (MH to MH) have areas deflected over 5% with one location approaching 10%. Radial cracking, crown and invert flattening, and corrugation expression (growth) have also increased. Radial cracking is observed in 16% of the pipe and sagging in 24% of the pipe sections.



Video Image on Project 1, Nicholasville Road, showing 10% deflection and corrugating growth.



Video Image on Project 1, Nicholasville Road, showing severe radial cracking near a joint.

Project 2 - US 68/Ky 80, Bowling Green

Information indicated that the pipe was installed in 1989 and 1990. Deflections in the cross drains and storm drains are below 5%. Significant deflections of 12% is observed in a 24-inch outfall line near the south end.

In July 2005, current visual inspection and laser deflection indicates that movement has occurred in several of the line segments. It is estimated that sections of the 24-inch outfall line are now deflected approximately 20%. The 36-inch cross drain near Moss Middle School is deflected approximately 13 to 14% near the inlet end in addition to signs of dimpling. Deflection readings taken by Wiss, Janney, Elstner Associates Inc. in 2002 indicated that that the pipe had deflected 11%, indicating deflections have increased within the last three years. Recent laser deflection data taken in 18 and 24 inch storm drains indicated average deflections between 5 and 10%. Radial cracking, invert and crown flattening, racking, and sagging is also observed in several of the line segments. Radial cracking is observed in approximately 24% of the pipe sections, and sagging is observed in 45% of the pipe sections. These developments were not observed in previous site investigations.

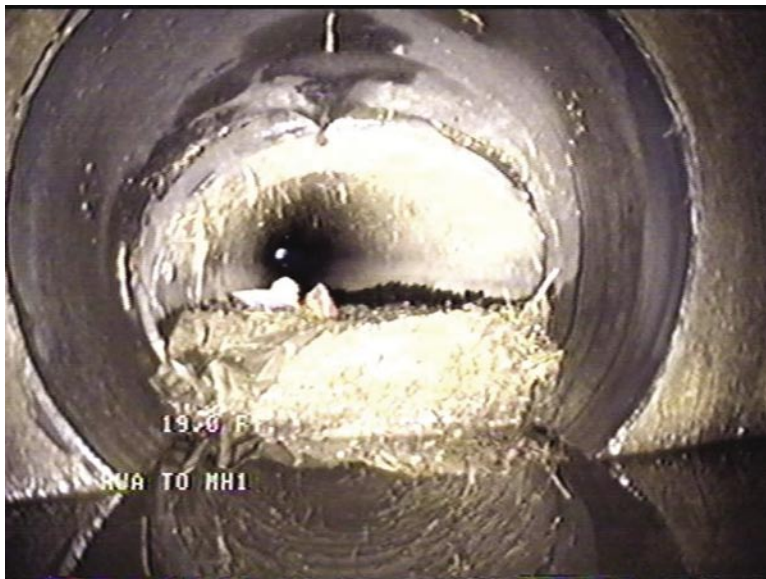
Project 3 - KY 210, Hodgenville

No historical construction or performance information was available. The manufacturing date was May, 2002 and the estimated installation date was 2002. Granular material was not required in the specifications.

Two cross drains were evaluated on this project in July 2005. The first cross drain has several areas of significant deflection ranging from approximately 10 to 13 percent. The other cross drain appears to be in better condition. Both drains contain large amount of silt/debris. The laser was not utilized on this site due to the amount of debris in the lines. Sagging is difficult to evaluate due to the debris in the lines. Cracking is observed in two of the approximate six pipe sections. Deflection topped at 13% and cracking has developed. Both cross drains should be cleaned and profiled and monitored for long-term performance.



Video Image on Project 2, US 68/KY 80, showing approximately 20% deflection.



Video Image on Project 2, US 68/KY 80, with severe damage due to deflection and joint separation.

Project 4 - US 31e, Hodgenville

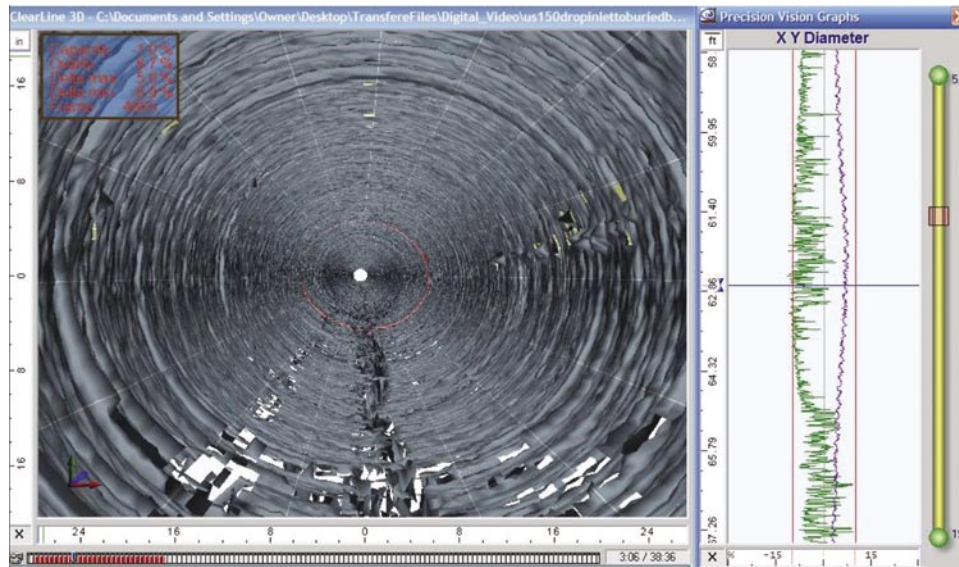
This project did not have any historical construction or performance information available. The pipe was installed in 1994 and the KY DOT specification required a granular backfill.

Significant to severe deflections, crown flattening, racking, and cracking are observed in several of the pipe sections throughout this site. Cracking is observed in approximately 8% of the pipe sections and sagging is noted in 33% of the pipe sections. The failed 18" storm drain has 50% deflection and should be removed and replaced.

Project 5 - US 150, Stanford

Historical construction or performance information was not available for this site. The pipe was installed in 2002 and again the KY DOT specification required a granular backfill.

In July 2005, several of the lines segments have deflected approximately 10%. Sagging is observed in 36% of the pipe sections. Cracking is not observed in any of the line sections that were inspected.



