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TTC EVALUATION REPORT

Report No. TTC-2007.01

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EVALUATION SUBJECT:

Review of Test Data and Field Trials for the MainSaver Process

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DATE:

April 9, 2007

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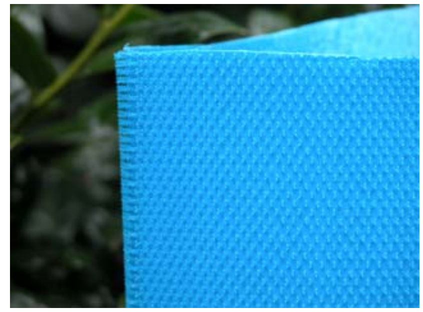
A. BACKGROUND

	MAINSAVER LINING SYSTEM
Basic description of lining system	MainSaver is a composite lining system comprising an interior thin polyethylene tube interlocked with a cementitious grout layer that fills the annular space between the polyethylene tube and the host pipe. The polyethylene tube is made from a sheet that is smooth on the side facing the center of the pipe and contains closely spaced hooked tabs on the side facing the pipe wall. The composite lining is intended to address water quality, corrosion problems, eliminate leakage in a water pipeline and to correct some small localized minor to moderate structural defects in a generally sound host pipe. The lining is not intended to be a full structural lining, i.e. it relies on the host pipe for resistance to internal pressures and external soil loads. More detail on the lining system is provided in the body of this report. The lining system as used in Europe was known as “CemPipe”. However, due to the extensive changes made to the system materials and quality control procedures for North American applications, the system has been given the new name “MainSaver”. The process is protected by a U.K. patent (GB 2302153) and U.S. patent 6,167,913.
	IMPETUS FOR THIS REPORT
Requested by CemPipe Americas (now MainSaver)	The review of existing test data relating to the performance of the MainSaver/CemPipe Pressure Pipeline Rehabilitation process that is described in this report was initiated by CemPipe Americas which later changed its name to MainSaver. The report reviews prior test data carried out in the U.K. and recently conducted testing carried out in the U.S. Field trials of the MainSaver/CemPipe process were observed twice at the MainSaver facility and a field installation using the system was observed on a project in Albuquerque. The report also summarizes the design and performance issues that need to be addressed when using a liner system such as MainSaver for the rehabilitation of water distribution piping and comments on the extent to which the provided test data address these design and performance issues.
	CONDUCT OF THE STUDY
Carried out by Dr. Ray Sterling and John Matthews	The review was carried out between May 2006 and March 2007 by Dr. Ray Sterling, P.E. and John Matthews, B.S. M.S., both from the Trenchless Technology Center (TTC) at Louisiana Tech University. The review began with the test data and documents provided by the company on the MainSaver process. Further documentation and referenced standards were obtained as necessary to gain a full understanding of the test procedures and the extent to which the testing conformed to the established standards for those tests. It was documented in the contract for the review that MainSaver must accept and make available the report in total and not abstract only portions of the review without the consent of the TTC. The report contents were developed without any involvement in their preparation by MainSaver – except for the provision of specific process details. MainSaver had the opportunity to submit clarifications or corrections to material contained in the report but the final decision on the content of the report remained with the TTC.

B. DESCRIPTION OF THE MAINSAVER PROCESS AND ITS APPLICATION

The MainSaver process uses a factory manufactured sheet of polyethylene containing deformed (hooked) polyethylene studs 2.9 mm (0.114 in) in length distributed over the surface of one side of the polyethylene sheet (in this form termed a "tape"). These "tapes" are then cut and fused to the proper width for the pipe diameter to be lined. This "sheet" is then seam welded to form a "tube" with the smooth side of the polyethylene tube on the inside and the studded side on the exterior. The seam(s) in the final liner are longitudinal and the maximum length of a single tape is 1050 ft (320 m). Once cut to length, the polyethylene inner liner is passed through a simple folding device to facilitate its ease of insertion into the existing host pipe. The liner is pulled through the existing pipe using a previously installed cable. Once in place, a pressure fitting is installed at one end of the liner and a tensioning and back-pressure device is installed at the other end of the liner. The pressure fitting allows a special cementitious grout mixture to be inserted into the space above and below the liner at one end of the pipe. The pressure fitting also is designed to allow the forcing of a flexible circular swab through the inside of the polyethylene liner once the correct volume of grout has been inserted into the annular space. As the swab travels down the inside of the polyethylene liner, the combination of the swab and the pressure that is maintained within the liner behind the swab cause the grout to flow ahead of the swab and to fill the annular space while at the same time re-rounding the polyethylene liner. The annular space thickness is defined principally by the height of the polyethylene studs on the liner surface since a properly sized liner will stretch radially to conform to the inside surface of the pipe. The far end of the liner is held open against the inside of the host pipe but is not fixed in longitudinal position. This allows for the slight straightening and extension of the polyethylene liner as the swab passes through it. A partial restriction of the annular space flow at the exit end allows air to escape from the annular space but allows the grout to fill the complete circumference near the end of the pipe. Once the swab has passed through the polyethylene liner, the pressure inside the liner is adjusted and maintained for 16 hours until the grout has set. Once the grout has sufficiently hardened, the internal pressure is removed and the ends of the liner trimmed. Connections to adjacent sections of lined pipe or new pipe sections are made by connecting to a new pipe spool with pressure couplings.



Polyethylene Liner Tube

Inserting tube into host pipe

Swab Insertion Chamber

Liner Tensioning Device

Expected Advantages for the Lining System

The following advantages are expected for the MainSaver system:

- Behavior as an AWWA M28 Class III structural composite
- Cement grout layer provides active corrosion protection to the interior surface of a metal host pipe
- PE tube ensures water quality by avoiding any potential pH rise in the conveyed water from a cement mortar lining
- PE tube also protects the effectiveness of the cement layer from being degraded over time through calcium depletion

- Grout layer provides structural rigidity while the PE layer provides a smooth, tough inner layer
- The MainSaver system can improve the life cycle performance of a water pipe and reduce leakage at a low cost compared to replacement or more expensive relining systems
- Relatively simple techniques and non-specialist equipment plus straightforward and low cost mobilization and training reduce the market entry barriers for the relining system.

Field Sample from City of Albuquerque Project

Potential Limitations for the MainSaver Lining System

The following limitations need to be addressed in a successful lining project using the MainSaver process:

- The length of line to be rehabilitated at one time is currently limited to 300-600 ft. An excavation must be made and the host pipe broken into at intervals less than 300 ft to insert the lining. The system is not intended to line through valves and other fittings as these should be replaced anyway.
- The lining system is not intended to act as a full structural lining or to bridge major breaks in a pressurized water pipe. Thus, the choice of where the lining system can be effectively applied is an important one. MainSaver is classified as a Class III structural system per AWWA M28.
- If the host pipe already has some leakage areas, the external groundwater pressure may act directly on the completed lining. This is not a problem during normal internal pressure operation (since the internal pressures exceed the external groundwater pressures) but the expected external water pressure should not exceed the capability of the MainSaver lining system if the line is depressurized. The tests described later in the report address this issue in terms of the ability of a liner with a substantial (1-inch or 2-inch diameter hole to withstand an external hydrostatic pressure.
- The studded polyethylene "tape" is made in a factory and the welding of the sheet into tubes is also done in a controlled environment at a central facility. The contractor will have field capability to repair small defects only. The remainder of the installation process must be carried out on site. This means that adequate quality control procedures must be in place to provide a quality job on each installation. Quality control issues to be addressed for the MainSaver liner system are:
    - Quality of the "tape" (sheet stock), e.g. absence of pinholes, consistent material properties, etc.
    - Quality of the weld forming the tape into a lining section.
    - Avoiding overstress or tearing of the polyethylene lining when pulling the lining into the host pipe.
    - Having the correct sizing of the polyethylene lining so that the lining is expanded tightly against the host pipe without wrinkling due to excess material and without excessive stretching of the polyethylene liner tube or crushing of the polyethylene studs that define the grouted annular space. Under sizing of the liner is not a major concern if sufficient grout is used to fill the annular space. During installation, an internal air pressure of around 1-2 psi is used so that the PE will not stretch excessively.
    - Controlling the proper grout properties during the installation and subsequent curing process (especially flowability and bleeding resistance during installation and strength gain during curing).
    - Ensuring full grout coverage within the annular space. Infrared thermographic video (IRTV) for full grout coverage verification is being used to confirm quality control with respect to grout coverage.

These and other design and performance issues for composite pressure pipe liners are reviewed in the next section together with a discussion of the testing and quality assurance/quality control procedures that have or can be used to provide confidence in the proper long-term performance of the liner system.

C. DESIGN AND PERFORMANCE ISSUES FOR COMPOSITE PRESSURE PIPE LINERS

In order to determine whether the existing test results adequately reflect the design and performance issues for a pressure pipe liner, it is worthwhile reviewing the potential risks for inadequate performance of such liners when used in water distribution system piping. The more common potential risks are listed in this chapter.

