Tunnelling and Underground Space Technology 50 (2015) 451–464

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

A retrospective evaluation of the performance of liner systems used to rehabilitate municipal gravity sewers

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ARTICLE INFO

Article history:
Received 10 March 2015
Accepted 22 August 2015

Keywords:
Sewer
Rehabilitation
Lining
Condition assessment
Testing
Life cycle evaluation

ABSTRACT

This paper provides new results gathered as part of a 6-year project funded by the U.S. Environmental Protection Agency (USEPA) to document the in-service performance of trenchless pipe rehabilitation techniques. The results from a pilot study focusing on cured-in-place pipe (CIPP) rehabilitation technologies were previously reported and the research program was extended to allow collection of additional CIPP samples and also to extend the study to other rehabilitation technologies (specifically included in this Phase 2 research were fold-and-form, deform–reform, and sliplining technologies). The establishment of a database to house performance evaluation data for rehabilitation technologies used in the water and wastewater sectors is also described. The additional retrospective data for CIPP and other rehabilitation technologies are reported and an overall assessment of CIPP life cycle performance is provided. The examination of CIPP liners with up to 34 years in service and other rehabilitation technologies with up to 19 years of service has shown that all of the rehabilitation technologies are showing little evidence of deterioration in service. The test results for 18 CIPP samples from nine cities across North America indicate that properly designed and installed CIPP liners should meet and likely exceed the typical 50-year expected design life. For the fold-and-form, deform–reform, and sliplining technologies, there are only two to three samples per rehabilitation technology and hence less can be said about overall performance. Nevertheless, all of the samples tested still met the material property requirements at installations after 14–19 years of service. In summary, the results provide an excellent prognosis for the rehabilitation technologies evaluated.

1. Introduction

In the U.S., there are approximately 16,000 wastewater systems incorporating approximately 740,000 miles (1,190,660 km) of public sewers plus 500,000 miles (804,500 km) of private lateral sewers. Some components of the U.S. wastewater infrastructure are well over 100 years old. The combination of age, neglect, and mishaps gives rise to approximately 50,000 sanitary sewer overflows (SSOs) per year, along with the resulting illnesses and environmental degradation and as much as 10 billion gallons of raw sewage released yearly (EPA, 2004). The latest 2013 infrastructure report card issued by the American Society of Civil Engineers (ASCE) provides a "D" grade for wastewater infrastructure (ASCE, 2013). ASCE estimates that nearly $300 billion is needed for capital investments over the next 20 years (ASCE, 2013). Use of pipe rehabilitation and trenchless pipe replacement technologies has increased over the past 30–40 years and represents an increasing proportion of the approximately $25 billion annual expenditure on the operation and maintenance of the nation's water and wastewater infrastructure (EPA, 2002). Despite the massive public investment represented by the use of these technologies, little formal and quantitative evaluation has been conducted on whether they are performing as expected and whether rehabilitation is indeed cost-effective compared to replacement. This paper provides a follow up to an earlier paper (Allouche et al., 2014)

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http://dx.doi.org/10.1016/j.tust.2015.08.011
0886-7798/

documenting the results of a pilot study funded by the U.S. Environmental Protection Agency (USEPA) to assess the in-service performance of cured-in-place-pipe (CIPP) trenchless rehabilitation techniques.

In this paper, new test results are reported, the creation of a database to house performance evaluation data for rehabilitation technologies used in the water and wastewater sectors is described, and the comprehensive results obtained to date are presented and analyzed in terms of their implication for the long-term performance of the trenchless rehabilitation technologies studied. The full reports on both the pilot study (EPA, 2012) and the extended study (EPA, 2014) are available for free download through the USEPA websites (www.epa.gov/awi or http://nepis.epa.gov). The details of the retrieval and testing protocols used and the full presentation of the results for each sample can be found by accessing those reports. Several review reports on the state of technology for water and wastewater rehabilitation were also developed as part of these research efforts (EPA, 2009, 2010, 2013).

The pilot project focused on CIPP liners because they were the first trenchless liners (other than conventional slipliners) to be used in pipe rehabilitation and they hold the largest market share within relining technologies. The pilot testing used CIPP samples from both large and small diameter sewers in two cities (EPA, 2012). The follow-on work took up two of the recommendations from the prior work: to develop a database structure for the exchange of performance information on rehabilitation technologies and to collect a wider sample of physical test data and performance data on such technologies. In the follow-on work, the physical evaluation was extended to the use of CIPP in additional cities. A total of 13 new CIPP samples from seven cities were added to the five CIPP samples from two cities tested in the pilot study. The 18 CIPP liner samples from both the current and the pilot study mostly ranged in age from 17 to 34 years, while two younger liners (5 and 9 years) were also included. Samples of other types of rehabilitation liners (two polyvinyl chloride [PVC] fold-and-form liners, three high density polyethylene [HDPE] deform–reform liners, and two polyethylene slipliners) were also collected and tested during the extended research project.

