American Society of Civil Engineers

Pipeline Division

Proceedings of

Pipeline Research and Technology Transfer Symposium

Conducted on Sunday, July 30, 2006

In Conjunction with ASCE 2006 Pipeline Conference

Chicago, Illinois

Edited by Steven Kramer and Mohammad Najafi

April 2007

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Foreword

This report presents the results from the ASCE Pipeline Research and Technology Transfer Symposium held on Sunday, July 30, 2006, in Chicago, Illinois. The Symposium was sponsored by the Research Committee of the ASCE Pipeline Division. The Symposium provided a forum for presenting and discussing new pipeline technologies, processes or techniques that have merit but have not yet been successfully transferred or regularly used in the marketplace. The presented technologies came from research institutions, universities, consulting/engineering companies, contractors, suppliers and manufacturers.

The Symposium included presentations by ten speakers on emerging pipeline-related technologies. Five separate breakout sessions were subsequently held to develop strategies to assist emerging technologies become accepted in the marketplace. Each session addressed two technologies and included facilitators, a report leader, and a recorder to capture information during each breakout session.

The emerging technologies included:

- Pipe Renewal Methods
- Utility Corridors
- Enhancements to Directional Drilling
- Condition Assessment
- Pipe Materials for Trenchless Applications
- Freight Pipelines
- Tomographic Ground Imaging
- Corrosion Control

Attendees included a strong cross section of practitioners, suppliers, researchers and academia. Each of these groups has an important role to play in the advancement and acceptance of new methods.

Our industry needs a continuing friendly and objective forum where people from within and outside of the industry can showcase new technologies. It is my hope that that this type of forum can continue to serve this role and support the advancement of the pipeline profession.

I am very appreciative of the many individuals who graciously contributed their time to make this Symposium a success.

Steven R. Kramer, PE

Chair, ASCE Pipeline Research Committee

and Symposium Chairperson

ASCE Pipeline Research and Technology Transfer Symposium

Sheraton Hotel, Chicago, IL, Sunday, July 30, 2006

Agenda

8:30 a.m. **Welcome, Introductions and Objective of Symposium** – Steven Kramer

8:45 a.m. **Session 1 on Emerging Technologies** (15 minute presentations per technology)
Moderator – Steven Kramer
- Exploitation of Utility Corridors: Michael Welch, BRB Contractors
- Freight Pipelines: Dr. Henry Liu, Freight Pipeline Company
  (Focus on pneumatic capsule pipelines for underground freight transport)
- SPR Technology for Pipe Rehabilitation: Michael Yen, Sekisui SPR America
- Enhancements to Horizontal Directional Drilling Equipment: Grant Jameson, Entec

10:00 am. Break

10:30 a.m. **Session 2 on Emerging Technologies**
Moderator: Dr. Sam Ariaratnam
- Condition Assessment: Dr. Brian Mergelas, Pressure Pipe Inspection Company and Mark Holley, Pure Technologies
- Alternative Pipe Materials for Trenchless Technology: Collins Orton, TT Technologies and Dr. Sam Ariaratnam, Arizona State University
- Geophysical Ground Imaging: Paul Fisk, NDT Engineering
- Corrosion Prevention of Ductile Iron Pipelines, David Kroon, Corrpro
- Large-Scale Laboratory Validation of Field Behavior, New Products and Advanced Sensors, Dr. Tom O'Rourke, Cornell University

12:00 Noon Lunch

1:00 p.m. **Session 3 - Breakout Sessions**
Develop strategies to assist emerging technologies become accepted in the Marketplace.
Five Individual Sessions with 2 Technologies per Session:

Session	Topics	Facilitators/Report Leaders/Recorders
1	- Fiber Reinforced Polymer Reinforcement for Pipelines - Large-Scale Laboratory Validation of Field Behavior, New Products and Advanced Sensors	Facilitators: Dennis Doherty & Paul Savard Recorder: Deepak Bhattachar & & Anitha Palanisamy
2	- Exploitation of Utility Corridors - Tomographic Ground Imaging	Facilitators: Jey Jeyapalan & James Chae Report Leader: Samuel Ariaratnam Recorder: Somik Ghosh
3	- Freight Pipelines - Corrosion Prevention of Ductile Iron Pipelines	Facilitator: Henry Liu & Randy Conner Report Leader: Alan Atalah - Recorder: Oleh Kinash
4	- SPR Technology for Pipe Rehabilitation - Condition Assessment	Facilitator: Tony Almeida Report Leader: Sanjiv Gokhale Recorder: Alhad Panwalkar
5	- Enhancements to Horizontal Directional Drilling Equipment - Alternative Pipe Materials for Trenchless Technology	Facilitator: Brian Dorwart & Collins Orton Report Leader: Brian Dorwart and Mohammad Najafi Recorder: Maryam Ajami

2:30 p.m. Break

3:00 p.m. **Session 4 - Presentations on methods to assist in technology transfer** –
Presentations by Facilitators

4:30 p.m. **Conclusions**

5:00 p.m. Adjourn

Session 1 Breakout Report
SPR Technology for Pipe Renewal

Dennis J. Doherty, Jacobs Engineering, Inc., Boston, MA

Breakout Participants

Facilitators: Dennis Doherty

Report Leader: Anil Misra

Recorder: Aritha Palanisamy & Deepak Bhattachar, Graduate Students, Michigan State University

Participants: Michael Yen, Anis Somani

Introduction & Background

There are many storm water and sanitary sewer conveyance pipes that are non-circular in shape and in some instances truly rectangular or square. Many of these pipes are constructed from brick and mortar, cast -in-place concrete, or prestressed concrete box sections. As is well known in the industry concrete and mortar are subject to corrosion due to sulfide attack. Due to limited rehabilitation methods, most of these non-circular pipes have gone un-rehabilitated and are in danger of failure. As a growing number of these pipes are exceeding their expected useful life, they are in need of rehabilitation if the lives of the pipes are to be extended. Until now, there has been limited technology that can be applied to the non-circular pipes.

A relatively new method for rehabilitating these pipes has been introduced to the United States. The method was developed in Japan by Sekisui SPR. Information on this method was presented at the ASCE Pipeline Research and Technology Transfer Symposium held in Chicago as part of the ASCE Pipeline Conference in 2006. As part of the Symposium, a group discussion was held to review the advantages as well as the disadvantages of the method; where it has been used; and the factors that need to be considered if this technology is to be accepted in the United States.

Factors to be considered while implementing any new technology and how the technology is advantageous over existing methods used to rehabilitate non-circular pipes. For example:

- Technical Advantage
- Competitive Advantage
- Life span
- Value added advantage
- Cost effectiveness
- Applicability

This report is written to review the group’s findings.

Engineering Technology for SPR

The SPR Method is based on a spirally wound PVC, grouted annular space, and host pipe forming a composite structure and can be installed in low to moderate flow conditions. Figure 1 is a sample of the composite structure. The key is the interlocking PVC liner that is installed by machine. Figure 2 is a sample of the interlocking PVC. Figure 3 illustrates the SPR Technology's 6-step Process.