	CONSTRUCTION/INSTALLATION FAILURES

Potential risks:	▪ Inability to install the system within the existing pipe (due to sharp offsets or lack of access)
	▪ Inability to obtain a tight fit without liner wrinkles in the existing pipe due to irregularities, sharp bends and offsets in the existing pipe
	▪ Lack of adequate quality control of field processes
	    o Liner sizing
	    o Liner welding
	    o Installed grout properties
	▪ Incomplete grout coverage within the annular space formed by the studded liner
	▪ Insufficient grout to fill the annular space plus any corrosion holes or gaps created by misplaced or leaking joints.

Discussion:	Any lining system has field conditions for which it is not suitable and these must be determined during the planning and design process. The MainSaver process uses a thin flexible liner that can be installed in pipes down to 4” in diameter. The process is not intended to be used to line around sharp pipe bends. Significantly offset joints are relatively unlikely in a water distribution system to be relined because such joints would not hold pressure and would have likely been repaired. Some pipe deviations and pipe cross-section distortions can be expected, however, due to previous mechanical damage, ground movements and due to misalignment of previously repaired sections. The MainSaver process is intended to line nominally straight sections of pipe but can accommodate some deviations from this ideal. The grout can accommodate an uneven annular space and the polyethylene inner liner can accommodate some change of direction or curvature in the pipe without significant distortion.

Relevance to test results:	The extent of deviation from a straight pipe that can be accommodated during the installation process has not yet been formally established by tests. Problems with offset joints will result in high grout thickness near the offset joint and a reduced flow section. An angular distortion at a joint may induce wrinkling on the inside of the angle and some stretching of the polyethylene tube on the outside of the angle. Shear and angular distortion after installation are addressed in the test reported later in this document. The existence of liner wrinkling problems and uneven grout thickness were reported in the testing of the early version of the system in the U.K. Since that testing, the method of installation, the welding process for the liner and the grout used have all changed. The field trials observed in this study were part of the process of documenting the most reliable procedure for ensuring a successful liner. Testing of the minimum bend radius and the maximum angular offset at a pipe joint that can be accommodated should be carried out in order to provide application limits. The optimum sizing of the polyethylene liner with respect to the host pipe diameter (and expected variations in this diameter) needs to be established through documented and inspected field trials. Likewise, recommend grout volume and its full coverage along the pipe also must be established by documented field trials and then monitored in routine installations for quality assurance. Liner weld quality and the creation of pinholes/tears in the polyethylene tube during manufacture/handling/installation of the liner are additional quality control/assurance issues for the installation rather than questions concerning the basic process or materials used. The other construction problems involve planning, design or procedural issues which do not involve testing of the product or system itself.
	STRUCTURAL FAILURE
Potential risks:	▪ Failure of the liner under internal pressure ▪ Loss of adequate support to the liner from the host pipe ▪ Failure of the liner caused by exceeding permissible strains or stresses in either component of the composite liner. ▪ Failure of the liner through buckling caused by external water pressure acting between the host pipe and the liner ▪ Radial liner deflection to a degree that compromises the function of the pipe

<table>
<tr><td>Discussion:</td><td>The liner may be subject to a variety of stress conditions over its lifetime. The most common conditions are likely to be:
- Internal water pressure resulting from normal operating conditions in the lined pipe and from short-term pressure spikes caused by transient effects such as water hammer
- External water pressure within the annular space that acts on the liner (resulting from the defects in the host pipe and the presence of a temporary or permanent groundwater level above the host pipe). This should only be a problem during depressurization of the lined pipe.
- Temporary internal vacuum within the lined pipe
- Local or general deformation of the host pipe that will transmit loads to the liner from the surrounding soil or live loads from the ground surface. This may result from changes in ground conditions or from continued deterioration of the host pipe. This mode of failure is less likely in a water distribution pressure pipe than in a gravity sewer pipe because the line should become unserviceable for pressure applications well before it ceases to withstand the soil loadings. Also, a pipe in a condition where this problem could occur is not a candidate for this lining system.</td></tr>
<tr><td></td><td>The design of liners against structural failure is covered in various international and ASTM standards. The provisions of such standards give guidance on the design loading conditions to used, the analysis techniques that can be used to determine the required thickness and material properties for the liner, and the testing requirements to make sure that the product in question will meet the requirements.
Failure due to external groundwater pressure acting between the host pipe and the liner is usually caused by local buckling of the liner and the buckling pressure is affected by the thickness of the liner (moment of inertia against local bending of the liner), the long-term modulus of the liner material, the annular space gap between the liner and the host pipe, and any initial imperfections in the shape of the liner. For the MainSaver liner, the grouting process will provide either an adhered or very close fitting liner within the host pipe. The grout provides a relatively stiff layer compared to the polyethylene layer and this provides an enhanced resistance against liner buckling.</td></tr>
<tr><td>Relevance to test results:</td><td>Testing of the capability of the liner system to withstand internal pressure has been tested in the following conditions:
▪ Capability to span defects in the host pipe in terms of holes, joint gaps, etc. when under internal pressure
▪ External pressure resistance capability for the liner within the host pipe
▪ Capability of the liner to accommodate shear offsets at joints or angular distortion due to bending of the host pipe</td></tr>
</table>

	LINER MATERIAL DEGRADATION OVER TIME (Leading to one of the other failure modes)
Potential risks:	▪ Deterioration of the liner material in the presence of chemical or biological agents likely to be found in the service environment (internal fluid or external groundwater contacting the liner through host pipe defects. ▪ Deterioration or erosion of the liner due to abrasion from flowing particles within the operating liner ▪ Physical damage to the liner from maintenance operations within the pipe, e.g. cleaning.
Discussion:	It is necessary to know whether the material used for the liner is adequate for the expected service life of the relined pipe. If the liner material were to deteriorate in the service environment of the water main – either through chemical/biological action or through physical damage from abrasion/maintenance – then it could become too weak or to thin to withstand the stresses imposed on it (leading to collapse) or could be punctured in local areas (leading to renewed leakage and corrosion). The MainSaver process is intended only for water main rehabilitation and hence internal corrosion effects are not expected and cleaning operations typically involve hydrant flushing and cleaning only with a swab.
Relevance to test results:	Polyethylene has an established history in terms of its excellent resistance to degradation and abrasion in water applications. No specific testing with relation to corrosion or abrasion has been reviewed with respect to the MainSaver process. The major concern in terms of longevity for this product in a water distribution system is likely to be avoidance of physically aggressive maintenance activities that could damage the polyethylene-grout lining system.
	HYDRAULIC INADEQUACY
Potential risks:	▪ The flow characteristics of the lined pipe are not adequate for the service conditions of the pipe. This depends on the smoothness of the lined pipe and the loss of cross-section through the lining process.
Discussion:	It is inevitable that a liner installed within an existing host pipe (that is not in itself enlarged) will reduce the cross-sectional area of the pipe available for flow. This may or may not be important for a particular pipe depending on the flow requirements relative to its current capacity. The reduction of cross-section is usually offset in terms of flow characteristics by the improvement in the roughness coefficient of the pipe when using a liner with a smooth interior surface in comparison with the deteriorated surface condition of the host pipe. Whether the flow capacity is actually enhanced or not depends on the thickness of the liner, the diameter of the host pipe, and the change in roughness coefficient.
Relevance to test results:	The expected capacity of the lined pipe can be calculated using the reduced diameter of the lined pipe and a roughness coefficient appropriate for the polyethylene liner. No special testing is considered necessary to be able to carry out these calculations.

	LEAKAGE OF THE LINER
Potential risks:	▪ Leakage through the liner material itself ▪ Leakage through the welds in the liner material ▪ Leakage into or out of the lined pipe at service connections ▪ Leakage into or out of the liner pipe at connections between two lined sections or between lined sections and the remaining pipe system
Discussion:	Relining projects may have complementary objectives such as water quality improvement, preventing further deterioration of a water pipe, reducing leakage from the water system and restoring structural capacity in the water pipe. The MainSaver lining system is designed to address the first three of these objectives but it is not intended to provide a stand alone capability in resisting either internal or external pressures on the pipe. With regard to leakage reduction, a combination of laboratory and field testing should establish that the system can be constructed with no leakage or within an established leakage allowance. Once the basic process has been shown to be effective, then quality control procedures should be used to track quality during normal installation.
Relevance to test results:	Laboratory testing of the internal pressure capability of the liner is discussed in the next section. A plain lined section was tested as well as a lined section with a drilled and tapped connection.

