FIBERGLASS TANK & PIPE INSTITUTE

Sewer-Main Collection Pipe Joint Infiltration Testing and Life Cycle Cost Analysis

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I. Abstract

A. Research Projects: Major members of the sewer-main pipe manufacturing industry and the University of Houston completed and published the results of the following two research projects:

1. **Sewer-Main Collection Pipe Joint Infiltration Testing:** This research project measured the water infiltration rate of water-tight designed 30-inch pipe joints. The joint tightness testing was conducted at a minimum hydrostatic head of 15 feet (i.e., 7 psi) under axial, shear loaded and angularly deflected conditions.
2. **Life Cycle Cost Model** This research project developed an interactive model to estimate the costs of constructing, rehabilitating, operating and maintaining sewer mains under various infiltration levels over a 30-year life. The model has been calibrated with published data and may be used to compare different rehabilitation and maintenance scenarios to identify the most cost effective sewer main design.

   Ancillary costs such as infrastructure damage (e.g., roadway settlement, sink holes) were not included in the *Life Cycle Cost Model* and may be factored in from local conditions. However, as an example of potential infrastructure damage, this paper includes a case study showing the impact of joint infiltration in the city of Houston.

B. Project Costs and Funding: The two research projects were funded by participating industry members and the Environmental Protection Agency Office of Wastewater through a grant to, and administered by, the Fiberglass Tank & Pipe Institute. Fourteen Steering Committee members contributed some $50,000 and over 2,000 professional man-hours to the project from 2000 through 2003. This includes the cost of pipe joint testing paid for by the manufacturers and time attending a series of daylong meetings. By applying a value of $125 per hour for these professional services, industry's total contribution is some $300,000 plus the $100,000 EPA grant for a total project cost of $400,000.

C. Report Availability: The *Sewer-Main Collection Pipe Joint Infiltration Testing* research results consist of four reports, each of which describe the testing of participating pipe trade association member company products, namely the American Concrete Pipe Association, Fiberglass Tank & Pipe Institute, National Clay Pipe Institute and Uni-Bell PVC Pipe Association.

The *Life Cycle Cost Model* research report consists of a description of the model, default input data derived from an international literature search and an interactive model that may be downloaded and used by municipal or consulting design engineers.

The foregoing research project reports are available on the internet by searching for "cigmat" which will bring up the "Cigmat Homepage." Under this homepage heading will be the heading "Research Report." Click on Research Report to display each of the five reports in alphabetical order. Each report shows a list of individual report sections (i.e., Front Page, Preface, Table of Contents, Report and Appendices). The Life Cycle report list includes instructions for using both the model and the interactive model to be downloaded by the user.

Keywords: University of Houston, pipe joint, infiltration, infrastructure, life cycle cost, , model, angular deflection, shear load, Environmental Protection Agency, sewer overflow, Almeda

II. Introduction

Fiberglass Tank & Pipe Institute

The Institute was incorporated in 1987 as a non-profit trade association serving the major fiberglass piping, manhole, septic tank and oil/water separator manufacturers in the USA. The Institute provides a forum through which industry members can work together effectively toward common goals. This includes coordinating studies, combining resources to provide standard-setting organizations with superior technical data and disseminating information to the government, industry and the public.

III. Background

The September 23, 1997 US Environmental Protection Agency (EPA) report to Congress (The 1996 Clean Water Needs Survey) identified a need for the construction of new and rehabilitation of existing sewers to control sewage overflows resulting from premature piping failures (i.e., infiltration) and higher demand. As a result, we have seen much new construction and rehabilitation that has been funded under the State Revolving Fund provisions of the Clean Water Act.

Municipal entities are surveying their needs and considering various construction methods (e.g., open trench, no-dig) and materials (e.g., clay, concrete, ductile iron, fiberglass, PVC, polyethylene, steel) to upgrade sewer collection systems. The resulting capital projects are being evaluated and prioritized for federal funding. However, the project development process should provide those who implement the CWA with a method to evaluate the life cycle cost of the construction alternatives for sewer mains (i.e., excluding laterals) in different areas of the United States. This methodology would provide a means of comparing construction alternatives and the selection of the most cost-effective long-term installation.