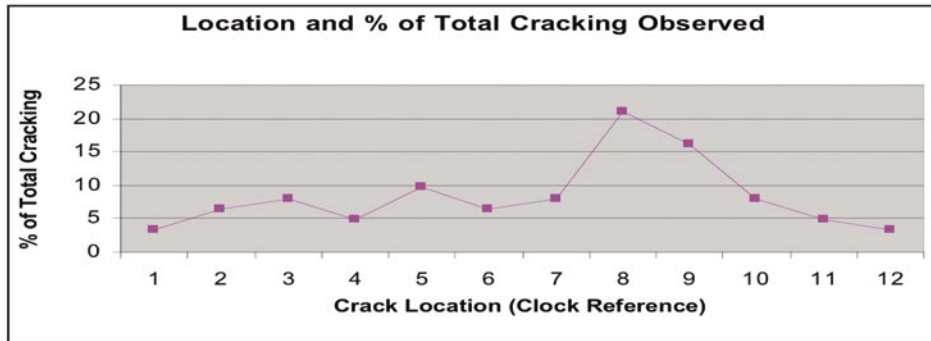
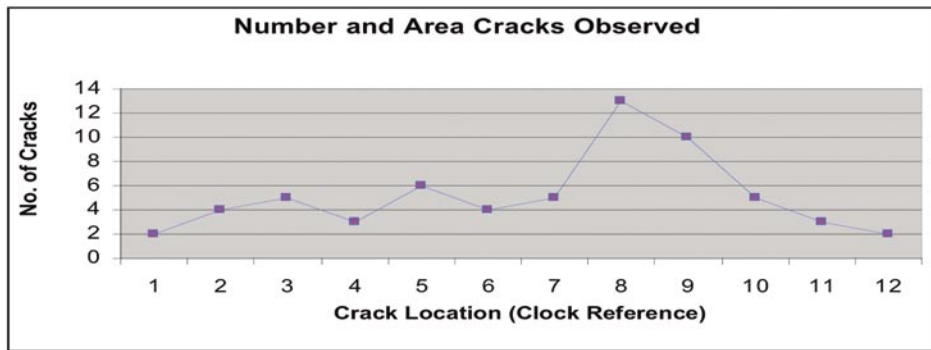
Video Image on Project 5, US 150, Stanford , 3D model and strip chart showing approximately 10% vertical deflection at 62 feet.

Project 6 - US 127, Owen County KTC

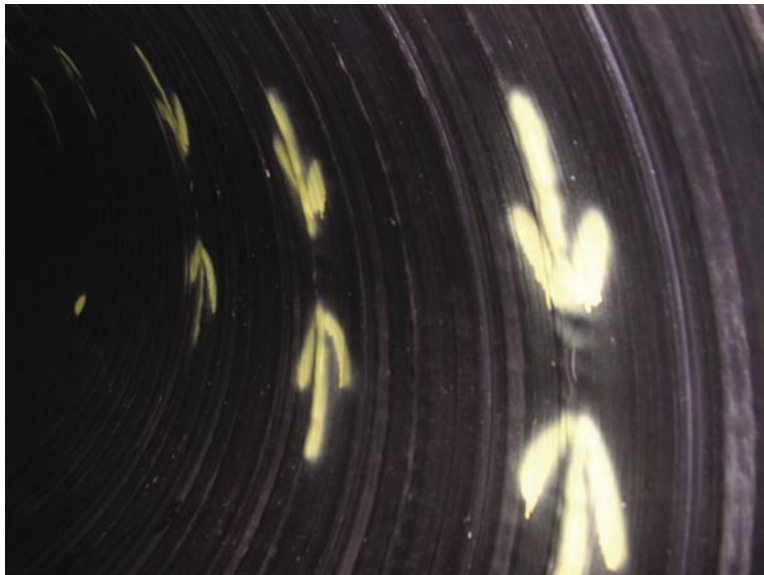
Research reports indicated that the 36-inch cross drains were completed in 1996 and that the 48-inch cross drains were completed in 1997.

Deflection readings were taken in the 48-inch pipe in 2000 by KTC. No noticeable deflection or dimpling was documented at that time. In 2002, Wiss, Janney, Elstner Associates, Inc. documented a 1" long crack 142' from the inlet and rippling (dimpling) 129-133 feet. A visual inspection survey conducted by the KTC and PDC in June of 2005 indicated that significant dimpling and radial cracking had occurred in the pipe from 108 to 176 feet from the inlet end. Most of the observed distress had occurred in the section of the pipe backfilled with crushed limestone pipe sand. This data indicated that the pipe is continuing to change eight years after installation and that significant changes have occurred in the past three years. At this time, pipe deflection is under 4%, but appears to be continuing to deflect in several new areas.

Deflection measurement of the 36-inch pipe was taken by Wiss, Janney, Elstner Associates, Inc in 2002. The cross drain was inspected again in June 2005, by KTC and PDC. At the time of the inspection there were no signs of significant distress or deflections. Corrugation growth (liner pushing inward) is the only noticeable issue.



Graph on Project 6, US 127, Owen County.



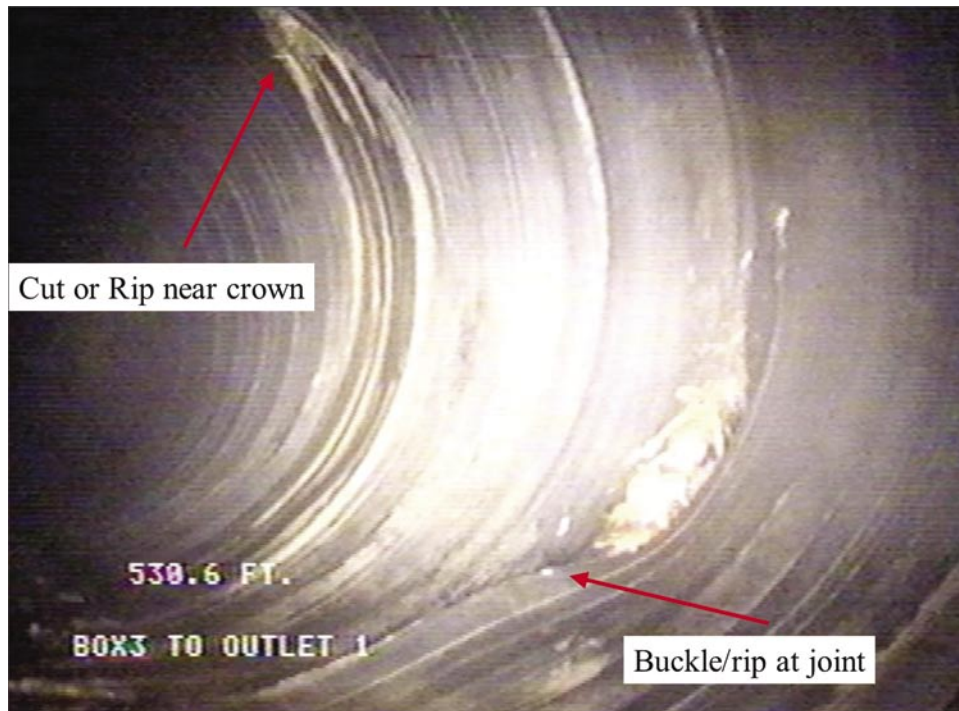
Video Image on Project 6, US 127, Owen County.

Project 7 - KY 207, Flatwoods

Information contained in KTC-91-17 indicated that the project was inspected in October of 1991. The report indicated that 10 to 20 % of the 11,220 foot construction project was inspected at that time.

The KTC-91-17 report showed approximately 20 percent of a 30-inch storm drain line was deflected over 5%. Maximum deflection was 5.5. The report also indicated that several sections of a 36-inch out-fall pipe had deflected over 5 percent with highest being 7.3 %.

In July 2005, 905 feet of pipe were inspected on this project. Laser deflection measurements were not conducted, due to limited access to buried manholes and possible dangerous conditions resulting from unknown laterals. The video inspection did indicate that several areas of the lines are significantly deflected. Several estimated deflection readings in the 36-inch outfall line appear to exceed 10 and 12%. These percentages are significantly higher than what was observed in 1991. The 2005 investigation shows that 33% of the pipes have signs of radial cracking and sagging is observed in approximately 4.5% of the lines.