	LONGITUDINAL LINER MOVEMENT
Potential risks:	▪ Expansion or shrinkage of the liner causing movement with respect to the host pipe and misalignment or distortion of service connections
Discussion:	In general, lining systems may be installed by dragging a liner within the host pipe, by curing the liner at high temperatures or by other procedures that may affect the longitudinal strain conditions within the liner. If these thermal or mechanical strains are not released or allowed to dissipate before the lateral reconnections are made, then problems due to misalignment of the connections may occur. Likewise, if the lining is not well fixed within the host pipe, it could become dislodged and moved longitudinally at a later date. With respect to the MainSaver system, longitudinal liner movement is only expected to be an issue during the actual installation and grouting process. Once the liner is installed and grouted, the grout will hold the liner in place longitudinally and the liner being thin and with a low modulus will not generate significant longitudinal forces compared to the compressive and shear strength of the grout. Also, any corporation stops that are threaded into the liner will act as locking points. During installation, the liner will undergo some longitudinal stretching and allowance is made for this during the installation process. The liner is also kept under a slight tension during the installation and curing process to maintain the liner form and avoid significant liner rotation.
Relevance to test results:	No specific tests related to this issue are included in the test set provided but the nature of the installation and grouting process should not allow longitudinal movements or stresses to develop following liner installation and grout curing.

D. OBSERVATION OF MAINSAVER INSTALLATIONS

1. MainSaver Demonstration – April 12, 2006 – Fairplay, Colorado

This demonstration, consisting of an installation in a 4 inch clear plastic pipe and in a 12-inch PVC pipe, was part of a series of tests in the yard at Western Slope Utilities, Inc. in Fairplay, Colorado. The tests were designed to demonstrate the process to interested parties and to continue the process of refining and documenting the installation process of the MainSaver System. The demonstration and discussions were attended by John Matthews, Ph.D. student at Louisiana Tech University, on behalf of the Trenchless Technology Center.

For these tests, the following materials and procedures were used:

Liner Material

- Manufactured by Velcro Limited at their Barcelona, Spain facility
- The polyethylene tube material is BP Solvay Polyethylene. According to the Product Technical Information sheet, "Rigidex PC 002-50 R968 is based on a special medium density copolymer with exceptionally high resistance to environmental stress cracking and is classified as a PE 80 material in accordance with ISO 12162. The blue compound contains suitable additives necessary for the manufacture of water pipe and fittings." Note: the material owner has subsequently changed hands with a subsequent name change for the identical material "ELTEX PC 002-50 R968" (see Appendix Page 11-12).

Grout Material

- The cement used was Portland Cement Type I-II
- The admixture used was latex based (Admix 50 Flexcrete plasticizer)
- This grout was only one of the grout mixtures being evaluated for optimum performance

Host Pipe Materials

- Host pipe #1 was a clear 4" plastic pipe about 40' long
- Host pipe #2 was a 12" PVC pipe 100' long

Process Observation Notes and Other Application Notes

- A 4-man crew is currently used for field installations
- An inflation tube is used to provide and maintain the internal pressure during installation
- During the swabbing of the 4" liner using the soft installation pig, the polyethylene liner was observed to twist (straighten) as the installation proceeded
- The inflation pressure for the 4" pipe was 2 psi for the entire length of curing
- The inflation pressure for the 12" pipe was 1.5 psi for the entire length of curing
- Due to a longer than anticipated discussion with the audience during the initial stages of the demonstration, the grout for the 4" pipe had started to set up which caused some installation difficulties with this pipe lining
- Grout volumes were not measured during the demonstration and no exact calculations were used. However, the calculated grout volume for lining a 100 ft length of 12" pipe assuming no host pipe defects and ignoring the volume of the liner studs would be nominally $2\pi RtL$ or $2\pi(6)(0.114)(100)(12)\ in^3 = 5{,}160\ in^3$ or approximately 3 ft^3. An allowance for wastage of approximately 40% is added to the calculated figure for the grout quantity mixed.
- In practice, services must be cut and plugged before lining and then reinstalled after lining.
- MainSaver reported that a roll of liner for 1,000 ft of pipe would be approximately 4 ft high
- No post-installation CCTV inspections of the liners were made for these demonstrations

Discussion Regarding the Demonstrations

The demonstrations conducted on the 4” and 12” pipes did not represent a demonstration of a fully developed process. Although the process had been used in the U.K. for several years, the U.S. owner of the process (initially CemPipe Americas and now MainSaver), has taken the opportunity to take a new look at the system components and installation processes to provide a higher level of quality control and to improve the component materials. The nature of the installation as a demonstration also detracted from its value as a documentation of a production installation process. Despite these shortcomings of the demonstrations for evaluation purposes, they did indicate or confirm several key issues in the installation process. Looking at the various elements of the installation process, the following preliminary observations were made:

- The polyethylene liner is factory made. Both the liner and the seam welding can be checked for quality control prior to liner installation
- Installing the loose liner into the host pipe presents no special concerns in a clean straight pipe (i.e. in pipes with no offsets or sharp bends)
- A high shear colloidal grout mixer performs best in mixing the grout. The specific grout materials and admixtures for use in the U.S. were still being evaluated at the time of the demonstration so no definite conclusions could be made about the grout materials. However, suitable grout materials to work with this process are available.
- The properties of the grout in terms of the length of the time window for installation after mixing, the rate of gain in strength during curing and the final strength and elastic modulus are important for trouble-free installations and final performance of the liner system.
- The installation proceeds very quickly once the grout is mixed and the liner installation is ready. Injection of the grout and its distribution using the swab should take less than 10-15 minutes for a 100 ft. length of pipe.
- The major field installation issue appears to be ensuring full distribution of the grout in the annular space around the circumference of the pipe and along the length of the pipe. Without the correct procedures, it is possible to leave ungrouted sections of the polyethylene liner. At the time of the demonstration, the modified installation procedures were still being refined in terms of the distribution of the grout around the circumference at the installation end, the speed of travel of the swab, and the control of the permeability of the annular space at the open end of the pipe. Proof that this operation can be done reliably can be provided using further demonstrations and field trials and quality assurance assessments can be done during normal projects to verify that full grout coverage has been achieved.

2. MainSaver Development Tests – May 24, 2006 – Fairplay, Colorado

Two test installations using the MainSaver process were observed by Dr. Ray Sterling on May 24, 2006. The test installations were part of the continuing optimization process for the MainSaver lining system to be used in the U.S. Both installations were made in a clear plastic pipe. The variables under consideration for the tests conducted that day were the mix proportions of the grout and the distribution of grout around the circumference of the annular space prior to moving the grout along the pipe using the swab.

Visual Comparison of Grout Properties

As in the demonstration discussed above, the various aspects of the lining process were described and demonstrated.

At this time, the grout material selection had been completed and a proprietary grout from a major grout supplier had been selected. Observation of the flow, consistency and separation properties of grout were visually observed by allowing the various grout mixes to flow over the studded side of the liner draped over a pipe (see photo). All the grout mixtures showed good consistency and no tendency to separate. The criteria for selecting the best mix proportions were good flow properties with minimal cracking of the grout during drying (note the grout is fully exposed on one side during drying in this test but is not exposed in the real application).

The test installations were not timed but proceeded smoothly. A sonde had been added to the swab to allow tracking of the passage of the swab through the pipe. The speed of movement of the swab could then be adjusted by altering the driving pressure. The two installations observed were made with different proportions of the grout injected above and beneath the polyethylene liner. From the action of the internal pressure applied within the liner and the passage of the swab, a grout slug moves ahead of the swab, filling the annular space. The grout does not have to flow extensively within the studded annular space since most of the flow along the pipe occurs during the expansion of the liner and not after the liner is fully expanded against the host pipe. In the test observed (through the clear plastic host pipe), circumferential grout coverage was complete for most of the pipe length (approximately 80 percent) but some air pockets were left in the annular space at the top of pipe in the remaining 20 percent of the length and the grout also did not fill the annular space at the top at the very end of the pipe. The air pockets in some cases were over 1 ft in length (see photo). The problem evidenced at the open end of the pipe was that grout preferentially flowed out of the annular space at the bottom of the pipe and hence sufficient grout was not directed to the top of the pipe where the air pockets occurred. Since the grout flowing ahead of the swab tends to form an inclined surface within the annular space, it is necessary to partially restrict the flow of the grout at the bottom end of the pipe to provide a back pressure to allow the grout slug to fill the upper portion of the annular space near the end of the pipe. The flow restriction must allow air to escape from the annular space and it must allow the inclined front of the grout slug to steadily fill the upper portion of the annular space with grout. This interplay of grout flow properties, speed of the passage of the swab, and placement of the grout slug at the beginning of the pipe section represents the "know how" for the lining method. The right combination of installation procedures for the grout type and consistency selected had not been achieved during the lining runs witnessed on this date since some air pockets were noted near the end of the 100 ft run. However, once the full coverage is shown to be repeatable, quality control in its application will be provided by an inspection technique (such as impact echo, infrared scan or ground penetrating radar) that will detect the presence of voids behind the polyethylene liner. (Note: see discussion below of infrared inspection in later trials).

In summary, the process is quick and effective in installing a grouted liner within the host pipe but the process was still under adjustment to provide complete grout coverage all the way to the end of the lined section.

3. MainSaver Field Installation Observation – December 12-13, 2006 – Albuquerque, New Mexico

Two field installations were observed by Dr. Ray Sterling during the period December 12-13, 2006 at a commercial project being carried out by MainSaver for the City of Albuquerque. The overall project involved lining 2,744 ft of 8" diameter asbestos cement water distribution mains. As this was the first commercial project for MainSaver in North America, the installations were being treated as a learning process both by the City of Albuquerque, its consultant, Boyle Engineering, and by MainSaver. The project area had been chosen to provide a minimum impact on residents and businesses if delays were to occur. General observations by the consulting engineers for the City on the MainSaver process are included in a separate section below.

