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A pilot study for retrospective evaluation of cured-in-place pipe (CIPP) rehabilitation of municipal gravity sewers

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ABSTRACT

Pipe rehabilitation and trenchless pipe replacement technologies have seen a steadily increasing use over the past 30–40 years. Despite the massive public investment in the rehabilitation of the US water and wastewater infrastructure, there has been little formal and quantitative evaluation of whether rehabilitation technologies are performing as expected and whether rehabilitation is indeed cost-effective compared to replacement. This paper describes the results of a pilot project for the retrospective evaluation of cured-in-place pipe (CIPP) liners. The pilot testing used CIPP samples from both large and small diameter sewers in two cities: Denver, CO and Columbus, OH. Testing on the liners included: thickness, annular gap, ovality, density, specific gravity, porosity, flexural strength, flexural modulus, tensile strength, tensile modulus, surface hardness, glass transition temperature, and Raman spectroscopy. In addition, environmental data was gathered as appropriate to each retrieval process including: external soil conditions and pH, and internal waste stream pH. Summaries of the test results and a discussion of their implications for CIPP performance are provided in this paper. All of the samples retrieved from the four locations involved in the pilot study testing were in excellent condition after being in use for 25 years, 23 years, 21 years and 5 years, respectively. Overall, it is concluded that there is no reason to anticipate that the liners evaluated in this pilot study will not last for their intended lifetime of 50 years and perhaps well beyond.

1. Introduction

This paper has resulted from a project funded by the US Environmental Protection Agency (EPA) to study and support technology development for the rehabilitation of water distribution and wastewater collection systems. During the early stages of this project, the need for a quantitative, retrospective evaluation of the performance of pipe rehabilitation systems emerged. Pipe rehabilitation and trenchless pipe replacement technologies have seen a steadily increasing use over the past 30–40 years and represent an increasing proportion of the approximately $25 billion annual expenditure on operations and maintenance of the nation's water and wastewater infrastructure (USEPA, 2002). Despite the massive public investment represented by the use of these technologies, there has been little formal and quantitative evaluation of whether they are performing as expected and whether rehabilitation is indeed cost-effective compared to replacement (Sterling et al., 2009). The major reasons for interest in a retrospective evaluation of pipe rehabilitation systems are:

- The biggest data gap in asset management for pipeline systems involving rehabilitation is prediction of the remaining asset life for the existing pipe and how long rehabilitation techniques can extend that life. Municipalities have expressed a strong desire for some hard data on the current condition of previously installed systems to validate or correct the assumptions made at the time of rehabilitation.
- Since several of the major pipe lining techniques have now been in use for at least 15 years (some nearly 30 years in the US and 40 years internationally), it is a good time to undertake such an investigation to assess whether the originally planned lifetime (typically assumed to be 50 years) is reasonable based on the current condition of the liner.

While the long-term goal of the retrospective evaluation effort is to provide significant and credible feedback on performance to the system owners and the engineers who specify rehabilitation and replacement, a few isolated evaluations of projects with a vari-

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ety of existing and service conditions cannot provide statistically significant data. Thus, the goals for the effort within the pilot project were: to draw attention to the need for this type of evaluation and to develop evaluation protocols that are technically and financially feasible for carrying out evaluations of the main rehabilitation and trenchless replacement technologies. The protocol should produce useful results at a cost that municipalities will be willing to pay to participate in the data collection. The subsequent drive will be to encourage municipalities and other system owners to conduct their own evaluations and then to contribute their data to a common database where the results can be aggregated on a national basis. The initial project focuses on cured-in-place pipe (CIPP) liners because they were the first trenchless liners (other than conventional slipliners) to be used in pipe rehabilitation and because they hold the largest market share within relining technologies. CIPP technology is one of a family of trenchless rehabilitation methods that allows the renewal of a buried pipe without the full excavation of the pipe from the ground surface. Such rehabilitation methods applied to sewer mainlines include the use of CIPP, close-fit linings, grout in place, spiral-wound linings, panel linings, spray-on/spin-cast linings, and chemical grouting. Pipe repair (e.g., repair sleeves) and replacement methods (e.g., sliplining and pipe bursting) may also be carried out using trenchless technology approaches. Further information on these various repair, replacement and rehabilitation technologies can be found in Sterling et al. (2010). It is intended to use the experiences derived from the evaluation of CIPP liners described in this paper to develop similar technology-appropriate protocols for other rehabilitation systems.