Video Image on Project 7, KS 207, Flatwoods, with buckling and ripping at joint and crown.

Evaluation

Camera and laser systems utilized on this project have provided significant information about pipe performance. It is clear that mandrel testing alone does not capture the entire pipe condition. Cracking, tearing, and buckling are evident in pipe that was not necessarily over-deflected, but could go undiscovered with a mandrel test only.

Corrugation “growth” (expression) did increase after installation. The average maximum recorded corrugation was 0.5 inches. It is unsure how this affects the hydraulics of the pipe. However, the Federal Highway Administration chart on Manning “n” roughness coefficients suggests a 0.5 inch annular corrugation equates to a 0.024 Manning’s “n” value. This is approximately two times greater than the manufacturers design recommendations of (0.010) for Manning’s “n” value.

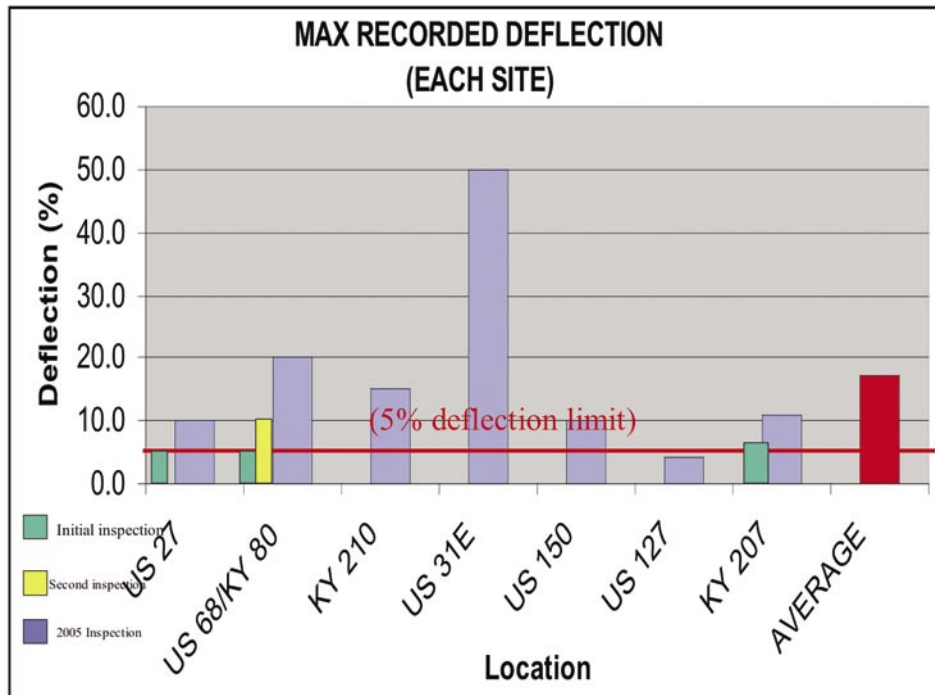
Radial cracking occurred after installation. It is uncertain how this cracking affected the pipe structurally, but it does cause problems when cracking occurs in the invert of the pipe and the inner liner pushes up and catches debris. Radial cracking is documented in approximately 20% of the pipes sections. This type of defect may have structural implications.

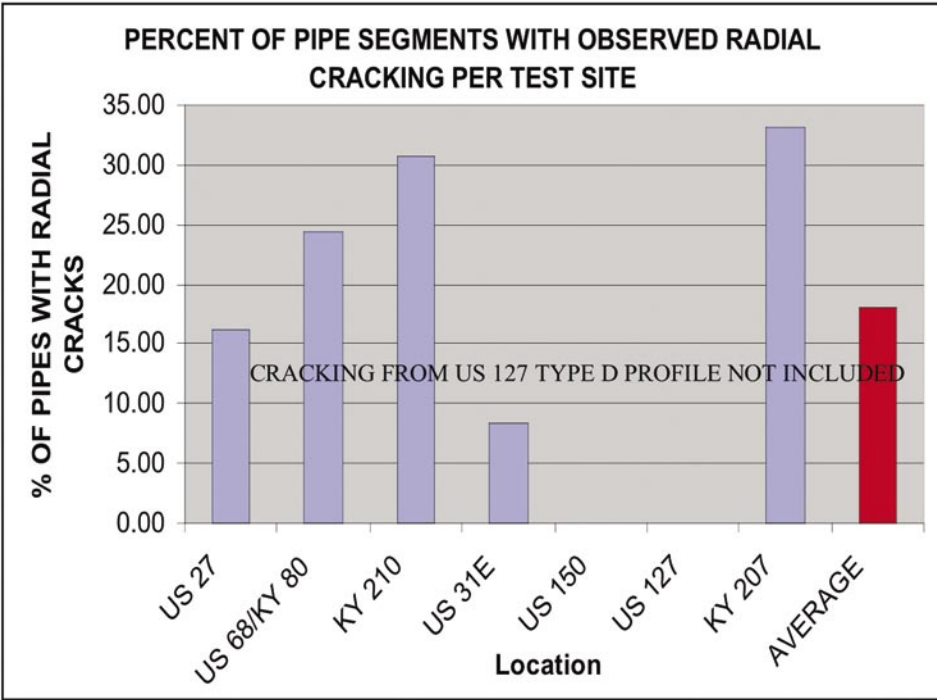
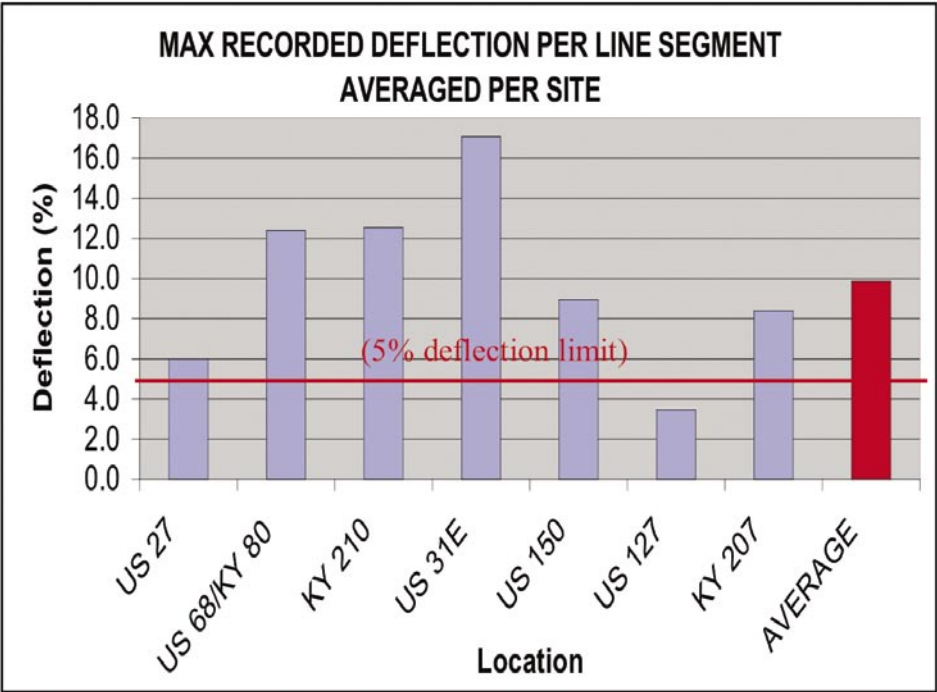
Sagging and ponding are observed in 26% of the pipe sections. Racking is also observed but not quantified. The majority of the pipes investigated on this project would not pass a 5% deflection test and most of the sites have pipe sections that would not pass a 10% deflection test. It is documented in the complete report that several of the pipes have continued to deflect since initial installation. It is also evident that the HDPE pipes are sensitive to construction installation and proper care is needed to ensure good performance. It is apparent that cracking, and deflection had continued to occur in several of the projects since they were last inspected.