The liner installation procedures were basically the same as described in the earlier demonstrations with the following installation details in terms of procedure:

- Pipe being lined was nominal 8 inch diameter asbestos cement pipe. 12 in diameter is the current limit for the process.
- 300 ft is the current length limit attempted in a single pass.
- Current ratio for fluid grout placed on top of liner and grout place beneath liner is 70/30.
- One pass of the pig is made to remove any twists. This was increased to two for the second trial.
- A small vacuum is pulled to deflate the liner prior to actual installation. In the two trials witnessed, the

tension was released during this process. This was discovered on the 3rd day to lead to folding of the liner which increased the resistance to the swabbing once the grout was placed for installation. The installation practice has since been adjusted to maintain tension continuously on the liner during the preparation and installation process.

- Grout density measured on December 12 was 190 g/cc compared to the 193-196 target. Acceptable range is considered to be 190 to 205 g/cc.
- 5 batches of grout were used with 6 bags for each batch.
- Normally, the grout is pushed along the pipe with a pressure of 4-7 psi and then a 0.5-2.0 psi pressure is maintained for 16 hours until the grout has reached a sufficient strength for the internal pressure to be removed.
- It is possible to check if the liner has leaks by checking the pressure drop with the pig in different locations.
- A detachable pressure constraint at the exit point of the lined section is used to prevent splitting of the liner when the swab reaches the end of the section.

In the observed installation on December 12, the swab appeared to be stuck at approximately 1/3 of the length along the line segment. The pressure behind the swab was pushed to 15-17 psi to get the swab moving again. It then became stuck again at the end of the run and the pressure was increased again to move the pig to the end of the line. At this high pressure, when the swab came out of the end of the line segment, the end of liner was split. This was observed to be at least partially a result of the external liner restraint being moved during the deflation and re-inflation process and not reinstalled to provide proper constraint but it was also later found to be due to the release of tension during the deflation process. The liner was estimated to be split to only within 2 ft of the end of run. To allow the remainder of the liner to be left in place, the swab was reinstalled before this location and an internal pressure was applied within the liner to keep the liner tight to host pipe while the grout cured and gained strength. The next day, the lined pipe was televised with both a camera and an infrared scanner (see separate discussion) and the liner was shown to be in good condition and with no areas of missing grout.

The next section of water main to be lined was then prepared (on December 13) and the swab passed through the line twice to make sure that the liner was straight. As for the previous day, the tension in the liner was released after the preparatory swab was passed through. During the grout dispersal along the pipe, the swab again became stuck at approximately 1/3 of length along the pipe section; the pressure was again increased but this time the pig split the liner and traveled the rest of the length on the outside of the liner. Since this liner was not salvageable, the liner and grout was pulled out and a swab used to clean the line ready for a new liner the next day.

The reinstallation on December 14 was not observed directly but following some adjustments to the liner installation process to be used on December 13, the liner was reported to be installed successfully without problems. The principal change was to maintain tension on the liner continuously through the preparatory swabbing process, preparation for the grout injection and dispersal along the pipe section. It was deduced that when the liner tension was released as the liner was deflated with a small vacuum, it was bunching within the pipe and did not re-expand smoothly during the grout installation. Since 8 lines had been installed in Albuquerque without this problem occurring prior to December 12 and 13, it was felt that a change in the method of welding of the liner may have also made a difference in the response of the liner to the swabbing, vacuum deflation and re-inflation during grout installation.

Discussion

Both of the field trials directly observed in Albuquerque had problems during grout dispersal. In both cases, it appeared that the cause was the same – allowing the liner to bunch longitudinally when the liner was vacuum deflated. Once the tension was kept continuously on the liner during the whole installation process, this problem did not reappear (this was confirmed with the City of Albuquerque's engineer and inspector – see separate report below) in the reinstallation the following day and the two subsequent lining installations on the Albuquerque job in January 2007.

Important positive lessons from the difficulties observed were that:

- The December 12 lining was able to be retained in place – requiring only an additional 3-4 ft of pit excavation to reconnect to a good section of lined pipe.
- The lining on December 13 was not salvageable but was able to be removed immediately and the line swabbed and cleaned to remove the grout from the pipe. This was able to be done within a few minutes and the lost cost is relatively small – the actual installation time, the liner cost and the grout cost. The preparatory work remains in place and a new liner was installed the next day.
- The quality of the liner can be observed using a combination of CCTV inspection and infrared scanning of the interior of the lined pipe.
- This means that a City, utility owner or contractor has the ability to have the liner removed using simple procedures if site problems occur and that the combination of CCTV inspection and infrared scanning provide a strong quality control record that the liner is installed properly, free from defects and without missing sections of grout behind the polyethylene tube.

4. Infrared Inspection Scanning – Review of field installation and review of test tapes provided on January 16, 2007

Subsequent to the April demonstration observed in Fairplay CO, an infrared scanning technique was developed as a quality assurance protocol to ensure that the grout was fully distributed in the annular space behind the studded polyethylene tube that forms the inner surface of the liner. The inspection process relies on the fact that the liner is thin and will heat much more quickly with air behind the liner (missed grout area) than where the grout is in place. The heating is provided by incandescent lights just ahead of the infrared camera. When combined with the CCTV visual inspection of the internal surface of the liner, excellent quality assurance about the quality of the liner installation is provided.

Infrared scan from bench test section

The field operation of the CCTV and infrared inspection was observed during the December 12-13, 2006 field installations in Albuquerque. The quality of the visual CCTV scan is excellent and the infrared scan, while lacking some definition is clear enough to show the consistency of the scan image when the grout coverage is consistent.

Infrared scan of buried test section

Two 10-ft sections of 8 inch diameter PVC pipe were specially prepared with various cutouts in the wall of the pipe. The pipe sections were lined with the cutouts in place but then the cutouts were removed and the grout carefully removed within the cutout areas. Prior to scanning, the cutouts were replaced over the sections with missing grout. In the infrared scan done with the pipe on the floor of the shop building, the missing areas of grout are clearly visible as localized white areas within a grey overall color representing the surface temperature of the remainder of the lining surface (see top adjacent figure). The two sections of lined pipe were then buried at about 4-5 ft in depth within an approximately 300-ft long section of 8-inch diameter PVC pipe. The defect areas still showed up clearly within the lined pipe sections (see bottom adjacent figure).

The ability of the infrared scan to pick up missing grout sections provides an important quality assurance for the main area of concern for field installation of the liner – that the liner will be installed with an apparently good installation from internal visual inspection but that the grout would not be fully distributed behind the polyethylene liner skin.

5. Discussions regarding the MainSaver Installation at the City of Albuquerque

The field installations in Albuquerque were discussed on two separate occasions with engineers that were familiar with the installations and were not connected to the MainSaver Company. At the time of the first discussion, there had been four line segments completed. Two had been successful and two were not successful. The problems encountered in the unsuccessful segments were: some bubbling of the liner and trapped air pockets, some tube welding problems with inadequate overlap of seams, some suspected pinholes in the liner that were thought to cause the air pockets. When the liner was pulled out in one case, the pipe was cleaned but some partially adhered grout fell into the invert and caused a bump in the relined section. In terms of overall impression of the MainSaver system, it was felt that the approach could have some benefits once the remaining quality control (QC) issues had been resolved. The infrared scanning was felt to be a very useful QC tool and was effective. In terms of overall trenchless rehabilitation of water lines, the need for a temporary bypass was felt to be a significant issue in terms of comparison with open cut installation which typically installs a new line and then moves the service connection from the old line to the new line before abandoning the old line in place.

The second discussion concentrated on the two segments completed in January 2007 after the observed field trials and the related adjustments to the installation process. The first section attempted in January was not successful. There had been no evidence of problems during the installation but the liner once inspected was found to have excessive wrinkles in the finished liner, sags, and full collapse. The line segment was dug up and replaced by open cut at the contractor's expense. The second and last line segment carried out in January was successful and everything worked fine. In terms of the overall impression of the MainSaver system, it appears to be a good system. The process still needs additional work to make it reliable and eliminate surprises from wrinkle, sag and collapse problems. One of the difficulties at present to develop a full understanding of system reliability is that aspects of the system installation are being adjusted at the same time. Once the optimum installation approach is refined, then it will be important to demonstrate that the liner will have a high predictability of success for installation. One of the main reasons to choose a trenchless installation method is to avoid traffic disruption and a dig up and replace of a failed installation negates this advantage

6. Discussions with Mike Gay, City of Thornton regarding the MainSaver Installation under Interstate 25

A field installation of the MainSaver process was carried out on March 22, 2007 and involved the relining of approximately 300 ft of 8-inch diameter water line crossing Interstate 25 within the City of Thornton, Colorado. Mike Gay, Utilities Operations Manager, City of Thornton was interviewed on March 30, 2007 as to the City’s experience with using the MainSaver process. Mike Gay provided the following information on the reasons for choosing the process and their experience with the process including their intention to use the process again for another crossing of Interstate 25 within the City.