IV. Project Funding and Participation

The Fiberglass Tank & Pipe Institute was awarded a $100,000 EPA Grant to serve as seed money and develop a life cycle model to address sewer main pipe joint infiltration costs. The University of Houston (UH) Department of Civil and Environmental Engineering was selected by the Institute as the research contractor. During the development phase of the project, UH determined that, while ASTM standards existed for certain joint infiltration leak rate tests, these standards were not universally applicable to all pipe materials or joining methods. Further, leak test data was generally not available for joints that were subjected to underground installed axial, angular deflection and shear stress conditions. Thus, there was a need to develop a universal test method, conduct comparable leak rate tests and develop test data as input to the life cycle cost models. Therefore, UH research was conducted on two projects namely, *Sewer Main Pipe-joint Infiltration Leak Rate Testing and a Sewer Main Collection System Infiltration Life Cycle Cost Model.*

Invitations to participate in the project were made to all large diameter (i. e., 30-inch and larger) sewer-main pipe manufacturers and trade associations. While certain trade associations declined, the following four trade associations participated in the project:

- American Concrete Pipe Association
- Fiberglass Tank & Pipe Institute
- National Clay Pipe Institute
- Uni-Bell PVC Pipe Association

The project moved forward as a cooperative research project funded by the Environmental Protection Agency Office of Wastewater and the foregoing four trade associations. Each trade association contributed technical manpower to assist UH during the joint testing phase and reimbursed UH for each joint test. In addition, the trade associations funded legal filings, committee meeting room and other costs incurred during the three-year project life to ensure full participation of interested parties.

V. Research Steering Committee

A Steering Committee was formed and consisted of 14 members from industry, academia, EPA Office of Wastewater and chaired by Mr. J. E. Pate, Pate Engineers Inc. of Houston, Texas. Industry was represented by the four trade associations; public users by four cities (Houston, Victoria and Conroe in Texas and Montgomery, Alabama); Professional technical input came from three engineering companies, UH and a major underground pipe installation contractor. Project administration was provided by the Institute which developed the following to ensure project equity and credibility:

- Confidentiality Agreement executed by Steering Committee members.
- Federal Trade Commission and Department of Justice notification under the national Cooperative Research and Production Act of 1993.

The Steering Committee provided oversight of the University of Houston (UH) research projects including:

a. Meeting three to four times per year at the UH testing facility for on-site updates on UH research project status.
b. Providing overall UH research project guidance and recommendations that helped achieve project goals.
c. Reviewing and developing Steering Committee consensus approval of the infiltration test protocols developed by the Civil & Environmental Department of the University of Houston for pipe joints.
d. Determining through laboratory controlled testing, the infiltration leak-rates for large diameter sewer main pipe joints.
e. Developing an interactive life cycle cost model for different infiltration rates of large diameter sewer main collection system joints and costs incurred as a result of infiltration over the life of the system.

f. Reviewing draft UH project task reports, offering comments and developing a Steering Committee consensus approval before final reports were released.

The following membership of the Steering Committee provided a balance of producers and non-producers (i.e., users, governmental, those with expertise):

Organizations	**Representatives**
US EPA Office of Wastewater	Charles P. Vanderlyn
University of Houston	Dr. C. Vipulanandan
City of Houston, Texas	Henry N. Gregory
City of Victoria, Texas	Kenneth E.Gill
City of Conroe , Texas	Brent Sherrod
City of Montgomery, Alabama	Danny Holmberg
Laughlin-Thyssen (HCA contractor)	Clifford L. Tubbs
Parsons Brinckerhoff (Design Engineers)	Richard Thomasson
Black & Veatch (ASCE Representative)	Rick Nelson
Pate Engineers (Design Engineers)	J. E. Pate
American Concrete Pipe Association	Matthew S. Childs
Fiberglass Tank & Pipe Institute	Richard C. Turkopp
National Clay Pipe Institute	Ed Sikora
Uni-Bell PVC Pipe Association	Shah Rahman

VI. Sewer Main Pipe-Joint Infiltration Leak Rate Testing

Objective: The <u>overall</u> objective was to determine, through controlled laboratory testing, the infiltration leak-rates for different types of 30-inch diameter sewer pipe-joints under various loading conditions.