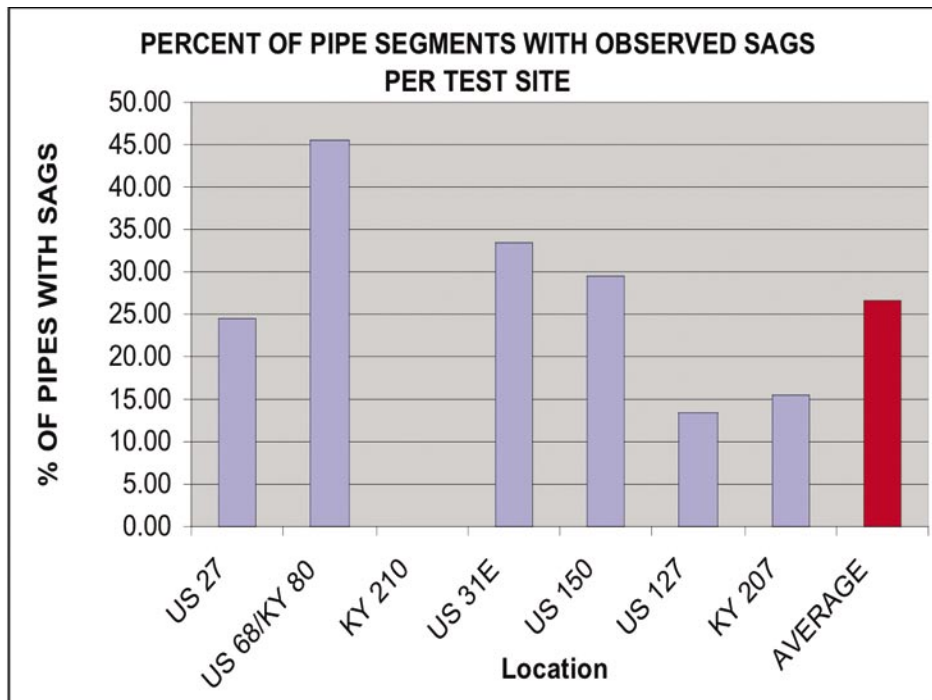
Recommendations and Comments:

Further testing is needed to evaluate the long-term performance of HDPE pipe. It is recommended that all previous monitoring points established on prior research projects be measured and evaluated for long-term hydraulic and structural performance.

This study clearly demonstrates the difficulty in achieving a problem-free installation of HDPE pipe and that the pipe does not always perform in accordance with theory. Significant to severe deflections, corrugation “growth”, crown and invert flattening, racking, sagging, and radial cracking are observed in several of the pipe sections throughout these sites.







Excessive deflection is a major problem. Just one excessive deflection location in a line can result in bad joints, grade problems, poor hydraulic performance, stress related problems, or surface (ground or pavement) irregularities. These problems are an indicator of likely future failure.

Proper specifications should be developed to ensure that correct bedding and backfill requirements, proper soil densities, and proper compaction efforts are realized as outlined in ASTM D 2321 and AASHTO Section 30 for all new installations. It is further suggested that an onsite geotechnical engineer monitor and confirm that proper placement techniques are followed. Specifications should require the proper Post Installation Testing procedures which include at a minimum, video and mandrel testing.

The following recommendations are suggested:

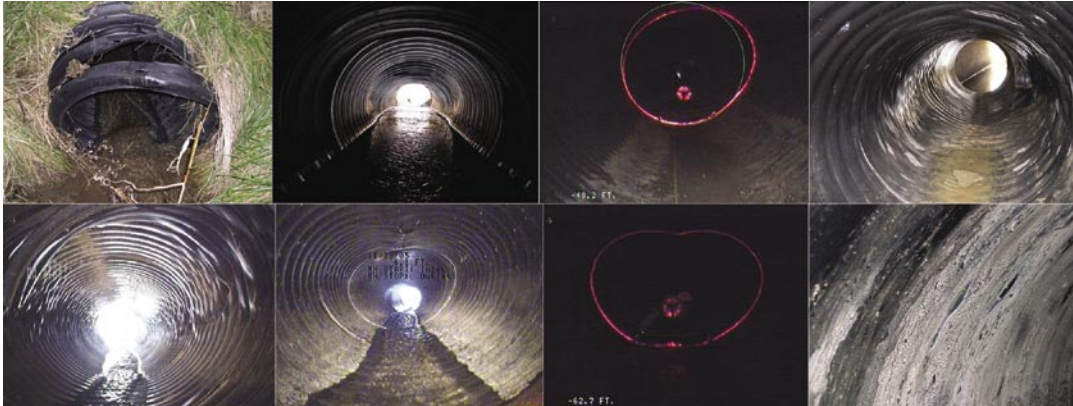
- * Further monitoring should be conducted.
- * Post-installation deflection and video inspection be required.
- * Deflection should be limited to 5% max with the anticipation of some post-construction “creep”.

This study, which cites extensive problems on six DOT projects is cause for more investigations on public and private projects. What might one expect on private or municipal projects that normally do not have the scrutiny of a DOT project?

⁽¹⁾ Significant historical information used for comparisons was obtained from KTC-91-17, Field Performance Report on Corrugated Polyethylene Pipe, Kentucky Transportation Center, November 1991. Historical performance information was also obtained from Condition Investigations of HDPE Pipe In-Service in the United States (six states), January 24, 2002, Wiss, Janney, Elstner Associates, Inc.

EVALUATION OF HDPE PIPE PERFORMANCE ON OHIO DOT CONSTRUCTION PROJECTS

Completed 1/17/06



Background:

This report is an independent study conducted by Pipeline and Drainage Consultants. It was partially sponsored by the American Concrete Pipe Association.

In 2001, Wiss, Janney, Elstner Associates, Inc. conducted a performance evaluation of high density polyethylene (HDPE) pipes in six states in the United States. On January 24, 2002, a final report "Condition Investigations of HDPE Pipe In-Service In the United States (Six States)" was issued. The report clearly defined the condition of the pipes in 2001.¹ In the fall of 2005, Pipeline and Drainage Consultants conducted a follow up performance study of the 13 HDPE pipe sites in Ohio that were included in the 2002 report. Due to onsite conditions, only 11 of the 13 sites were reviewed. The construction procedures, backfill methods, compaction methods, and materials utilized on each pipe section and test site were not available. Contained in this report is a summary of field testing equipment and findings from each test site. Also included are individual images of observed distresses, laser and manual deflection measurements, and preliminary conclusions and recommendations.