Testing of the various liners over both projects included thickness, annular gap, ovality, specific gravity, porosity, flexural strength, flexural modulus, tensile strength, tensile modulus, surface hardness, glass transition temperature, Raman spectroscopy, environmental stress crack resistance and pipe stiffness as appropriate to the liner type and condition.

2. Choosing retrospective samples for retrieval in Phase 2

It was a goal of Phase 2 of the evaluation to extend the sample retrieval and testing beyond just the widely used CIPP lining process. A brief summary of the evaluations of various liner types in terms of suitability for Phase 2 of the work is given below.

- Since CIPP is by far the dominant liner technology used for trenchless rehabilitation, it was considered important to extend the testing beyond the 5 samples retrieved in the pilot study. Under Phase 2, samples from 13 CIPP liners from seven cities were obtained and tested.
- Newer CIPP systems including UV cure and reinforced liner systems are gaining popularity in application, but have less time in service compared to standard CIPP installations. With the main focus of the research to date being on CIPP, it was desired to address other rehabilitation technologies before adding other CIPP variants.
- Sliplining has a long history of use and has been considered in the two categories of large diameter sliplining and small diameter sliplining. The large diameter applications would allow the removal of samples from the pipe wall by person entry. However, the techniques for patching and the arrangements for access/bypass can present significant barriers. Smaller diameter sliplining often involves continuous lengths of pipe and hence functions more as a replacement pipe than a rehabilitated pipe. Sliplining samples were recovered for testing in this phase of the research as one of the oldest replacement techniques used by the City of Houston, which participated in the study.
- Close-fit linings for sewer application have typically comprised fold-and-form (PVC) and deform–reform (HDPE). Although neither is marketed in the U.S. at present, there is a reasonable service life for samples in some municipalities. Municipalities were available that could provide samples and it was considered worthwhile to study these systems as a guide to municipalities that already have such systems and as a guide for evaluating issues should future similar systems come to the market. Samples for both fold-and-form and deform–reform were recovered in this phase of the research.
- Grout-in-place linings and panel linings are typically large diameter installations and access/bypass issues are similar to those for large diameter sliplining. There are, however, installations with reasonable lengths of service around the country, but none were identified as being available for participation in the current phase of the research.
- Spiral wound linings have been used in small diameter sewers and also as grout-in-place linings in larger diameters. However, they have not been used in many cities and hence it is necessary to find a municipality with older spiral wound installations that are willing to participate in the study. For the larger diameter applications, access/bypass expenses remain issues.
- Although new technologies are emerging for trenchless pipe rehabilitation, spray and spincast lining technologies have historically been primarily applied to manholes within the sewer sector and therefore were not considered for a retrospective evaluation.
- Rehabilitation (infiltration and inflow [I/I] sealing) by grouting is an important technique with quite different cost and application criteria when compared with relining strategies. It is considered very worthwhile to collect better information on the longevity and performance issues for grouting applications, but the sampling and evaluation protocols present significant difficulties due to the nature of the process. The precise locations of grouting within a main and the contractor proce dures/pressures/materials, etc. used are often unknown for a particular section to be evaluated, complicating any evaluation. It was decided not to include grouting evaluation in this phase of the research.
- Water main rehabilitation technologies are a good target for future evaluations, but were deferred until a later phase of the research because, with the exception of corrosion protection linings, the application of the technologies is more recent than for sewer systems.
- Force main (pressure sewer) rehabilitation technologies also should be a future target, but the same issues apply as for water systems and sewer force mains are not as prevalent as gravity sewer mains or water distribution mains.

3. Testing and measurement protocols

The testing and measurement protocols were carried out in accordance with EPA NRMRL's QAPP Requirements for Applied Research Projects (EPA, 2008) and the project-specific QAPPs (Battelle, 2012a,b, 2013). The details of these protocols are described in the EPA report (EPA, 2014) and (for CIPP samples) in the previous paper (Allouche et al., 2014). ASTM testing standards were followed according to the parameter being measured. Where ASTM standards were not available (e.g. visual inspection, annular