MainSaver Installation under I-25 in the City of Thornton

During some prior construction work related to I-25, an asbestos cement water line was damaged beneath the freeway and was considered to be a significant risk for a future failure. To replace the water line, a directional bore had been planned for the approximately 300 ft long crossing. Mr. Gay had become aware of the MainSaver process and had attended both a demonstration in Fairplay and one of the field installations in Albuquerque in late summer 2006. He was able to get approval to try the technique on what was expected to be a straight segment of pipe. In fact, the longitudinal profile of the pipe across the freeway resembled a flattened “W” shape. The MainSaver lining was pulled in, grouted and cured without incident and the line was pressure tested to 200 psi. It also quickly passed the bacterial test.

He expected the commercial cost of the MainSaver lining to be 40% - 50% of the other alternatives that were being considered and that the roughness factor for the flow surface would also be substantially improved over the existing pipe condition. He had confirmed with the City of Albuquerque that they were not having any problems with taps installed in the MainSaver lining last year. He indicated that each time he had observed the process, he saw improvements in the application. One issue that had been dealt with successfully on his project but that caused some setup delays was the temperature of the water used for grout mixing. This was initially too cold to get the desired grout properties but now a heating system is provided for the grout mix water.

The City is pleased with the results of using the MainSaver system and plans to use the system again in mid April on a 12-inch diameter water main also crossing I-25 in a critical traffic area that would make open cut replacement highly undesirable.

E. SUBMITTED REPORTS ON TESTING OF THE MAINSAVER AND CEMPIPE PROCESSES AND MATERIALS

This chapter outlines tests performed on the MainSaver and CemPipe Processes that were submitted to the TTC for consideration in preparing this report.

1. WRc (U.K.) CEMPIPE INSTALLATION TRIAL PHYSICAL TESTING RESULTS, JUNE 1999

▪ **Reference**	**Kalaugher, L., K. Adams and J. Trew, 1999. *Cempipe Installation Trial – Physical Testing Results*, WRc Ref: UC 3432, June 1999, Water Research Center, Swindon, U.K.**
	TESTING REPORTED
	The Water Research Center (WRc) in the U.K. was asked to conduct a series of test on the CemPipe process during its early development in the U.K. in 1999. The testing included observation of lining trials using samples of pipe removed from service followed by physical testing of the lined samples. Since many aspects of the process – the welding of the liner tube, the grout used and the installation protocol have changed, the specific test results are not representative of the current system. Hence, only the range of test results and comments about the performance of the system are provided in this report.
	SCOPE OF TESTING
▪ **Scope of testing**	The CemPipe system was installed in 100 mm diameter new ductile iron pipe for the laboratory tests. Sections of pipe approximately 0.3 m and 1 m in length were connected to form two pipes each approximately 8 m long. The tests conducted using the lined pipe were: ▪ Positive pressure tests (with host pipe defects) at different lengths of cure time ▪ Positive pressure test of a lined socket joint ▪ Negative pressure test ▪ Longitudinal tensile test (pull apart of host pipe sections) ▪ Cyclic pressure test (positive internal pressure) ▪ Shear test (shear displacement of one pipe section)
	INSTALLATION OBSERVATIONS
	The test installations conducted by the WRc evidenced several problems including: twisting and severe creasing of the liner during installation, uneven grout thickness in the annular space, and an air pocket at the end of the lined section. The liner as installed was not completely airtight – thus necessitating the use of a second liner to maintain the inflation of the liner during curing. The liner at this stage of the CemPipe process development was manufactured using a spiral welding process of strips of the studded polyethylene "tape". In addition, the installation process did not use a soft swab to re-round the liner and because of the creasing that occurred on one side of the liner, the liner did not extend all the way to the wall on the other side of the liner.

DISCUSSION

Very few aspects of the process have remained the same as in these tests conducted in the U.K. The liner at this stage of the CemPipe process development was manufactured using a spiral welding process of strips of the studded polyethylene "tape". In addition, the installation process did not use a soft swab to re-round the liner and because of the creasing that occurred on one side of the liner, the liner did not extend all the way to the wall on the other side of the liner. Nevertheless, the tests do allow an assessment of the advances made in the lining system and point out a number of application issues to be tracked. The original spiral welding of the liner led to a number of problems including twisting of the liner during installation and poor weld quality leading to liner leakage.

Application issues raised by the WRc authors of the report were:

- Appropriate methods for reinstallation of service taps in the lined pipe
- End sealing of the annular space at each end of a lined section to prevent drying of the grout during curing
- Pipe gradient impacts on the pipe lining installation
- Installation in a cleaned pipe with potentially sharp edges
- Selection of improved grout and fibre reinforcement were suggested as potential improvements.

SUMMARY

Liner improvements are resolving prior application issues

Most of the installation problems indicated in the WRc tests have been demonstrably improved in the installation process and materials used in the Fairplay lining demonstration and the subsequent field installations observed. From these test results, the original CemPipe lining system did not function effectively to hold an internal pressure when bridging large voids in the host pipe or large circumferential open cracks. Small cracks and holes should be bridged comfortably at normal operating pressures but holes or cracks larger than 20 mm were outside the scope of the lining system performance. (See later test results of the improved MainSaver system). Weld integrity in the PE layer also appears to be an important element in allowing the MainSaver lining to reduce leakage in a water distribution system as well as provide corrosion protection and water quality improvements.

2. Hauser Testing Program, July 2006 – March 2007

▪ **Reference**	**Hauser Laboratories, 2006. MainSaver/CemPipe Testing Report, July 2006, Hauser Laboratories, Boulder, CO.**
	TESTING CONDUCTED
▪ **Scope of testing**	Hauser Engineering was contracted by CemPipe Americas (later changed to MainSaver) to conduct the following tests on lined samples of pipe: ▪ External pressure or vacuum test ▪ Internal pressure tests with maximum allowable hole and circumferential gap defects in the host pipe ▪ Leakage of service tap under internal pressure ▪ Offset and displaced joint tests
	RESULTS ***Hauser Test Report: 0607-00024-03 External Hydrostatic Pressure Resistance (see Appendix: Page A1 for report)*** These tests studied the ability of the MainSaver liner to span defects in the host pipe. External pressure resistance of the liner, representing the condition of an internally depressured line below the water table, was tested using a prepared 2.36 inch (60 mm) circular defect in the host pipe. In one test, a complete liner with full grout coverage spanned the 2 inch opening. The pressure at failure of the liner was 100 psi. In a second test, a liner with only partial grout coverage was tested and withstood 40 psi external pressure. Only short term pressure resistance needs to be considered for this condition since a water line will only remain depressurized for short periods of time.
	Hauser Test Report: 0607-00024-04 Internal Hydrostatic Pressure Resistance (see Appendix: Page A3 for report) This test examined the ability of the MainSaver liner to span across a host pipe defect under an internal pressure within liner. The defect was a manufactured circular hole in the host pipe of 1 inch diameter. The liner was tested to an internal pressure of 500 psi for 5 minutes with no observable leakage.

Hauser Test Report: 0607-00024-05 Internal Hydrostatic Pressure Resistance for Service Tap in New Liner (see Appendix: Page A4 for report)

This test examined the ability of the designed service tap for the new liner to resist an internal hydrostatic pressure without failure or leakage. Four observation holes were placed 2 inches from the service tap (2 axially and 2 circumferentially on each side of the tap). Three tests were conducted on one lined pipe sample including a service tap and tested in a vertical orientation. The first test raised the pressure inside the lined pipe to 210 psi and held the pressure for 1.6 hours. A “very slight” seepage in the observation hole 2 inches below the tap was noted after 0.8 hours but no increase of rate was noted over the rest of the test period. The pipe was then left unpressurized but full of water for 17 hours before being repressurized to 210 psi. In this case, very slight seepage was noted in the same test hole after 0.2 hours with no increase of seepage rate over an additional 1.1 hours. The pipe was then left unpressurized but full of water for 7 days before being repressurized to 210 psi but with the lined pipe this time in a horizontal orientation. The same test hole was “visibly moist” after 5 minutes but attempts to measure a flow rate did not collect any water. By comparison with placing a known water flow (provided by a syringe) at the same observation hole, the leakage flow rate was determined to be significantly less than 0.5 mL/min (0.19 galls/day).

Hauser Test Report: 0610-00153-02 Internal Hydrostatic Pressure Resistance (see Appendix: Page A6 for report)

This test also examined the ability of the MainSaver liner to span across a larger host pipe defect under an internal pressure within liner. The defect was a manufactured circular hole in the host pipe of 2 inch diameter. The liner was tested to an internal pressure of 500 psi for 5 minutes with no catastrophic failure but some evidence of “weepage” in the area of the defect.

