OPTICAL IMAGING TECHNOLOGY FOR PIPELINE CONDITION ASSESSMENT

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Abstract: This paper discusses how optical imaging technology has transferred from the oil and gas industry to the sewer pipe inspection industry to become known as the Sewer Scanner and Evaluation Technology (SSET). The first generation of the innovation system was developed in 1996, and the system was expanded and advanced to the second-generation system in 1998. Approximately 38,400 meters of sewer lines was scanned with the developed system as part of the evaluation program in 1997 and 1998. The system was first utilized in a pilot commercial contract in 1999. Lessons learned from experience and the future direction for optical scanning technology for sewer pipe internal inspection will be discussed.

1. INTRODUCTION

All trenchless systems are designed to cope with a specific range of conditions, and none is universally suitable. Knowledge of what exist below ground therefore influences not only the cost of the project, but also the choice of system to be used. For repair and renovation the main need is for accurate information about the size, shape, and route and condition of the existing main or service, including data on any fittings or chambers. For rehabilitation projects, accurate sewer pipeline condition assessment is vital to developing a cost effective and efficient pipeline renewal (i.e., rehabilitation, replacement, etc.) program. One of the longest established investigative tools is closed-circuit television (CCTV) which first appeared in the 1950's and came of age in the eighties when modern electronics produced higher reliability, improved performance and lower cost. Typically, pipeline renewal recommendations are based on a field technician's assessment of the pipeline's condition. The need for standard condition assessment ratings has been discussed for about 30 years; yet, to date, no standard rating system exists in most country. This paper will provide a description of an innovative assessment technology that actually removes the operator/technician from providing assessment ratings. The developed technology was evaluated during 1997 to 1999. The evaluation program was involved 13 municipalities. Approximately 38,000 meters of sewer lines were scanned with the developed system. Experience and lessons learned from the evaluation program will also be discussed.

2.SEWER PIPE ASSESSMENT TECHNOLOGY

CCTV (closed circuit televising) was introduced as a sewer pipeline internal inspection tool in the 1960s. It replaced the utilization of mirrors to reflect light into the pipe to form a visual image of the inside condition. CCTV became widely used in the U.S.A. during the 1970s as a result of the EPA Construction Grants Program that required standard investigation techniques be utilized to execute a Sewer System Evaluation Survey (SSES). From the 1970s, CCTV has remained the standard or conventional sewer pipeline assessment technology.

CCTV technology and sewer data entry/management systems have advanced greatly since the 1970s from black and white cameras winched through the pipe on skids and manual data collection/management systems. No doubt, these technologies/systems will continue to advance. However, the danger of relying on CCTV condition assessment methodology does not relate to the technology. It is a "people" problem. The merits of the methodology are solely dependent on the skill, experience, and alertness of the operator/technician. This process requires the operator to make rapid field judgments to accurately classify, code or rate defects. This individual is under constant pressure to maximize production and provide a thorough condition assessment. Often this results in a compromise that eventually results in higher cost later. For example, a member of the program management team for a major wastewater improvements program explained that a recent sewer rehabilitation contract resulted in 92 field change orders simply because the CCTV operators went so fast they missed defects that were later identified by the rehab contractor during construction impacting cost and schedule.

When a methodology is so dependent on an operator to acquire, assimilate, and classify field data, this individual is critical to the quality, reliability, and cost of a sewer rehabilitation/maintenance program, deterioration prediction models, etc. In a recently developed Sewer Condition Classification Manual states that Surveyed sewer condition classifications vary as widely as the municipalities that use them. What one surveyor calls a fracture, another may consider a third degree crack. Neither of these classifications may suit the needs of the engineer evaluating the survey results. It is this lack of consistency in nomenclature that forces duplication of effort and higher inspection evaluation costs. (Montgomery Watson, 1999)

3. DEVELOPMENT OF SSET

In the oil and gas geophysical borehole imaging industry there are three distinct types of imaging tools and techniques. These are (i) acoustic imaging, (ii) electrical imaging, and (iii) optical imaging.