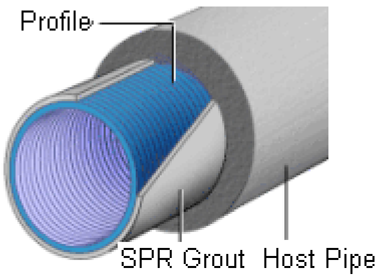

Figure 1- Composite Structure

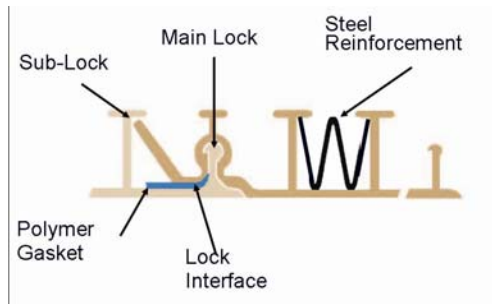

Figure 2- Interlocking PVC

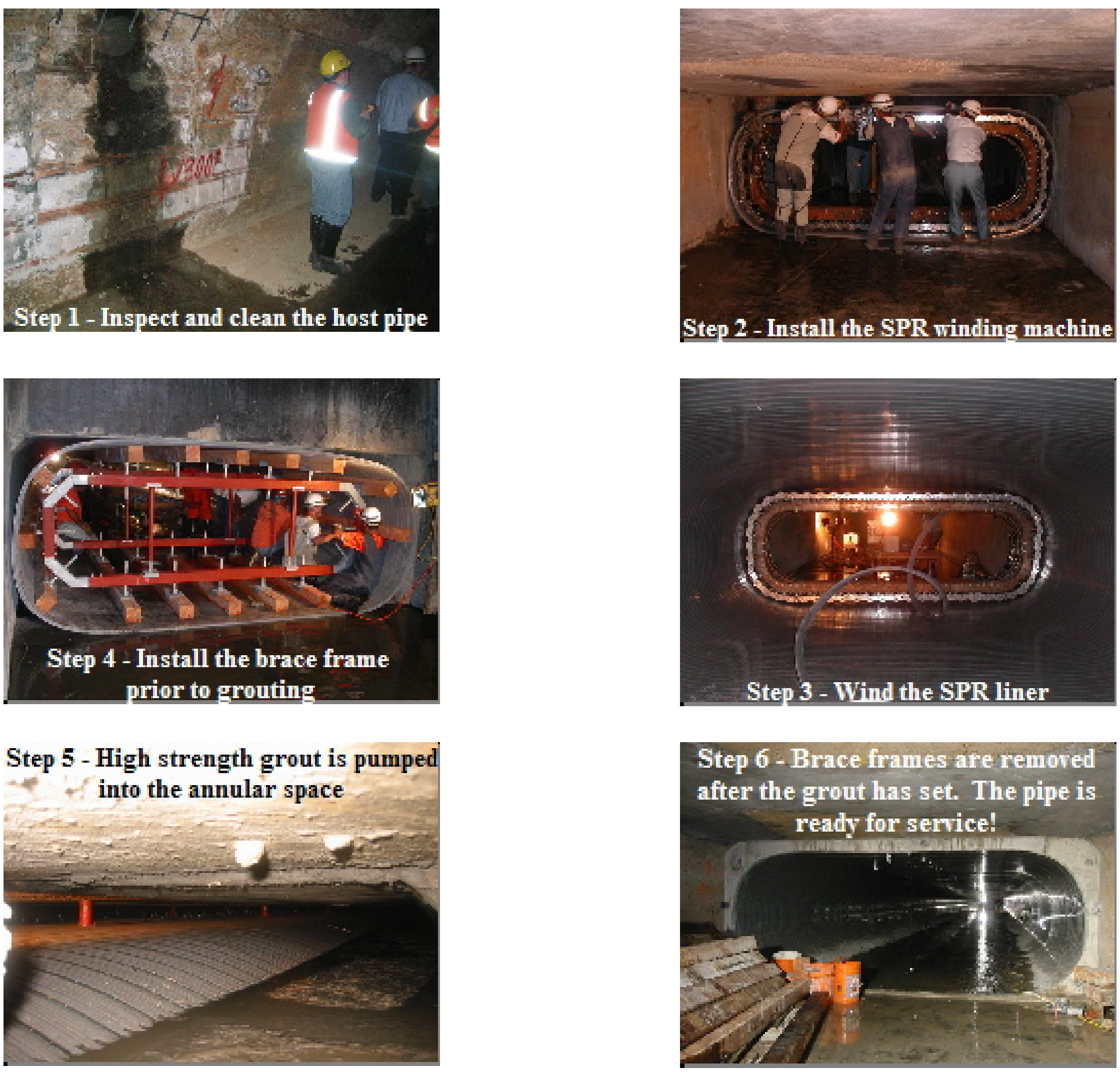

Figure 3 -- The Basic 6-Step Process for SPR Technology

Current Use of Technology in World and United States

The SPR Technology developed and has been used in Japan. The technology has also been used in Europe, but has limited use in the United States. The US EPA's Office of Wastewater Management in a July 2006 report stated that the SPR Technology to be in its embryonic stages as a new technology in the United States.

Breakout Questions & Answers

During this session, five questions were addressed for each of the two technologies during the breakout session. These are presented in the following sections.

1. What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?

There are a number actions and steps that need to be taking if the SPR Method is to be an accepted technology in the United States.

- It seems to be well established outside the US. Currently there is insufficient use in the United States. However, it has been accepted in California.
- The SPR Method needs to be installed as a demonstration project in several regions of North America so that regional authorities can witness its installation practice.
- Case histories of successful installations in the United States need to be presented as national and regional seminars.
- Academic studies need to be prepared outlining the hydraulic characteristics of the installed SPR Technology versus uninstalled host pipe and the structural improvements of the host pipe.
- Frame proper standards in The US instead of following local standards/ Approaches
  For Example: Green Book Standards in Southern California.

2. What are the key technical issues preventing further acceptance of the emerging technology?

There are also a number of issues that will continue to prevent the acceptance of this technology in the United States. These include:

- No multiple Vendors – Hence fair competition issues
- Method of installation – Safety, Certified / Qualified Contractors , and Cost & Schedule
- Political – Where, when, why, Individual issues, Group Culture
- End Product (Back-up what is claimed)– capacity, Structural, Mechanical seal for corrosion barrier

Until these issues are overcome, the SPR Technology will have a slow growth in acceptance in the United States.

3. **What organizations (public or private) could assist with technology transfer process?**