Hauser Test Report: 0701-00139-01 Resistance to Shear Displacement at Joints (see Appendix: Page A7 for report)

This test examined the resistance of a lined pipe to subsequent shear displacement at a weak or failed joint in the host pipe. The MainSaver lining was carried out through two 3-ft sections of pipe that were butted together but not physically joined. The lined pipe was tested under an internal pressure of 45 psi and the lined pipe withstood a vertical shear displacement at the joint of 0.5 inches without catastrophic rupture but with some leakage from the joint area after the 0.5 inch deflection.

Hauser Test Report: 0610-00153-02 Internal Hydrostatic Pressure Resistance (see Appendix: Page A9 for report)

This test examined the resistance of a lined pipe to subsequent angular distortion at a weak or failed joint in the host pipe. The MainSaver lining was again carried out through two 3-ft sections of pipe that were butted together but not physically joined. The pipe was tested under an internal pressure of 45 psi and the lined pipe withstood a central deflection over a 6 ft-span length of 0.49 inches without catastrophic failure but with some leakage at this deflection. The maximum test deflection is equivalent to an angular distortion at the joint of 2.3 degrees.

DISCUSSION

For the external pressure resistance, 40 psi pressure resistance is approximately equivalent to 92 ft of external water depth. This is well above what would be expected to occur in most water mains which are usually shallow buried (i.e. less than 5-10 feet depth of burial depth). For the internal pressure resistance, 500 psi is approximately 4 times the peak maximum service pressure that would be expected during water hammer events and approximately 6-8 times a normal service operating pressure. For the service tap pressure test, seepage that was too small to directly measure was observed at 210 psi internal pressure. After leaving the sample for 17 hours and retesting and then 17 days and retesting, the seepage appeared earlier but the rate of seepage did not increase. The shear and angular distortion testing of the ability of the liner to maintain its integrity when a failed host pipe joint is distorted indicated the ability of the joint to withstand 0.5 inch shear distortion and 2.3 degrees of angular distortion without catastrophic failure.

SUMMARY

The liner alone shows more than sufficient internal and external short-term pressure capability when spanning 2 inch defects under both internal and external pressure. Pipe with defects as large as a two-inch diameter hole equivalent are at the upper limit of applicability for this lining technique. The service tap shows some slight seepage at a pressure around 3 times a typical line operating pressure. For mains with high operating pressures (above 100 psi) with service taps along the lined section, it is recommended that additional testing of the service tap connection be carried out to investigate any variability in the sealing capacity of the service tap to the new liner. For water mains with normal operating pressures below 75 psi, the connection would appear to provide a sufficient safety margin against leakage although examination of field service taps after a reasonable period of time in service is recommended to confirm this. The performance of the liner in resisting shear and angular distortions at joints is considered to very adequate for this semi-structural type of liner.

E. GENERAL SUMMARY AND CONCLUSIONS

	SUMMARY
	The MainSaver Lining process offers a semi-structural lining providing leak control as well as water quality improvements and corrosion protection in deteriorating water distribution mains. The lining system has been under a continual refinement during the period of this evaluation and the system has been used under real field conditions in North America as well as in Europe (in its earlier configuration). Problems in consistency of the field installation process have been evident as the process has been refined. One key to a leak-free system using the MainSaver lining appears to be in testing the PE liner for defects prior to installation, followed by ensuring full grout coverage during installation. The grout coverage concern has been addressed by providing an infrared scan as well as a visual scan of each completed liner. Installation difficulties were evident at each of the applications witnessed by the Trenchless Technology Center. Such installation problems were also reported in about 50% of the segments rehabilitated by the engineers for the City of Albuquerque that oversaw all the water main segments rehabilitated using the MainSaver process. However, the most recent installation in a critical location under Interstate 25 in the City of Thornton, Colorado was completed successfully and the City planned to use the process again in April 2007 on a similar water line under Interstate 25. The liner properties as tested by Hauser Laboratories are sufficient to provide the necessary performance for the liner to behave as a semi-structural lining.

CONCLUSIONS

The liner process as currently established is a much better process than when first adopted from its initial use in Europe. The materials, liner tube welding process, installation parameters, etc. have all been examined in detail and refined to provide more reliable installations and the ability for quality assurance of the installed liner.

Laboratory test reports provide the evidence of the ability of the liner to withstand the various planned and potential operating conditions that are appropriate to a Class III structural system per AWWA M28.

Despite the installation difficulties witnessed first hand, it appeared that the installation process was close to being a repeatable reliable procedure and this conclusion was given some weight by the most recent experience in the City of Thornton. It was also noted that, when installation problems were evident during the installation process, the liner could be removed and a new liner installed. However, installation problems (especially wrinkles and air pockets) that are not detected until the liner is cured and inspected are not correctable by a relining process. In this regard, the problems with full grout coverage in the early trial installations in Fairplay seem to have been significantly reduced in the later field installations.

With the confirmation of grout coverage by infrared scanning plus the visual inspection, the quality assurance procedures for the completed liner are assessed to be quite good. If lack of grout coverage is evident by infrared scans of the hardened liner or other liner problems are discovered by the visual inspection, then a dig up and replace could be necessary, or a parallel new installation could be made using directional drilling (or other trenchless installation technique) or, if the pipe segment has sufficient flow capacity, a second liner could also be installed inside the first.

The overall conclusion of this report is that the MainSaver process has an identifiable niche for rehabilitation of water lines within a water distribution network. Its installation process risk has been observed to decrease over the past 12 months and, once installed, the existing owners appear to be pleased with the installed quality and the effectiveness of the product.

REFERENCES

Some Standards for Materials, Testing, or Design Relevant to the MainSaver Process

	AMERICAN SOCIETY FOR TESTING AND MATERIALS
ASTM D 1598-02	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
ASTM D 1599-99	Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
ASTM F 1216-07	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
	AMERICAN WATER WORKS ASSOCIATION
AWWA M28 Jan 2001	Rehabilitation of Water Mains
	NATIONAL SANITATION FOUNDATION
NSF ANSI 61 (USA)	NSF Drinking Water System Components Program - Standard 61
	U.K. STANDARDS
	Water Industry Act 1991, Section 69 (UK) Regulation 25 (1)
	Water Supply (Water quality) Regulations 1989 (UK)
	Water Supply (Water quality) (Amendment) Regulations 1991 (UK)
	Drinking Water Inspectorate Approval – Reference DWI 56.4.403 (UK) of 18 October 1999

Publications and Product Information

Innovene, 2005. Product Information Sheet for Eltex® PC002-50 R968 Blue

Kalaugher, L., K. Adams and J. Trew, 1999. Cempipe Installation Trial – Physical Testing Results, WRc Ref: UC 3432, June 1999, Water Research Center, Swindon, U.K.

TEST REPORT

CLIENT: W.S.U., Inc.
PO Box 2098
Breckenridge, CO 80424

Attention: Dan Cohen

OBJECTIVE: Test samples with the CemPipe Americas polyethylene / grout pipeline rehabilitation system installed as a liner were tested for resistance to internal and external hydrostatic pressure.

SAMPLES: Each test sample consisted of a 36-inch length of 6-inch nominal diameter carbon steel pipe with NPT threads at each end. The samples had been lined by the Client with the CemPipe product prior to delivery to Hauser Laboratories. The individual samples included fabricated "defects" intended to replicate host pipe defects that would cause pipes in service to require rehabilitation. The sample detail is provided below.

PI-STEP-1-1: Fully lined steel pipe with 60mm diameter circular hole.

PI-STEP-2-1: Incompletely lined steel pipe with 60mm diameter circular hole.

TESTING: For all tests, the test sample was capped with 6-in nominal diameter steel caps with NPT threads. One of the caps included two ¼-inch threaded ports; these ports were plugged for the tests.

The pressure tests were performed with plugged ports in the caps, so the test sample was a sealed empty vessel. The sealed sample was placed inside of a length of 8-in nominal diameter PVC pipe, which was then capped with restrained gasketed end fittings. The annular space between the PVC pipe and the test sample was filled with water, and was pressurized using the same equipment used for internal pressure tests of pipe per ASTM D1599. In this test configuration, the test sample is subjected to external hydrostatic pressure. Failure was detected as a rapid drop in pressure, and was confirmed by disassembly and examination.

RESULTS: See Table 1 for results.

Table 1: External Pressure Tests

Sample	Configuration	Failure Pressure	Failure Mode
		psi	
PI-STEP-1-1	external	100	Fracture of grout and 12-in by 5-in elliptical "blister" in PE
PI-STEP-2-1	external	40	Small leaks in PE with no apparent rupture

DATA REVIEWED AND REPORT WRITTEN BY:

D. W. Woods
Senior Scientist

REPORT REVIEWED BY:

Steve Ferry
Director - Hauser Laboratories

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SAMPLES: The test sample consisted of a 36-inch length of 6-inch nominal diameter carbon steel pipe with NPT threads at each end. The sample had been lined by the Client with the CemPipe product prior to delivery to Hauser Laboratories. The individual sample included a fabricated "defect" intended to replicate a host pipe defect that would cause pipes in service to require rehabilitation. The sample detail is provided below.