Acoustic imaging is also referred to as acoustic borehole televiewer. Mobil Oil Company developed the first analog acoustic borehole imaging/televiewer capability in 1969. The purpose of this technique was to detect fractures in rock formations. In the early 1970s, Simplex Corporation, utilizing the Mobil patents, produced the first commercial versions. By the late 1980s, all of the major oil and gas industry service companies had developed digital borehole televiewers. All tools rely on the same basic principles of operation, which utilize short bursts of acoustical energy emitted by a transducer to travel through the borehole fluid and then partially reflected by the borehole wall. The data acquired from this process provides the capability of producing full 360-degree borehole coverage. (GMI, 1999)

Schlumberger introduced the capability of logging microresistivities using pad tools with arrays of sensors in 1985. The data acquired from this process resulted in the development of electrical imaging. Initially, the tools were 2 Pad FMS (Formation MicroScanner). However, the 2 pad FMS tool advanced to a 4 Pad four-arm tool. In 1993, Halliburton introduced the six-arm, 6 Pad microresistivity tool, and Western Atlas combined a 6 Pad resistivity array tool with their acoustic imaging tool. The latest generation of electrical imaging tools consists of an 8 Pad four-arm tool known as the FMI (Fullbore Formation MicroImager). (GMI, 1999)

Optical imaging, utilizing borehole photographic cameras, was the first type of borehole imaging capability. Initially, stereoscopic cameras were mounted on packer systems. These systems pumped a clear fluid bubble in front of the lens generating the image. In the 1960s, video cameras (closed circuit televising (CCTV)) were used to televise the borehole. In the late 1980s, a rotating optical imaging system was introduced. In the early 1990s, optical imaging evolved into a process consisting of a downhole digital video camera mounted above a conical mirror and illumination ring assembly. By the mid-1990s, the capability was further improved by utilizing a hyperbolic mirror. The camera continuously records the reflections from the borehole wall to the mirror as the system is lowered into the well. A single diameter (ring of pixels) of the conical/hyperbolic mirror is digitized at each 0.5 mm depth interval. The probe acquires the rings of pixels, which correspond to scans of the borehole walls. These rings of pixels could then be built up into a continuous unfolded 360-degree image of the borehole. (GMI, 1999) (Robertson, 1999).

Acoustical, electrical, and optical imaging technologies have application for pipeline assessment. However, optical imaging has the potential for offering the greatest benefit for sewer pipeline inspection. This paper will discuss how this technology has transferred from the oil and gas industry to the sewer pipe inspection industry to become known as the SSET (Sewer Scanner and Evaluation Technology).

The main feature of the Sewer Scanner and Evaluation Technology (SSET) is being able to optically scan the inside surface of a pipe digitally to produce an image that can be unfolded or laid out flat to provide analytical capabilities not possible with conventional assessment techniques (i.e., closed circuit televising (CCTV), sonar, etc.).

The Version 1 SSET probe consisted of the following major components (CERF, 2000):

1. A CCTV located at the front of the probe was utilized to obtain the forward-looking view. This view is significant for navigational safety purposes, but was not utilized for the analysis.
2. A mechanical optical scanner that utilized a rotating two piece scanning mirror to reflect light produced by an arc lamp to the interior wall surface of the pipe. The image of the illuminated spot is then reflected on the other side of the mirror and guided through lens to the optical sensor. The optical sensor converts the image into a digital signal in full color (RGB-each with 256 gradations) through an analogue/digital converter.
3. A three component mechanical gyroscope.

The probe collects data for 500 dots (pixels) in each rotation of the mirror. The mirror rotates 54 times per second. As the probe moves through the pipe, the scanned lines get stretched apart. The resolution in the longitudinal direction depends on the travel speed of the probe. Typically, the Version 1 probe moved through the pipe at a uniform rate of speed that ranged from about 7 feet/minute to about 10 feet/minute.