There are many opportunities to interact with federal agencies and professional organizations to accelerate the evaluation and transfer of new technology for water pipeline applications.

4. **Are there any specific people who should be contacted to assist with the emerging technology?**

The discussions in the Breakout Session focused chiefly on organizations/agencies as opposed to specific individuals. Organizations (public / private) that might assist with the technology transfer process include:

- LA County - The SPR Technology has been accepted in LA County and has been successfully used in the county on non-circular pipe rehabilitation.
- ASCE / WEF / NASTT – Funded research for university studies as well as presenting a forum for presentation of case studies and results of research.
- Additional Research Funding resources may be obtained from US EPA, Federal Highway, and Transportation Research Board.
- University – Academic research on the hydraulic and structural improvements.
- US EPA, State Environmental Agencies, State Departments of Transportation to accept the technology.

Specific people who could be contacted to assist with the Technology include:

- John Rednar, LA County (Ret), Keith Hanks, City of LA, Eric Lindquest , Private Consultant, Other key people who are involved in pipeline renewal.

Conclusions and Recommendations

The SPR Technology is a promising technology that will address the significant deterioration of large diameter non-circular pipes that are part of the United States underground infrastructure with minimal impact to surface activities. The technology can improve the structural integrity of the pipes as well as improve system hydraulics. However, due to the fact that the technology is "foreign" to most public agencies in the United States as well as being unknown to much of the engineering establishment, growth of this technology will be limited. Well established academic research facilities will provide technical credentials to the technology and with this become more readily accepted by the public agencies and the engineering community in general. Presentations of the technologies benefits as national and regional engineering and construction trade shows will further educate the engineering community and local and state public agencies of this technology. Finally, national research and federal government endorsement will also help establish the credentials of the SPR Technology.