Field Testing and Equipment:

A detailed manual and/or video inspection was performed at each HDPE pipe site. The inspection was conducted in five phases. A detailed video evaluation, laser deflection testing, and analysis was conducted on only half of the sites.

Phase I: a manual walk through inspection conducted at all 11 HDPE pipe sites. Manual vertical and horizontal deflection measurements were taken, and any observed distress was documented.

Phase II: a comparison of measurements and distress with what was observed during the 2001 inspection.

Phase III: Phase III and Phase IV were conducted in conjunction with each other. A detailed video inspection of the pipe with high intensity lighting was conducted utilizing a Cues OZ II pipe line inspection camera. The Cues OZ II camera was utilized due to its optics, which has little to no barrel distortion that could be mistaken for pipe deflection.

Phase IV: A pipeline profiling laser ring was placed into the pipe at the far end of the culvert and was pulled back with little to no light in order to maximize the visibility of the red laser ring. The laser ring shows significant areas of pipe distortion such as racking, crown flattening, and vertical and horizontal deflection that may not have been observed/captured by video inspection or mandrel testing.

Phase V: a detailed post-evaluation of the Phase III video inspection and the Phase IV laser ring profiling data.

The project sites included inspection of 672 feet of HDPE pipe sections at the following locations. Site numbers listed below correspond to site numbers utilized in the 2002 Wiss, Janney, Elstner Associates, Inc. report.¹

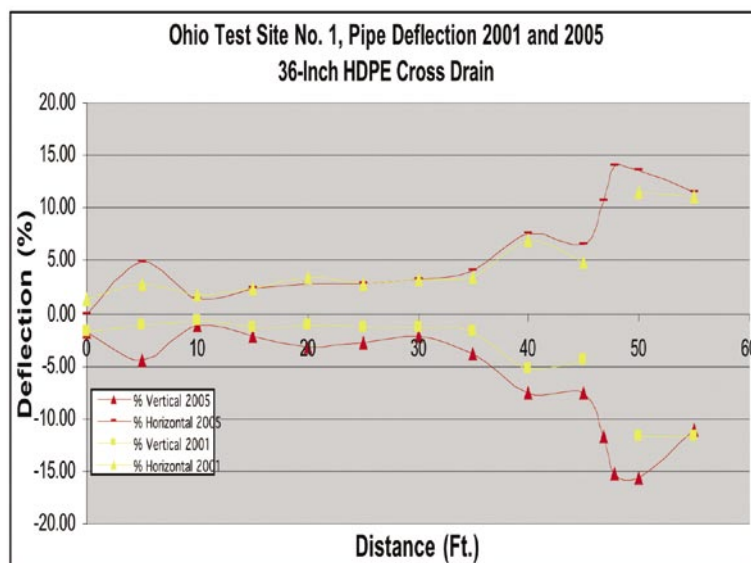
1	SR 294, Harpster, Ohio	55
2	SR 81, Dola, Ohio	80
3	(Not Inspected)	
4	(Not Inspected)	
5	SR 715, Danville, Ohio	60
6	SR 715, Danville, Ohio	70
7	SR 715, Danville, Ohio	20
8	SR 229, Newcastle, Ohio	62
9	SR 229, Millwood, Ohio	80
10	SR 661, Homer, Ohio	51
11	SR 657, Homer, Ohio	55
12	US 40, Jacksontown, Ohio	55
13	SR 13, Jacksontown, Ohio	84

Findings

Project 1 - SR 294, Harpster

The 36-inch cross drain was installed in 1992 near Harpster, Ohio, with a maximum depth of cover of approximately 5 ft. The pipe was inspected in 2001 and on December 6, 2005.

Wall buckling and dimpling were noted in the areas of deflection of 7.5% or greater. This was noted in the 2001 inspection and appear to have increased. Manual deflection measurements taken in 2005 indicate that the pipe has continued to deflect with a maximum deflection recorded in 2001 of 11.81%, and a maximum deflection of 15.63 % in 2005. Approximately 23% of the vertical measurements taken in 2001 would not pass a 5% deflection test and approximately 43% would not pass in 2005. Deflection readings indicate changes vertically and horizontally occurred near the outlet and inlet ends of the pipe. The 2001 report documented one crack, and seven cracks are documented in 2005.





Video Image on Project 1, Harpster, showing significant change in pipe deflection near outlet.

Project 2 - SR 81, Dola

The 60-inch cross drain was installed in 1995 near Dola, Ohio, with a maximum depth of cover of 5 feet or less. The pipe was inspected in 2001 and on December 6, 2005. No buckling or dimpling is noted during the 2005 inspection. Manual deflection measurements taken in 2005 indicate that the pipe has severely deflected outside the roadway. Vertical deflection readings indicate that 53% of the pipe has deflected greater than 5%. Vertical readings were not taken in 2001. Crown flattening and racking is apparent in some areas. Cracking was not documented in 2001. One radial crack is noted in the 2005 inspection. Crown flattening is apparent at both the inlet and the outlet ends where deflections are near or greater than 10%. Creasing may be occurring at 10 and 2 o'clock where deflection is near 10%.



Video Image on Project 2, Dola showing vertical deflection and racking

Project 5 - SR 715, Danville

The 30-inch cross drain was installed in 1997 near Danville, Ohio. It appeared that the pipe had less than 2 feet of cover. No buckling or dimpling is noted during the 2005 inspection. No significant deflections greater than 5% were noted in 2005. It does appear that the pipe is undergoing some possible defor-

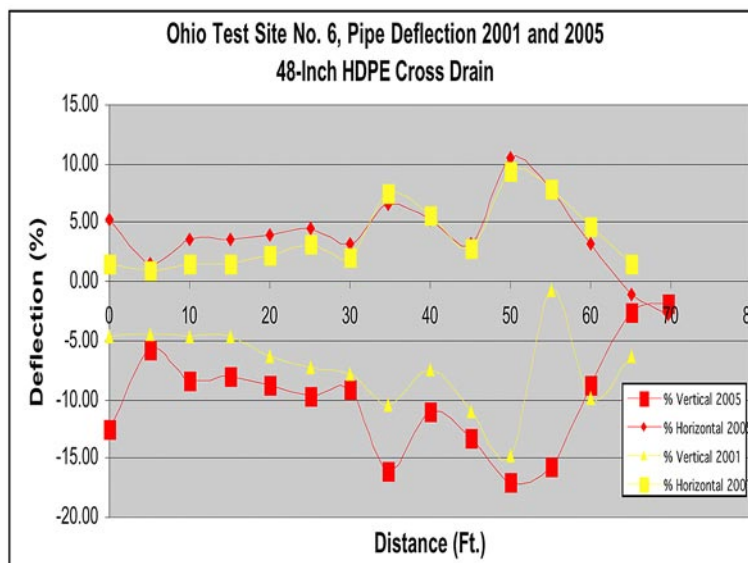
mation from dynamic/wheel loading. One crack was documented in 2001 and additional cracking has occurred since 2001. A spiraling crack is noted, going from 13-feet to 13.5-feet from the inlet end. The inlet end of the HDPE pipe has been severely damaged. It is uncertain if these deflections were introduced during installation or have occurred over time.