The average rate of advancement for these segments was 3.87 meter/minute. The rate varied from a low of 1.71 meter/min. to a high of 6.93 meter/min. This is on a new pipeline with no defects. The rate will tend to decrease dramatically as the level of deterioration increases. The rate is a function of the number of stops that must be made to accurately assess each defect. The variation in rate also increases.The SSET does not stop at each defect. It will travel at a uniform rate of speed regardless of the level of deterioration.

The SSET version 2 probe is shorter, faster, and has no moving parts. It utilizes a fish-eye lens and a VGA CCD sensor (600x480) to capture the image as opposed to a single CCD for each color band (RGB) as was used in Version 1. A thin annular area (ring scanline) in the image area is electronically scanned, digitized in the probe, and transmitted to a controller through the cable. Each scane frame collects 1200 dots (pixels) instead of 500 collected in version 1. The mechanical gyroscope was up-graded to a fiber-optic. The speed is in the range of what the CCTV system obtained in the above example. The operating system is Windows 98 compatible. This is the version that was used for a commercial Pilot Project and a evaluation program in 1999 (CERF, 2000). The technology is considered to be market ready in the end of 2000.

4. INSPECTION PROCESS OF SSET

The SSET internal pipe inspection process is similar to the traditional CCTV process in several aspects. Both techniques require the two stages described in the previous section. Both techniques require a camera or probe to be transported through the pipe to collect the data. Both require a vehicle of some sort (i.e., van, trailer, etc.) to transport the equipment to the site. Both require the same size field crew. However, that is about the extent of the similarity.

Sewer pipeline condition assessment involves two stages. The first stage is referred to as data acquisition, and the second stage is referred to as data evaluation or data analysis. As with any process, if garbage goes in then the output will be garbage. The standard practice involves a consulting engineering firm being retained by an owner (public or private) to conduct an SSES. This firm subcontracts the CCTV portion to a specialty firm. The deliverables of this subcontract would be copies of the videotapes and a report categorizing the defects. Because of the problems mentioned previously , a trend has developed with many consulting engineering firms where they have instructed their CCTV subcontractors not to attempt to classify any defects or even to describe them on the videotape. They require that the operator focus solely on doing the best job they can in collecting the video data. The consulting firms utilize their own engineers to do the defect rating, prioritizing, etc.

The necessity for more reliable data to permit the analysis to be done more efficiently lead to the development of the Sewer Scanner and Evaluation Technology (SSET). The driving force behind the SSET has been the need for decision-makers to make better decisions quicker. This process will be explained in more detail in the next section.

The field data acquisition phase is unique in that the field technician/operator does not need to stop at defects and service lines to pan, tilt, and zoom to describe the condition of each or to provide a rating. As mentioned previously, because of the problems associated with achieving uniform defect ratings, a trend has developed with many consulting engineering firms where they have instructed their CCTV subcontractors not to attempt to classify any defects or even to describe them on the videotape. They require that the operator focus solely on doing the best job they can in collecting the data. The consulting firms utilize their own engineers to do the defect rating, prioritizing, etc.

The SSET field data acquisition stage results in the technician/operator being able to monitor the forward looking view and the unfolded (360-degree flat) view of the pipe in real time as the probe moves through the pipeline. The technician can focus his/her attention at all times to what they have been trained to do which is to ensure that the equipment is being utilized properly, and to be on the alert for things that may cause problems such as collapsed lines, etc. The scanned data and gyroscope data is automatically collected on portable hard drives.