Session 2 Breakout Report

Exploitation of Utility Corridors/Geophysical Ground Imaging

Samuel T. Ariaratnam, Arizona State University, Tempe, AZ

Breakout Participants

Facilitators: Jey Jeyapalan (Jeyapalan Consulting) and James Chae (Jacobs)

Report Leader: Samuel T. Ariaratnam (Arizona St. University)

Recorder: Somik Ghosh (Graduate Student at Michigan State University)

Participants: Paul Fisk (NDT Corporation) and Vicki Sironen

Introduction and Background

This portion of the report covers the topics of "Exploitation of Utility Corridors" presented by Mike Welsh and "Geophysical Ground Imaging" presented by Paul Fisk. Mike Welsh is the President/CEO of BRB Contractors, Inc. in Topeka, Kansas. His presentation discussed pros and cons of utility corridors to help alleviate congestion due to the density of buried utilities. Paul Fisk works for NDT Engineering in Worcester, Massachusetts. His presentation discussed the use of geophysical survey methods as a cost-effective way of managing risk associated with various trenchless technology projects by mapping changes in soil or bedrock conditions and identifying man-made obstructions.

Geophysical Ground Imaging

Technological advancements in investigation methods include the use of geophysical methods for ground imaging. These methods include: 1) seismic refraction & reflection; 2) marine seismic reflection & side scan sonar; and 3) tomography. Geophysics for subsurface investigation has several benefits including: continuous data; fast and low profile; ability to obtain data in difficult to access areas; and overall cost savings due to risk reduction. Figure 4 illustrates seismic refraction & reflection technology that is used to emit a signal that recognizes different subsurface mediums.

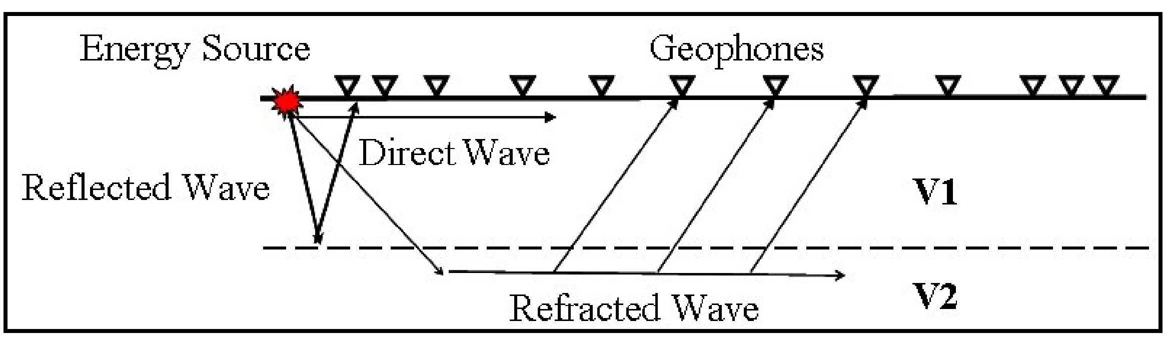

Figure 4 -- Seismic Refraction and Reflection Technology

Figure 5 illustrates the setup of surface geophones used in seismic refraction & reflection technology. This should be performed by a trained professional to ensure accurate data collection.

Figure 5 -- Installation of Surface Geophones

Marine seismic reflection & side scan sonar is a geophysical ground imaging technology that provides information on bottom obstructions in water (Fig. 6 & 7). The technology is particularly useful in the planning and pre-design phase.