Project 5, Danville, inlet

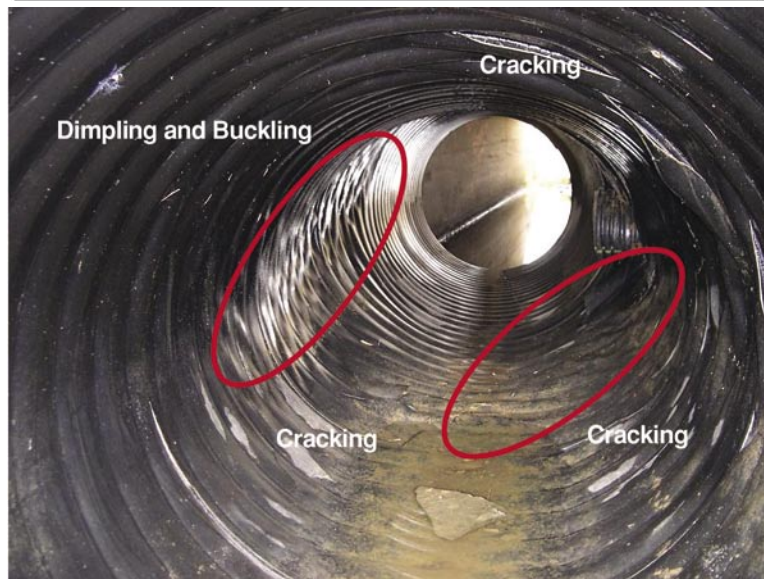
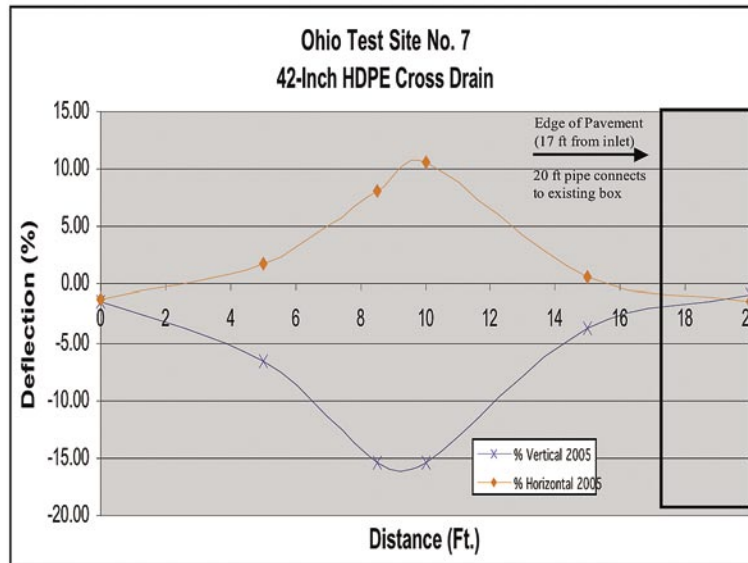
Project 6 - SR 715, Danville

The 48-inch, 70-foot long cross drain was installed in 1999 near Danville, Ohio. It appeared that the pipe had a maximum of 2 feet of cover. Dimpling and wall buckling were not significantly observed. Bulging at the invert was documented in 2001 at 12, 34, and 45 feet and cracking was also documented on top of the bulges. Additional bulging is documented in the 2005 survey at 1 and 48 ft. The 2001 report indicated that 60 percent of the vertical readings would not pass a 5% deflection test. Vertical deflection readings taken in 2005 indicate that 87% of the pipe is greater than 5% deflected. The 2001 report documented the greatest deflection of 14.84 percent at 50 ft. Deflection has increased to 17% and longitudinal cracking has occurred in the crown of the pipe. Cracking was documented in three locations in 2001 and in eight areas in 2005. A large portion of these cracks occur in bulged areas at the invert. Several of the cracks appear to have penetrated the entire invert of the pipe.



Project 7 - SR 715, Danville

The 42-inch, 20-foot long cross drain was installed in 1992 near Danville, Ohio. The pipe ties into a concrete box culvert. Dimpling and wall buckling are present in several areas throughout a large portion of the HDPE pipe, documented in 2001 and 2005. It is evident that the pipe has continued to deflect since the 2001 inspection with a maximum deflection recorded in 2001 of 11.61% and 15.48% in 2005. In 2001 cracking was documented at 4, 7, 10, and 13 feet. Additional cracking is documented at 4.9, 5.2, 11, and 12 feet in 2005.



Project 7, SR 715, Danville, showing buckling, cracking and dimpling.

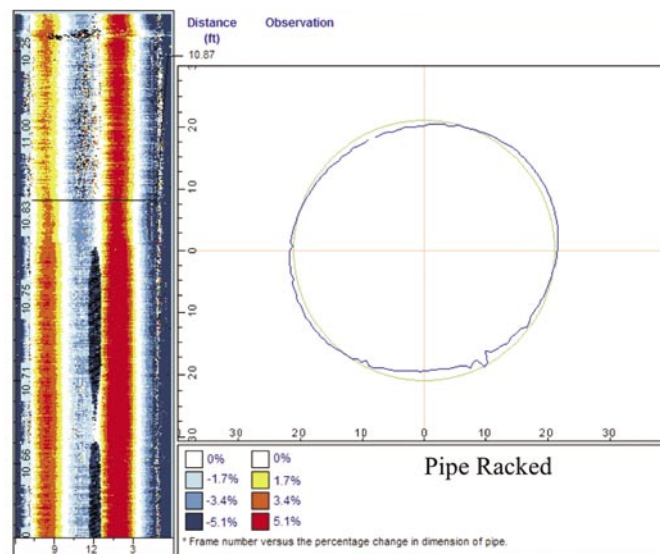
Project 8 - SR 229, Newcastle

The 42-inch, 62-foot long cross drain was installed in 1999 near Newcastle, Ohio. The HDPE pipe had a maximum cover of approximately three feet. No significant wall buckling or dimpling was noticed during the 2001 or the 2005 inspection. Severe deflection is observed in several areas of the culvert. Maximum deflection recorded in 2001 was 13.39% and the maximum deflection recorded in 2005 is 15.77%. In 2001 approximately 66.67% of the vertical deflection exceeded 5%, and approximately 71% exceeds 5% in 2005. Cracking is observed at 10, 16, 17, and 50 ft in 2001 and additional cracking is observed at 18, 30, 33.5, 35, 44.2, 47.9, and 52.2 in 2005. It appears that the pipe was not properly bedded

due to the material pushing through the invert of the pipe.