PI-STIP-3: Fully-lined steel pipe with 1.0-inch diameter circular hole.

TESTING: The test sample was capped with 6-in nominal diameter steel caps with NPT threads. One of the caps included two ¼-inch threaded ports to allow filling and pressurization; these ports were connected to the pressurized water supply and pressure gage for the pressure test.

The pressure test was conducted in general accordance with ASTM D1599-99 (2005). The D1599 provisions regarding time-to-fail were not followed in this test because there were no pre-existing expectations regarding the magnitude of the pressure needed to cause failure, but the pressurization time in this test was on the order of 1 minute. Had failure occurred, it would have been detected by a rapid drop in pressure in the sample, and confirmed by visual examination for leaks.

RESULTS: The sample was pressurized to 500 psi internal gage pressure, and was held at that pressure for 5.0 minutes, with no visible leaking. After the pressure was released, the sample was examined for evidence of leaking or damage and none was detected.

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REPORT REVIEWED BY:

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Microbac®

TEST REPORT

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PO Box 2098
Breckenridge, CO 80424

Attention: Dan Cohen

OBJECTIVE: Test samples with the CemPipe Americas polyethylene / grout pipeline rehabilitation system installed as a liner were tested for resistance to internal and external hydrostatic pressure.

SAMPLES: The test sample consisted of a 36-inch length of 6-inch nominal diameter carbon steel pipe with NPT threads at each end. The sample had been lined by the Client with the CemPipe product prior to delivery to Hauser Laboratories. The tested sample was fully-lined, and included a 1-inch nominal corporation-stop type fitting that had been installed at the approximate center of the 36-inch length after lining. The host pipe also had four 3/16" holes drilled, each 2.0 inches from the outer edge of the corporation stop flange. Two holes were axially aligned with the corporation stop, and two were circumferentially aligned with the corporation stop. The hole configuration was chosen to allow detection of water entering between the liner and the host pipe at the corporation stop, and migrating at least 2 inches. The sample was identified as PI-LTIP-1

TESTING: The test sample was capped with 6-in nominal diameter steel caps with NPT threads. One of the caps included two ¼-inch threaded ports to allow filling and pressurization; these ports were connected to the pressurized water supply and pressure gage for the pressure test. The corporation stop was maintained in the closed position.

The pressure test was conducted in general accordance with ASTM D1598-02. The pressurization ramp time in these tests was on the order of 1 minute.

RESULTS: Test 1: The sample was placed in its vertical position, pressurized to 210 psi internal gage pressure, and held at that pressure for 1.6 hours total test time. At approximately 0.8 hours, very slight leaking was detected at the weep hole directly below the corporation stop, as tested. The leak was observed to continue with no apparent change in rate throughout the test period.

Test 2: The same sample, which had remained full of water but unpressurized for approximately 17 hours, was repressurized to 210 psi. At approximately 0.2 hours, very slight leaking was detected at the same weep hole directly below the corporation stop. The leak was observed to continue with no apparent change in rate throughout the test period of 1.3 hours.

Test 3: The same sample, which had remained full of water but unpressurized for approximately 7 days, was repressurized to 210 psi. This test was conducted with the pipe horizontal, and the corporation stop at the top (crown) position. This configuration was used because it allows leaking from each weep hole, if any, to be separately observed, and, if in sufficient volume, collected and measured. After 5 minutes at pressure, the same axially-aligned hole that had leaked in previous tests was visibly moist. At 40 minutes, there was slight liquid water visible as a wet streak heading directly down from this weep hole. A reservoir was attached to the exterior of the pipe 90-degress around the pipe (at the springline), such that any water trickling that far around the pipe (about 5 inches) would be collected. The test was continued for 24 hours total test time, with no apparent change in the nature or volume of the leak, and no accumulation in the reservoir. Water deposited in the same location from a syringe at the rate of 0.05 ml/minute resulted in accumulated water in the reservoir within 1 minute, and continuous additional accumulation thereafter. Therefore, the maximum leak rate from the pipe in the 210 psi / 24-hour test was significantly less than 0.05 ml/minute throughout the test.

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Senior Scientist

REPORT REVIEWED BY:

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Director - Hauser Laboratories

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TEST REPORT

CLIENT: W.S.U., Inc.
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Breckenridge, CO 80424

Attention: Dan Cohen

OBJECTIVE: A test sample with the MainSaver polyethylene / grout pipeline rehabilitation system installed as a liner was tested for resistance to internal hydrostatic pressure.

SAMPLES: Sample PII-STIP-4 consisted of a 36-inch length of 6-inch nominal diameter carbon steel pipe with NPT threads at each end. The sample had been lined by the Client with the MainSaver product prior to delivery to Hauser Laboratories. The PII-STIP-4 Sample included a fabricated "defect" intended to replicate host pipe defects that would cause pipes in service to require rehabilitation. The sample detail is provided below.

PII-STIP-4: Fully-lined steel pipe with 2 inch diameter circular hole.

TESTING: The test sample was capped with 6-in nominal diameter steel caps with NPT threads. One of the caps included two ¼-inch threaded ports to allow filling and pressurization; these ports were connected to the pressurized water supply and pressure gage for the pressure tests.

The test was conducted in general accordance with ASTM D1599-99(2005). The D1599 provisions regarding time-to-fail were not followed in this test because there were no pre-existing expectations regarding the magnitude of the pressure needed to cause failure, but the pressurization time to fail in these tests was on the order of 1 minute.

RESULTS: Sample PII-STIP-4 was pressurized to 500 psi internal hydrostatic pressure within approximately 1 minute. The sample was then held at 500 psi internal pressure for an additional 5 minutes, without catastrophic rupture. The sample displayed slight weepage in the area of the fabricated defect, although an exact leak path could not be determined.

DATA REVIEWED AND REPORT WRITTEN BY:

Steve Ferry
Director, Hauser Laboratories

REPORT REVIEWED BY:

Joel Self
Engineer IV

TEST REPORT

CLIENT: W.S.U., Inc.
PO Box 2098
Breckenridge, CO 80424

Attention: Dan Cohen

OBJECTIVE: A test sample with the MainSaver polyethylene / grout pipeline rehabilitation system installed as a liner was tested for resistance to three-point bending while under internal hydrostatic pressure.

SAMPLES: Sample PII-DJIP-4 consisted of two 36-inch lengths of 6-inch nominal diameter carbon steel pipe sections with NPT threads at each end which were butted end to end with minimal gap. The sample had been lined by the Client with the MainSaver product prior to delivery to Hauser Laboratories. The sample detail is provided below.

PII-DJIP-4: Fully-lined butted steel pipes with minimal gap between the sections. This sample was tested with axial restraint.

TESTING: The test sample was capped with 6-in nominal diameter steel caps with NPT threads, with integrated internal seals which isolated the interior of the sample (in the interior of the lined section). One of the caps included a pressure port to allow filling and pressurization; this port was connected to the pressurized water supply and also contained a downstream pressure gage during the pressure tests. The test sample was fixtured in a universal testing machine (UTM) such that the butted sample was placed in 3 point bending (with a 49 inch span). The butt joint was free to move vertically within the UTM when force was applied (See Figure 1). The sample was pressurized to 45 psi internal hydrostatic pressure, and the joint was subjected to increasing deflection until leakage occurred. The pressurization testing was conducted in general accordance with ASTM D1598-02.

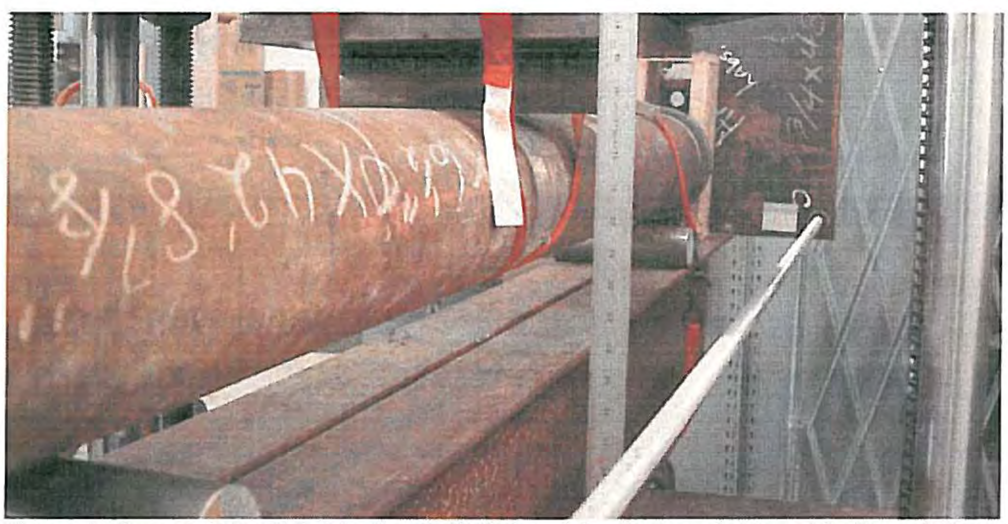

Figure 1: Sample PII-DJIP-4 in the UTM fixtured for three-point bend testing of the butt joint (just left of the vertical scale).