A. Specific Objectives

1. Develop a testing protocol to determine the infiltration at the pipe-joint under the following test conditions:
   - Straight joint (i.e., axial)
   - Angular deflection
   - Shear load
2. Develop a testing facility to perform the tests under external hydrostatic pressure equivalent to 15 feet of water (i.e., 7 psi).
3. Perform tests according to the testing protocol on pipe joints assembled by the pipe manufacturing representatives.

B. Testing Program

Two instrumented test stands were designed and constructed at the University of Houston. Each test stand was capable of accommodating two three-foot lengths (i.e., six feet) of 30-inches or greater diameter pipe joined together for testing. Provisions were made to constrain the pipe from moving laterally. The loading points were instrumented with 20,000 pound load cells to measure the applied and reaction loads. Test stand provisions also allowed the pipe-joint to be tested under deflection and shear load in accordance with the test protocol. Two sets of pipe-joints were first tested under no load and then the same pipe-joints were tested by first shear and then angular loading tests (i.e., 7 psi).

The test protocol required that the manufacturer joint designs and configurations tested had a history of successful field service for a minimum of two (2) years before January 1, 2000. the intent was to not test new or innovative pipe-joint designs, but instead those that should be available in the market place. In each case the specific joint designs and configurations submitted by the manufacturers demonstrated that these materials and joint designs should withstand a hydrostatic head of 15 feet of water without infiltration leakage.

VII. Life Cycle Model

Objective: The objective of this study was to develop a model that may be used by design engineers to estimate the Life Cycle Cost (LCC) for constructing, operating and maintaining a wastewater sewer system.

A. Specific Objectives

1. Identify the important parameters that influence the cost of constructing and maintaining a wastewater system with infiltration.
2. Develop a LCC model spanning a period of 30 years.
3. Quantify the major components (i.e., length of pipes, number of manholes, and size of treatment plants) of the wastewater system.
4. Incorporate certain maintenance and rehabilitation methods for various sizes of wastewater systems with changing populations and identify the most cost effective plan.

B. Model Development

The basic spreadsheet model has been developed to quantify daily infiltration caused by rainfall and/or groundwater based on population and average household occupancy. This model is capable of estimating the sizes of various components of a wastewater system based on default settings derived from new databases.

C. International Database Search

The new databases were derived from an international literature search, information on population, pipe lengths, number of treatment plants, number of lateral connections, average annual daily flow (mgd), pump station horse power (hp) and the treatment costs obtained from various cities across the United States. While a correlation was observed between various system characteristics to identify the model default settings, they may be reset by the user based on own experience, new or local data.

D. Major Model Components

Input spread sheet: Users of the model will enter variable data whereas default values are provided and may be used. Input values include such variables as population, number/type of establishments, manhole spacing, wastewater treatment cost. For example, the joints in pipeline are classified in three categories. Lateral-Main joints (joints at the intersection of lateral with main line sewer); Mainline joints (joints between the pipes of the mainline sewer) trunk line joints (joints between the pipes of the trunk sewer). The default spacing is 20 feet. The user can change the spacing as per their system.

E. Capital cost: The capital cost sheet shows the cost associated with laying out a wastewater system of the size obtained in the basic model sheet.

F. **5-year Outlook***:* There are 5-year model predictions based on incorporating the change in population every 5 years and one percent increase in system infiltration every year.

G. **Sanitary Sewer Overflow Outlook:** The model helps to check when the system flow exceeds the treatment plant capacity and the prescribed regulations of EPA for excessive infiltration (average dry weather flow not exceeding 120 gpcd-gallons per capita per day).

H. **Rehabilitation Cost:** Rehabilitation is performed every 10 years cycle. Rehabilitation is performed on 10% of the system. The cost calculation is done as per rehabilitation costs provided by the user (default values are also provided). 30 years rehabilitation cost is calculated based on two rehabilitation cycles.

I. **Life Cycle Cost:** The Life Cycle Cost sheet provides the cost of wastewater treatment for 30 years when system rehabilitation is performed every 10 years. An alternate Life Cycle Cost is also determined for no rehabilitation on the system. Thus the difference in the life cycle cost with maintenance and no maintenance is obtained.