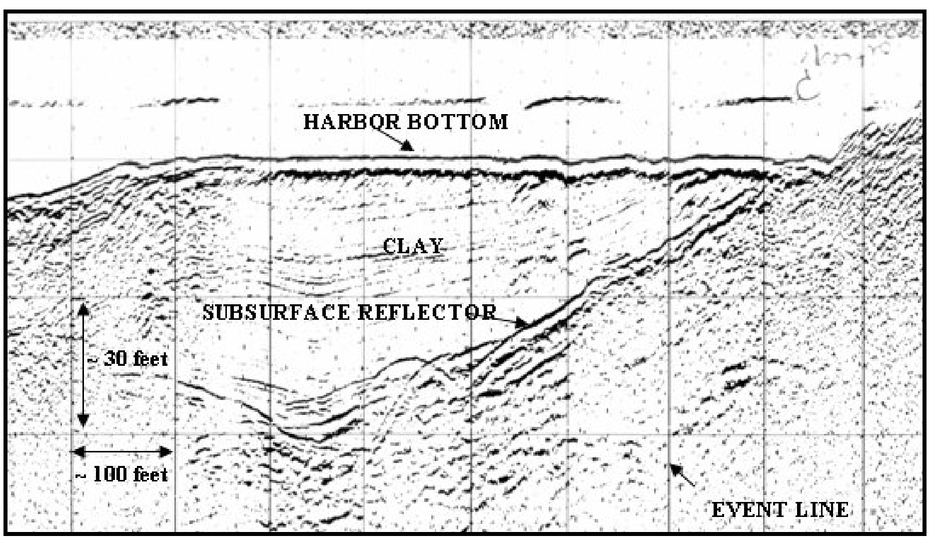

Figure 6 -- Marine Seismic Reflection Results

Vertical seismic profiling tomography provides information on the condition of bedrock to be penetrated. This is important in machine and tool selection for trenchless technology adaptation. Results of tomography are shown in Figure 8.