RESULTS: Sample PII-DJIP-4 was pressurized to 45 psi internal hydrostatic pressure and withstood a maximum mid-span deflection of 0.49 inches. The 0.49 inch mid-span deflection corresponds to an angular deflection at the butt joint of 2.30 degrees. The sample did not fail by catastrophic rupture, but displayed leakage from the butt joint area after reaching 0.49 inches deflection (See Figure 2).

Figure 2: Sample PII-DJIP-4 at 0.49 inches deflection (with leakage).

DATA REVIEWED AND REPORT WRITTEN BY:

Steve Ferry
Director, Hauser Laboratories

REPORT REVIEWED BY:

Joel Self
Engineer IV

Microbac

TEST REPORT

CLIENT: W.S.U., Inc.
PO Box 2098
Breckenridge, CO 80424

Attention: Dan Cohen

OBJECTIVE: A test sample with the MainSaver polyethylene / grout pipeline rehabilitation system installed as a liner was tested for resistance to shear deflection while under internal hydrostatic pressure.

SAMPLES: Sample PII-DJIP-3 consisted of two 36-inch lengths of 6-inch nominal diameter carbon steel pipe sections with NPT threads at each end which were butted end to end with minimal gap. The sample had been lined by the Client with the MainSaver product prior to delivery to Hauser Laboratories. The sample detail is provided below.

PII-DJIP-3: Fully-lined butted steel pipes with minimal gap between the sections. This sample was tested with axial restraint.

TESTING: The test sample was capped with 6-in nominal diameter steel caps with NPT threads, with integrated internal seals which isolated the interior of the sample (in the interior of the lined section). One of the caps included a pressure port to allow filling and pressurization; this port was connected to the pressurized water supply and also contained a downstream pressure gage during the pressure tests. The test sample was fixtured in a universal testing machine (UTM) such that one end of the butted sample was simply supported, while the other end was free to move vertically within the UTM when force was applied (See Figure 1). The sample was pressurized to 45 psi internal hydrostatic pressure, and the joint was subjected to increasing deflection until leakage occurred. The pressurization testing was conducted in general accordance with ASTM D1598-02.

Figure 1: Sample PII-DJIP-3 in the UTM fixtured for shear deflection testing of the butt joint (behind vertical scale).

RESULTS: Sample PII-DJIP-3 was pressurized to 45 psi internal hydrostatic pressure and withstood a maximum shear deflection of 0.50 inches. The sample did not fail by catastrophic rupture, but displayed leakage from the butt joint area after reaching 0.50 inches deflection (See Figure 2).

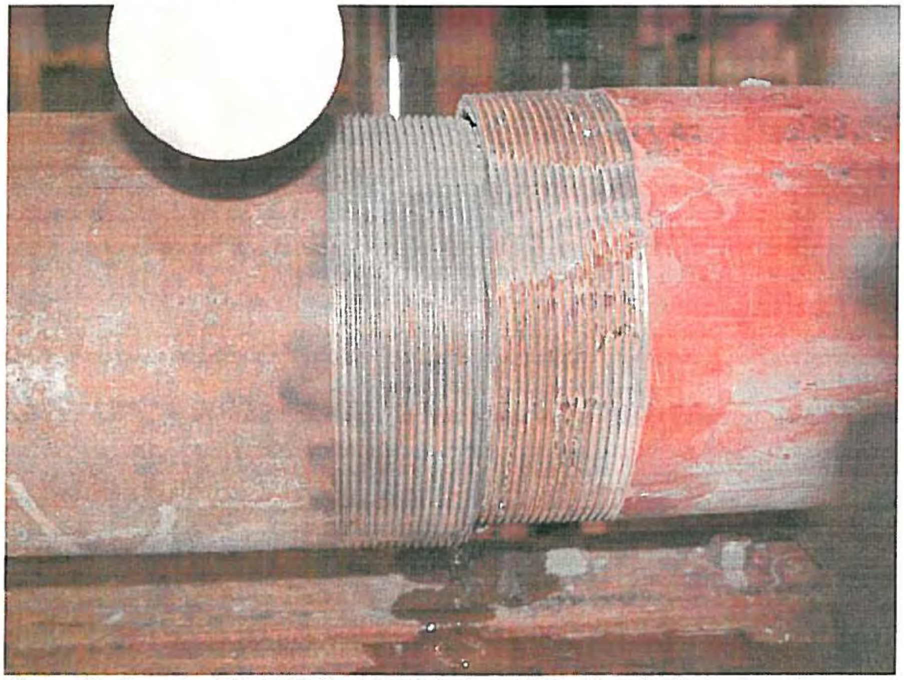

Figure 2: Sample PII-DJIP-3 at 0.50 inches deflection (with leakage).

DATA REVIEWED AND REPORT WRITTEN BY:

Steve Ferry
Director, Hauser Laboratories

REPORT REVIEWED BY:

Joel Self
Engineer IV

W.S.U. Inc.
CONVENTIONAL PIPELINE INSTALLATION
TRENCHLESS PIPELINE REHABILITATION

1/16/2007

Hello Ray

Enclosed is the vhs I promised you depicting my experiments to determine if IRTV would detect missing grout behind the Velcro lining tube.

Specimen Prep:

I took two 10 lf x 8.0"Ø sticks of sdr pvc and cut out various sized and shaped pieces of plastic. We then temporarily replaced the cut outs back in, holding them in place with duct tape. MainSaver was then installed. Prior to full hydration, the cut outs where removed and the exposed grout was excised using a water pic. The pvc cut outs were then permanently glued back into place and the grout was allowed to fully hydrate.

#1 Experiment

The first ir video shows a bench test on the floor of the shop of one of the MainSaver lined sticks of pipe. The pipe was heated with incandensent lights and inspected with irtv.

#2 Experiment

We trenched ± 300 lf of 8"Ø sdr pvc at a depth of 4-5 vf in our yard. The two MainSaver sticks were spliced in ~ equidistant. The entire length was backfilled. We then inspected with irtv. Although there is some "ghosting" of the power cable/pull rope, the images clearly show the defects. Standard light heads attached to the camera provide the transfer heat.

Best Regards,
Dan Cohen

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Issue: April 2005

innovene

Product Technical Information

Eltex® PC002-50 R968 Blue

Eltex® PC002-50 R968 is a medium-density polyethylene copolymer designed for the extrusion of pressure pipes for water applications. It is classified PE 80 in accordance with ISO 12162 based on ISO 9080 analysis.

Characteristics

PE 80 Blue pipe compound

Application

- Water

Properties

	Value	Units	Test Method
Physical			
Density (pigmented)	943	kg/m^3	ISO 1183/A
Melt Flow Rate (5 kg/190°C, Condition T)	0.85	g/10min	ISO 1133
Mechanical			
Tensile Strength at Yield (23°C @ 50mm/min)	18	MPa	ISO 527-2
Tensile Elongation at Break (23°C @ 50 mm/min)	>350	%	ISO 527-2
Tensile Modulus (23°C @ 1 mm/min)	700	MPa	ISO 527-2
Thermal			
VICAT Softening Point (1kg)	116	°C	ISO 306
Thermal Stability (OIT, 210°C)	>20	min	ISO 10837
Pigmentation			
Pigment Dispersion	<3	Grade	ISO 18553

The values given are typical values measured on the product. These values should not be considered as specifications.

Issue: April 2005

Food Contact Applications
As dispatched from our plants PP and PE grades (like Rigidex®, Eltex® and Eltex® P ones) meet the requirements of most European countries in respect of their usage in food contact and toys applications.
Official confirmation of compliance with current requirements in the individual countries will be provided on request. No liability can be accepted for any damage, loss, or injury arising out of failure to obtain such confirmation, or failure to observe any recommendations given.

Polyethylene, Polypropylene and the Environment
INNOVENE will act responsibly and caringly towards those who work for us, the community whom we serve and the environment in which we live.

Natural PE and PP polymers, as supplied, can be recycled, incinerated or disposed of in landfill without detriment to the environment.

With recycling, clean waste can be re-used for many less demanding applications.

Alternatively, with properly controlled and efficient incineration, preferably linked to heat or other energy recovery systems, polyethylene's high calorific value will assist the combustion of municipal solid waste.

In landfill sites, PP and PE grades do not degrade to produce voids, and do not emit dangerous gases or contribute to ground water pollution.

Natural PP and PE polymers, as manufactured, comply with the limit for heavy metals (100 ppm total of lead, cadmium, mercury and hexavalent chromium) in packaging materials as defined in the European Union Directive 94/62/EC on packaging and packaging waste and the corresponding US CONEG regulations.

If pigments or other additives are incorporated into the PP and PE polymers at the processing stage, the above statements may not be fully valid. INNOVENE will be pleased to offer advice in specific cases.

Health and Safety
Material Safety Data Sheets for our grades are available, and should be consulted before handling and using them.

Published by INNOVENE
April 2005