The second stage (i.e., data evaluation, and data analysis) of the SSET system is very unique. It does not require hours spent viewing video tapes which many times results in several viewings at increasingly higher levels in the decision making process. With the SSET process the field data is entered into an analysis software program that has been developed to present a wide range of information. This information includes:

*Forward looking view
*A full circumference scanned image of the pipe for the total length
*A computer color-coded print out of the defects
*A written description of defects at each location along the pipe
*Horizontal pipe deflections
*Vertical pipe deflections

Accurate measurements and statistics can be accumulated. All images are stored on a CD for later retrieval and manipulation as required.

5. EVALUATION OF SSET

The evaluation of the SSET was designed, performed and overseen by a technical evaluation panel. This panel consisted of representatives from 13 sewer agencies, CORE Corporation, Civil Engineering Research Foundation (CERF), and TTC (Trenchless Technology Center). The official evaluation plan was developed during the first panel meeting conducted at the CERF Headquarters in Washington, DC on August 4-5, 1997. From September 1997 until September 1998, CORE conducted the fieldwork component of the SSET evaluation plan. During this time, development activity was being conducted in Japan, which resulted in a new version of the SSET. The new version utilized a fish-eye lens camera to replace the rotating mechanical scanner and a fiber optic gyroscope to replace the mechanical gyroscope. (CERF 2000)

On November 17-18, 1998, the SSET Version 2 was introduced to the CERF evaluation panel during a second panel meeting in Houston. The purpose of this meeting was to review the experience gained during the field operations and the impressions of the SSET on the panelists. Since Version 2 appeared to successfully respond to limitations of the initial system, the panel recommended additional testing was scheduled to demonstrate the improvements. This additional, testing work was performed in Santa Rosa on May 12-13, 1999.

During the spring of 1999, approximately 6,000 meters of sewer lines ranging from 200 mm to 600 mm were internally inspected with the Version 2 SSET system as part of a pilot project. As a result of the CERF program and the Atlanta Pilot Project much has been learned about the utilization of optical scanning and imaging technology in a wide range of sewer pipe environments. The scientific approach taken by TTC to accurately document performance uniformly in 13 sewer agencies and the commercial work in Atlanta assisted greatly in providing documentation on what modifications will need to be made to allow this technology to be utilized as a viable inspection option.

5.1 Description of the CERF SSET Evaluation Program

This program was described briefly in a previous section. It is described in detail in the "CERF, 2000" reference; therefore, it will not be described in detail in this paper. It is significant to point out that 13 municipal and/or sewer agencies paid $20,000 to participate in this program. In addition to the cash contribution, each contributed much in the way of support for the field operation as well as evaluating the results. The four California agencies paid an additional $2,000 each to cover the cost of the additional SSET work for the version 2 systems in Santa Rosa. If all of the "in-kind" (indirect) and direct costs were accounted for, it would probably be in the $400,000 + range.

The question that must be addressed is why would so many agencies be that interested in evaluating a new sewer pipeline assessment technology. Obviously, agencies realize the importance of accurate and timely assessments. They are searching for advanced technologies that utilize digital data capability that will allow them to make better decisions quicker. The SSET evaluation criteria that was established by the 13 municipal/agency evaluators for the field data acquisition stage were: (CERF,2000)

- *Constructability/Practicality
- *Functional Performance
- *Maintainability
- *Safety
- *Environmental Characteristics

Because of the large volume of collected data, a comprehensive comparative analysis of scans was focused on a limited number of selected scanned segments. The components of this comparative analysis included: (CERF,2000)

- *Accuracy. Are the shown defects real or misinterpreted? Is the position of the defects accurate? How reliable are the gyroscope data?
- *Competence. Are scans showing more or less defects than the CCTV results?
- *Quality. What are the scan sharpness, coloring, and depth perception?