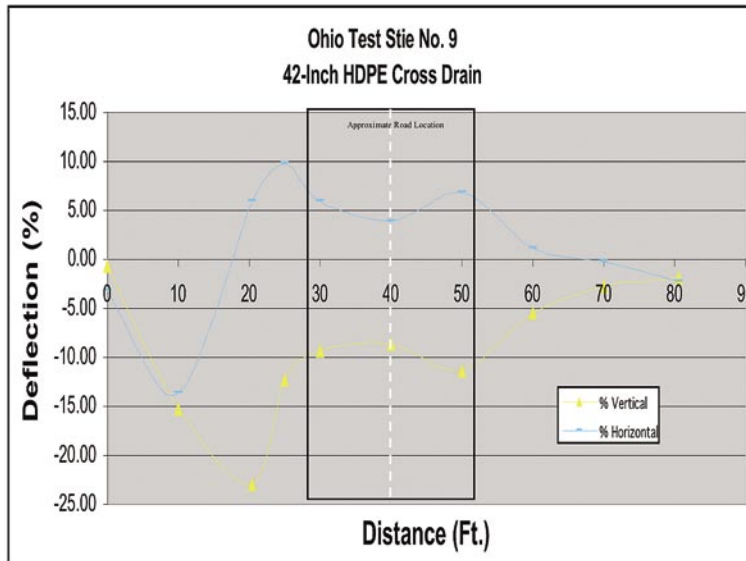


Video Imaging of Project 8, Newcastle showing large rock pushing through lower haunch



Project 9 - SR 229, Millwood

The 42-inch, 80-foot long HDPE pipe cross drain was installed in 1994 near Millwood, Ohio. The maximum fill height was approximately 10 to 11 ft. Rippling/dimpling was documented in the side walls throughout the pipe in 2001. Significant buckling has occurred in several areas since the 2001 inspection. Pipe deflection had significantly increased since the 2001 inspection with a maximum vertical deflection of 14.29% in 2001 and 22% in 2005. Inverse curvature of the crown has occurred, and 6" sections of the pipe wall have broken away at 20 feet. A large portion of the cracking has occurred in dimpled areas at the springline. The 2001 report only document 10 cracks (52, 54, 59, 63, 68, 70, 73, 75, and 79 feet), but in the 2005 inspection over 100 cracks are documented. It appears that the pipe was backfilled with a sand gradation and sand backfill is observed through cracks in the wall of the pipe in several areas. Geotextile fabric is also observed at the joints of each pipe section. Severe distress is apparent throughout large portions of the pipe.



Project 9, Millwood

Project 10 - SR 661, Homer

The 48-inch, 50-foot long cross drain was installed in 1999, under SR 661 near Homer, Ohio. The maximum fill height was approximately 2 ft. A bulge or buckle was reported in the crown of the pipe in 2001. It is apparent that the crown has continued to move since the last measurements were taken. Dimpling of the inner liner has occurred since the 2001 inspection and is observed from 30 to 40 feet around 10 o'clock. Dimpling is also noticed 39" from the inlet. In 2001 the vertical deflection at the bulge at 20 feet was 8.85%, and in 2005 it was 11.72%. In 2001, 9% of the vertical readings exceeded 7% deflection, and in 2005, 45% of the vertical readings exceed 7% deflection. Cracking is observed on the exterior of the pipe at the outlet end. No cracking is documented inside the structure. Corrugation creep of 3/8-inch to 9/16-inch is observed. Heavy corrugation creep is also evident from the laser profiles.



Project 10, Homer, showing bulge in crown



Project 10, Homer, showing cracks in pipe wall above spring line

Project 11 - SR 657, Homer

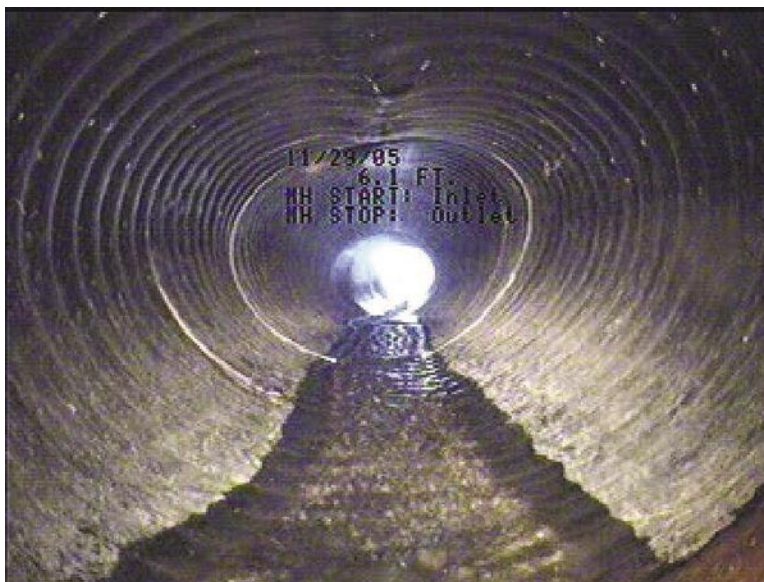
The 42-inch, 55-foot long cross drain was installed in 1999, under SR 661 near Homer, Ohio. The maximum fill height was approximately 2 to 3 ft. Limited wall buckling is observed in 2005. It appeared that dimpling has occurred and is cracking at 37.5 ft from the outlet. Corrugation compression is observed from 50 to 51.5 ft. Approximately 1" or greater corrugations are observed in the crown in this area. A long block of cut stone or concrete is observed over the crown of the HDPE pipe in the overlying file. Deflection readings in 2005 show a 0.89 % outlet deflection, an 8.93 % inlet deflection at 5 feet with a maximum inlet deflection of 13.24% at 10 feet. No cracking was observed in the 2001 inspection, but three cracks are observed in 2005.



Project 11, Homer, showing cracking and buckling approximately 2 feet from outlet

Project 12 - US 40, Jacksontown

The 48-inch, 55-foot long cross drain was installed in 1999, near Jacksontown, Ohio. The maximum fill height was approximately 7 ft. Wall dimpling was apparent in several sections of the pipe. Dimpling was documented at 2 and 8 o'clock from 40 to 48 feet, and at 9-10 o'clock from 6 to 13 feet. The maximum deflection recorded in 2001 was 9.9% and in 2005 the maximum recorded vertical deflection was 13%. The area of greatest deflection occurred in the area underlying the guardrail structure. Cracking was not documented in 2001, but is observed in five locations in 2005. A significant portion of the observed distresses appear to be occurring where the pipe is deflected greater than 5%.



Project 12, Jacksontown, showing crown inverted and cracking

Project 13 - SR 13, Jacksontown

The 42-inch, 84-foot long cross drain was installed in 1999, near Jacksontown, Ohio. The maximum fill height was approximately 5 ft. Inverse curvature in the crown, and wall buckling was documented in the 2001 inspection and it is apparent from the 2005 inspection that distress has significantly increased.

The maximum deflection recorded in 2001 was 18.75% and in 2005 is 23.21%. In 2001, 64.7% of the structure exceeded 5% deflection; the survey conducted in November of 2005 indicates that 79% of the structure exceeds 5% deflection, and that 50% of the structure exceeds 10% deflection. Limited cracking was documented during the 2001 inspection (1 crack 16 ft. from the outlet end), but five cracks are documented in 2005. From the distress plot and deflection plot, it is evident that the cracking is occurring in the areas of higher deflection. Brown precipitates are coming from a crack 72.5 feet from the inlet end. It is likely that the crack extends through the entire pipe wall.

Evaluation

The construction procedures, backfill methods, compaction methods, and materials utilized on each pipe section and test site were not available.