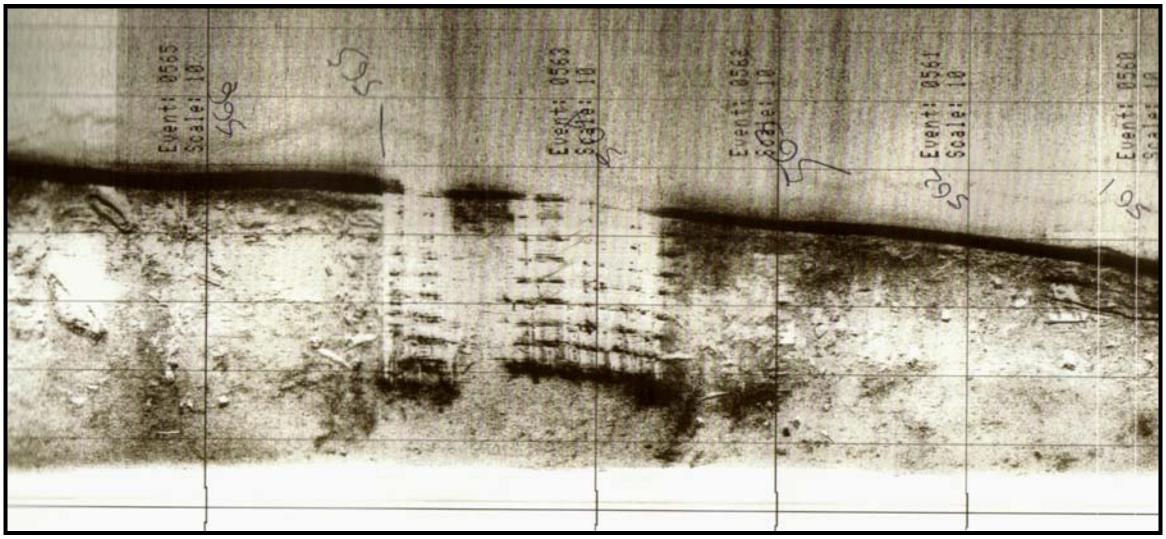

Figure 7 -- Side Scan Sonar Image

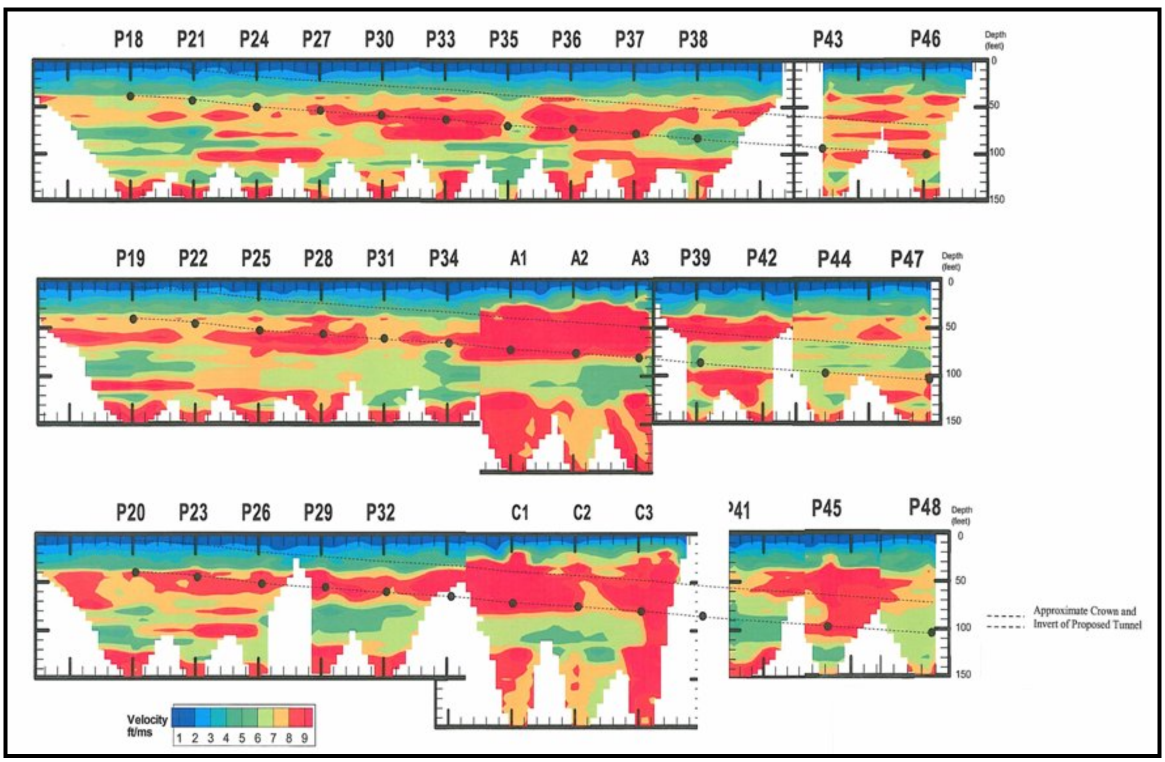

Figure 8 -- Tomography Results

Breakout Questions & Answers

During this session, five questions were addressed for each of the two technologies during the breakout session. These are presented in the following sections.

1. **What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?**

Exposure is paramount in gaining acceptance of geophysical ground imaging technology. Most people are not knowledgeable on the capabilities and limitation of this technology, as well as the appropriate application. It is recommended to familiar people through several approaches including:

- Papers / Conferences (ASCE, WEFTEC, AWWA, APWA, NASTT, SAGEEP, etc.)
- Free Training Seminars (for clients and consultants)
- Articles in Magazines / Case Studies
- Education at University level of geophysics

Additionally, it is important to show people how geophysical ground imaging can be used in a risk management program for underground construction.

2. **What are the key technical issues preventing further acceptance of the emerging technology?**

The biggest impediment to widespread acceptance of geophysical ground imaging is the lack of understanding of the technology. Subsequently, it is important to try and draw parallels between other industries such as oil/gas (i.e. fractures) and medical (i.e. ultrasound) that may be more familiar to the average person.

3. **What organizations (public or private) could assist with the technology transfer process?**

Organizations such as ASCE, FHWA, ITA, SMA, and municipalities can play vital roles in assisting with technology transfers. Additionally, technology vendors and consulting firms (i.e. NDT Engineering) are important.