2. Organization of protocol development and field studies

The pilot study generally followed the progression of activities outlined below:

- A comprehensive list of field investigations and laboratory testing was developed that could be used to evaluate the current condition of a CIPP liner and provide information on its potential longevity. A written summary of the proposed liner evaluation protocol and its expected benefits was prepared that could be used in discussions with interested municipalities.
- Municipalities were identified that would be interested in assisting with a retrospective evaluation of previously installed CIPP liners and that had CIPP liners with as many years of service as possible. The municipalities identified were the City of Denver and the City of Columbus.
- Detailed discussions were entered into with the identified municipalities to discuss their participation in the study and the division of responsibilities and costs for the field retrieval of samples.
- After the field samples were retrieved and testing conducted, the tests carried out on the liners were evaluated as to the nature and extent that they provide information regarding the liner's current condition relative to its condition immediately following installation, and also for their cost-effectiveness in a more widespread liner evaluation program.
- Conclusions from the initial testing were developed and recommendations were formed as to a suitable retrospective evaluation protocol for wider use in the US.

This work was carried out in parallel with a broader set of interviews with municipalities and sewer agencies internationally to determine whether any international efforts were underway in terms of retrospective evaluations and, if so, what types of evaluation and testing were being used. This international review was conducted by Jason Consultants and is described in Allouche et al. (2011).

3. Approaches and goals for a pilot study of retrospective evaluation techniques

A variety of approaches to evaluate the state of deterioration of previously installed liners were considered in the initial stages of the project (see Allouche et al., 2011). Most typically, in current municipal practice, rehabilitated sections are only evaluated using CCTV immediately following the installation and then perhaps periodically using CCTV depending on the overall inspection strategy of the agency. In some cases, this would mean a regular CCTV inspection at intervals of a number of years, while in other cases it may mean no follow up since the rehabilitated section would be moved to the lowest priority for inspection.

In terms of the prediction of service life for CIPP liners, most of the attention has been placed on the prediction of long-term buckling of the liner in the presence of external water and/or soil pressure. This form of analysis provides the principal design equations in the ASTM F-1216 standard practice for CIPP rehabilitation and has been the subject of a wide range of academic research (e.g. Zhao et al., 2005; Yousef and Nassar, 2006). Much less information is available on the actual mechanisms of field deterioration of CIPP liners from the variety of operational and environmental conditions that could influence this process although a study was carried out by the IKT Institute in Germany to look at various CIPP liners after between 2 and 10 years of operation (Bossler et al., 2001; Bossler and Schlüter, 2002). Their study found a variety of problems with installed liners but few that could be traced to deterioration in service rather than poor installation practices.

The goals of the retrospective evaluation of a rehabilitation technology in a specific municipality were:

- To gather quantitative data on the current condition of a specific rehabilitation system using a draft protocol for the inspection, defect classification, sample collection, testing, analysis and storage of such data.
- To evaluate the protocol as to its appropriateness for use under field conditions in a municipality. Will it produce the desired data? Is the terminology used universally accepted and understood by the municipal engineering community? Is it excessively burdensome on the utility? Can the data collected be used effectively to guide asset management decisions?
- To compile the evaluation results into a common database so that cities can understand how the systems that they are investing in today have performed over their commercial life to date.

Prior to conducting each of the Denver and Columbus retrospective evaluation programs, a Quality Assurance Protocol Plan (QAPP) was developed to ensure the quality and validity of the field and laboratory test data that would be used in further analysis. Each QAPP was approved by the Quality Assurance Officer for the US EPA National Risk Management Research Laboratory (NRMRL).

4. Results from the pilot studies for retrospective evaluation

This section reviews the series of tests that were carried out on the CIPP liners retrieved from the City of Denver and City of Columbus and compares the results across all four sites. A full presentation of all test results including more extensive graphical presentation of results can be found in Allouche et al. (2011). Table 1 provides the key details for the host pipe and liner at each site. Figs. 1–5 show the condition of the field samples and the field sample retrieval processes. The different samples are identified in the