The analysis was focused on the following defect types: (CERF, 2000)

- *Cracks (longitudinal, radial, spiral, multiple);
- *Area Defects (structural, corrosion, infiltration, root intrusion, debris);
- *Laterals (pre-manufactured or tapped-in, protruding);
- *Joints (offset, open);
- *Vertical deflection (above or below the designed grade)

5.2 Description of the Atlanta SSET Pilot Project

On July 29, 1999, in the U.S. District Court in Atlanta, the City of Atlanta reached a comprehensive agreement with Federal and State environmental officials to evaluate and upgrade its wastewater collection and treatment system during the next 14 years. The collection system consists of 3,520 kilometers of aging sewer lines. The agreement requires all sewer lines to be inspected including private lines. It is anticipated that the sanitary sewer evaluation survey will take two years. It is expected that approximately 50% of the collection system will need to be upgraded. (ENR, 1999) This commitment places Atlanta's Wastewater Improvements Program as one of the largest in North America. It ranks close to the Houston, TX: Miami-Dade County, FL; and

Jefferson County, AL programs.

A major component of Atlanta's sewer collection system improvement program is thorough pipeline condition assessment. It is impossible to select the best solutions to solve pipeline deficiencies without an accurate assessment. This is a "pay me now or pay me much more later" scenario. When pipeline assessment is not accurate or incomplete, the rehabilitation technique specified could be inadequate to solve the problem or too excessive (over kill) leading to increased costs. Inaccurate pipeline assessment often results in expensive construction change orders that develop when the rehabilitation contractor finds defects not indicated in the contract documents. (Peters, 1999)

The City of Atlanta, like most municipalities, is committed to adopting the best market proven technology to assess and renew their sewer system defects. The City does not provide financial support for technology development; however, the city encourages new technology development. Even though, in February 1999, the CERF-SSET Innovative Technology Evaluation Program was not finalized, the fieldwork was complete and the preliminary positive results were known. Due to the time demands for the Atlanta program, the City decided to develop an SSET Pilot Program. This became the first commercial project for this new technology. It involved the scanning and analysis of almost 6,000 meters of sewer line that varied from 200 mm to 600 mm in diameter. (Peters, 1999)

5.3 Lessons Learned from CERF and Atlanta

The SSET approach to internally inspecting sewer pipeline has been evaluated scientifically and commercially. The approach is believed to have merit; however, many inadequacies were discovered as a result of the intense field trials. All of these inadequacies are discussed in detail in the CERF/TTC report. Many of these inadequacies discussed in the CERF/TTC report were eliminated or minimized with the introduction of version 2. However, some recommended improvements remained. The following quote from one of the 13 CERF agency evaluators best describes the status:

SSET system is important to the Sewer Industry worldwide that are responsible for maintaining, repairing, and replacing the collection system infrastructure. In the past 30 years, no significant efforts was being put into research and development of new technology that would enable the managers of collection systems to more efficiently operate and evaluate their systems. As the result of Seattle No-Dig conference that presentation, the County of Sacramento, County Sanitation District No. 1 (CSD-1), agreed to put up $20,000 with twelve other agencies to have CERF, in cooperation with TTC, evaluate this technology." (Hassey, 1999)

6. CONCLUSIONS

Much time, effort, and money has been spent on developing and evaluating the SSET. The conclusion of this effort is the realization that the SSET will be market ready in the end of 2000. It has produced some fantastic results, and it has proven that this is definitely the direction that must be taken in the future. Nevertheless, more research and development must be committed to in order to overcome current inadequacies.

As a result of the previous work and the dedication expressed by all participants of the CERF/TTC program and the Atlanta Pilot Project, a major worldwide leader in subsurface imaging technologies and services has made a commitment in this area. The developer is committed to expanding its significant experience in the groundwater, oil & gas, environmental and geotechnical industries to meet the unique demands of the trenchless technology industry. Particularly, the developer will draw from its many years of experience in developing advanced digital borehole imaging systems to address the need for accurate, high-resolution imaging systems for internal and external pipeline assessments. The primary focus of this commitment will be to transfer the optical televiewer (OPTV) high-resolution borehole imaging technology into a SSET system that can overcome the inadequacies learned from previous experience.

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