VIII. Research Reports and Model Availability

The *Sewer Main Collection Pipe Joint Infiltration and Life Cycle Model* research reports may be downloaded from the internet and should provide municipal and consulting design engineers with the tools to compare infiltration tightness of available pipe-joint materials/methods and the model to determine life cycle costs for sewer main projects. The foregoing research project reports are available on the internet by searching for “cigmat” which will bring up the “Cigmat Homepage.” Under this homepage heading will be the heading “Research Report.” Click on Research Report to display each of the five reports in alphabetical order. Each report shows a list of individual report sections (i.e., Front Page, Preface, Table of Contents, Report and Appendices). The Life Cycle report list includes instructions for using both the model and the interactive model to be downloaded by the user.

IX. Case Study: Joint Infiltration and Infrastructure Damage

A. Almeda Road, Houston, Texas

It started as a typical urban pothole on Almeda Road in Houston, but by 2002 the hole grew to 40 x 60 feet – a cave-in big enough to swallow a full sized car. The sinkhole closed the road and rerouted traffic for months while the city assembled a team of consulting engineers and contractors to assess soil conditions an effect pipeline replacement. and cost the city of Houston $10 million to repair.

B. Almeda Road Sewer Line Failure

The 84-inch sewer line along Almeda road was originally installed in 1978. It is some 40 feet below grade and 30 feet below the water table. Years of groundwater infiltration weakened the native soil and in 1991, 330 feet were replaced. Later by 1994, much of the pipe was internally or externally grouted in an effort to extend the life of the pipeline. However, after years of groundwater infiltration smaller cracks grew into larger cracks, weakening the pipe bed and caused a nearby waterline break. Ultimately, the affected area caused the closing of the four-lane heavily trafficked street.

C. Sewer Line Replacement and Cost

Ground-penetrating radar was used to determine where the soil strength was compromised and soil grouting was required to provide bedding for the replacement pipe. In addition, 28,000 feet of existing interceptor piping was inspected by closed circuit television. The area adjacent to the sinkhole was stabilized, dewatered and a liner plate shaft constructed. Fiberglass 72-inch diameter pipe with 46 psi stiffness was used to slipline three sections including 1,700, 360 and 370 feet. Direct bury 72-inch pipe was installed in the location of the sinkhole for a total replacement of 2,500 feet. All pipe joints were gasket sealed to be leak free and prevent future infiltration. The Almeda sewer line infiltration failure cost the city of Houston $10 million to repair.

X. Summary

A. Sewer-Main Collection Pipe Joint Infiltration

The sewer-main pipe industry and University of Houston completed the pipe joint infiltration research project to measure the water infiltration rate of 30-inch pipe joints at a minimum hydrostatic head of 15 feet (i.e., 7 psi) under axial, shear loaded and angularly deflected conditions. The project was funded by participating industry members and the Environmental Protection Agency Office of Wastewater through a grant to, and administered by, the Fiberglass Tank & Pipe Institute. The research project determined that certain pipe joints designs submitted by concrete, fiberglass, clay and PVC trade associations for leak testing under a 15 foot hydrostatic head did not leak under axial, shear load and deflection conditions. Design engineers may use the test reports to specify the use of such pipe joints to minimize infiltration leakage in new and rehabilitation projects.

B. Life Cycle Cost Model

Certain members of the sewer-main pipe industry and University of Houston completed the infiltration life cycle cost model research project, which was designed to estimate the costs of constructing, rehabilitating, operating and maintaining sewer mains under various infiltration levels over a 30-year life. Ancillary costs such as infrastructure damage (e.g., roadway settlement) are not included. The project was funded by participating industry members and the Environmental Protection Agency Office of Wastewater through a grant to, and administered by, the Fiberglass Tank & Pipe Institute. The model has been calibrated with published data and may be used to compare different new, rehabilitation and maintenance scenarios to identify the most cost effective sewer main design. Design engineers may use the model to test alternative designs and determine the lowest long term cost of a new or rehabilitation sewer line project.

C. Infiltration Infrastructure Damage

The foregoing model does not include major life cycle costs associated with infrastructure damage and a $10 million sinkhole and roadway rebuilding project experienced in Houston, Texas. Design engineers may be able to gather historic infrastructure damage data and apply the associated costs to future new and rehabilitation projects.

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