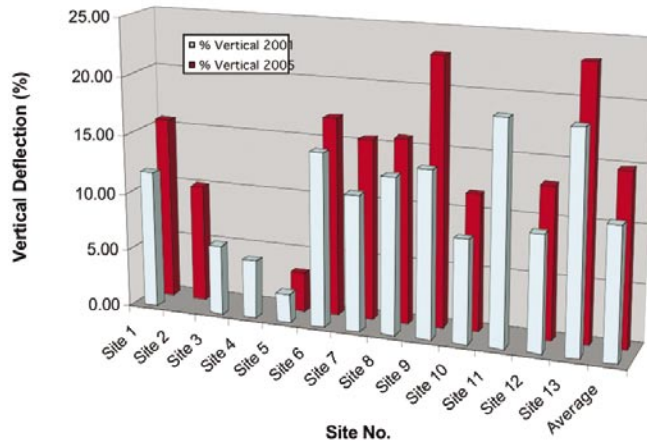
Camera and laser systems utilized on this project have provided significant information about pipe performance. The video inspection clearly show defects such as cracking, tearing, buckling, and sagging. Sagging was not analyzed due to the amount of water in the inverts of several of the pipes at the time of the inspections. The laser clearly provides more information than could be provided by mandrel testing alone. The laser provides information on crown flattening, invert flattening, racking, deflection, and general pipe shape.

HDPE pipe corrugation “growth” has occurred after installation and continues to progress. Limited measurements were taken on this project. The maximum recorded corrugation depth is 0.56 inch, with typical averages of approximately 0.39 inch. These corrugations occur in what is supposed to be a “smooth wall” pipe. This pipe has published Manning’s *n* values of approximately 0.012 (based on unloaded pipes). Typical corrugated metal pipe with 1/2" corrugations has a Manning’s *n* value of .022. Design Manning’s *n* values for smooth-lined HDPE pipe should be based on the anticipated condition of the pipe in the field.

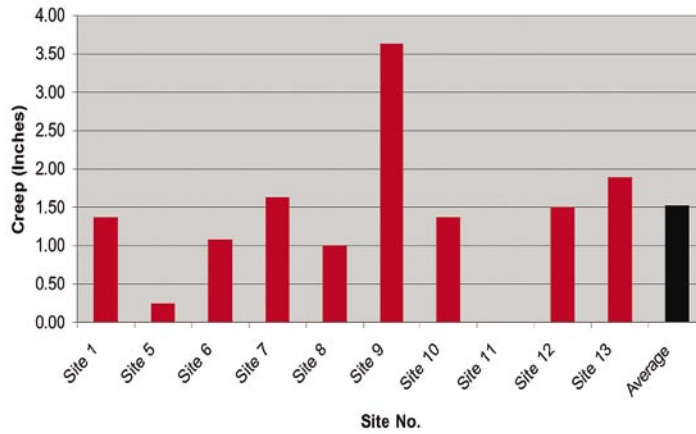
Cross drains inspected for this project show that cracking has increased by four to seven times since 2001. A total of 164 cracks were observed in 672 feet of cross drain that was inspected. Approximately 108 cracks have occurred in Site No. 9. Several types of cracks were observed including radial cracks in the inner wall or liner, cracking of dimpled areas, cracking in flattened inverts, longitudinal cracking in the crown in heavily deflected areas, diagonal cracking in buckled wall sections, and cracking in inverts resulting from bulges caused by improper bedding. Radial cracking is also observed on the exterior outlet ends of three of the culverts. Several of the inspected cross drains reveal cracking through the entire HDPE pipe wall. Sagging and racking were observed but not quantified.

The majority of the pipes investigated on this project would not pass a 5% deflection test and most of the sites have pipe sections that would not pass a 10% deflection test. The majority of pipes have continued to creep/deflect since the 2001 inspection. A significant number of the profiles indicate that horizontal movement/deflection has stopped, but movement is continuing vertically.

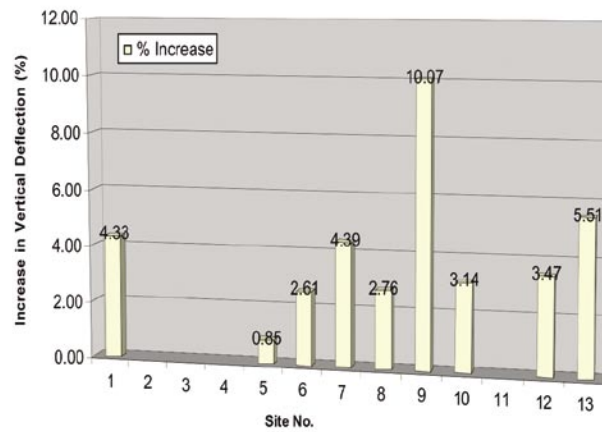
**% Vertical Deflection at Maximum Deflection Points
(2001 and 2005)**



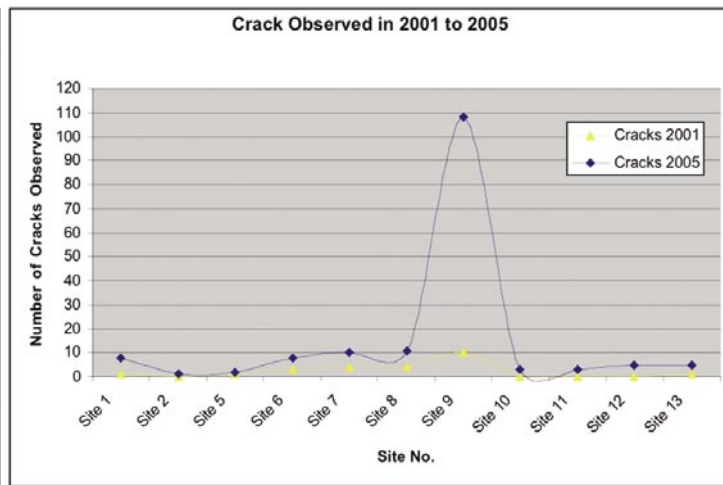
**Inches of Movement/Creep at Points of Maximum Deflection
(2001-2005)**



Change in Vertical Deflection from 2001 and 2005



Site No.	Cracks 2001	Cracks 2005
Site 1	1	8
Site 2	0	1
Site 5	1	2
Site 6	3	8
Site 7	4	10
Site 8	4	11
Site 9	10	108
Site 10	0	3
Site 11	0	3
Site 12	0	5
Site 13	1	5
Total	24	164
Total w/o 9	14	56



Recommendations and Comments:

Knowledge of the long-term performance properties of HDPE pipe is limited at this time. The laser clearly provides more information than could be provided by mandrel testing alone. Further testing is needed to evaluate the long-term performance of HDPE pipes.

The following recommendations were made:

- * Further monitoring of HDPE pipe installations should be conducted.
- * Post video inspection and deflection testing should be required for quality control and quality assurance.
- * Deflection should be limited to 5% with the anticipation of some post construction creep.
- * It is recommended that all previous monitoring points established on prior research projects be measured and evaluated for long-term performance.
- * Specifications should ensure that correct bedding and backfill requirements, proper densities and proper compaction efforts are achieved as outlined in ASTM D 2321 and AASHTO Section 30.
- * A uniform pipe assessment/inspection program should be adopted for quality control and for long-term performance monitoring.
- * A quality control/quality assurance inspection program should be established for all drainage materials and structures.
- * Video inspection and laser profiling should be evaluated for adoption into the ODOT specification for quality control and quality assurance.

(1) Significant historical information used for comparisons was obtained from “Condition Investigations of HDPE Pipe In-Service in the United States (six states),” January 24, 2002, Wiss, Janney, Elstner Associates, Inc.