4. **Are there any specific people who should be contacted to assist with the emerging technology?**

There are numerous individuals who should be contacted to assist with promoting geophysical ground imaging including:

- Daryl Tweeton, GISCO, Minneapolis, MN (software author for interpreting data from geophysical ground imaging methods)
- Silas Nichols, FHWA (his goal is to promote geophysics within FHWA)
- Paul Fisk, NDT, Boston, MA
- Geotechnical Engineering Professors at various universities

5. **Are there any funding sources that can be approached to assist in the implementation process?**

Potential funding sources to approach in assisting in the implementation process include the following:

- Federal Highway Administration (FHWA)
- National Science Foundation (NSF)
- Environmental Protection Agency (EPA)
- Utility Owners (for implementation)

Exploitation of Utility Corridors

With a vast network of utilities buried beneath our cities, there is a concern about the crowded density of these systems. There is an estimated 7,000,000 km of underground utilities in the United States. Figure 9 presents a breakdown of these utilities indicating 26% of natural gas lines followed by 19% potable water and 18% sanitary sewers. In particular, there is limited space available for new utility installation in keeping with minimum separation prescribed in underground facility laws. Buried telecommunications systems are

Utilities are being buried underground for a number of reasons including: increased security against third party damages; aesthetics; and protections against inclement weather. Today, many overhead electrical lines are now being installed underground using trenchless methods such as horizontal directional drilling. Singapore, Iceland, and Holland lead worldwide with 100% of their electrical cable system buried. In contrast, only 8% of the electrical network in the United States is buried. A breakdown of several nations is presented in Figure 10.

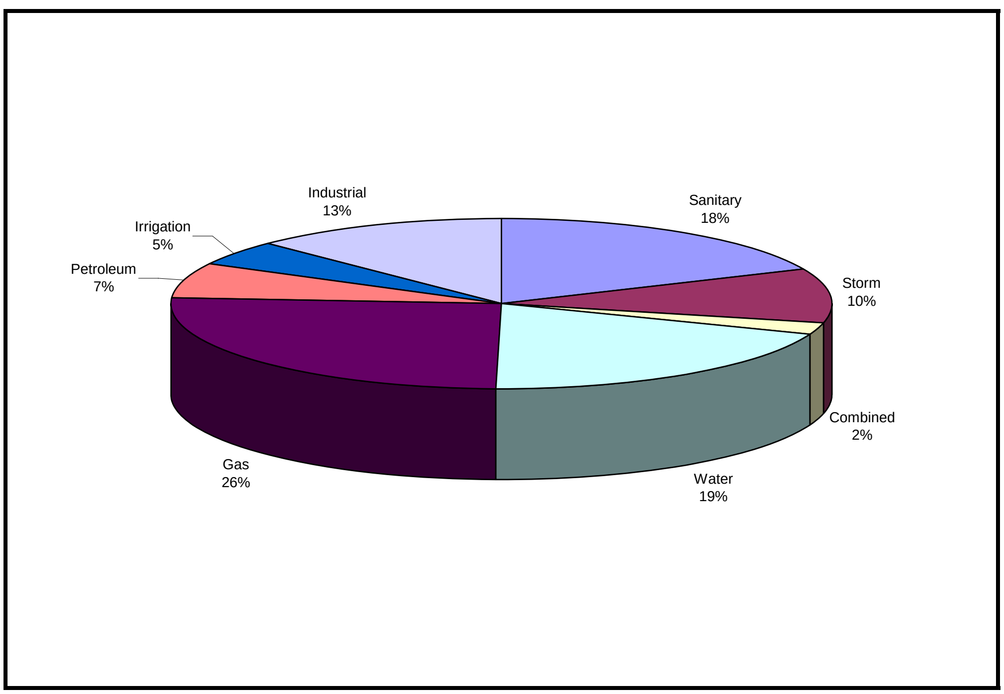

Figure 9 -- Breakdown of Underground Utilities in the United States

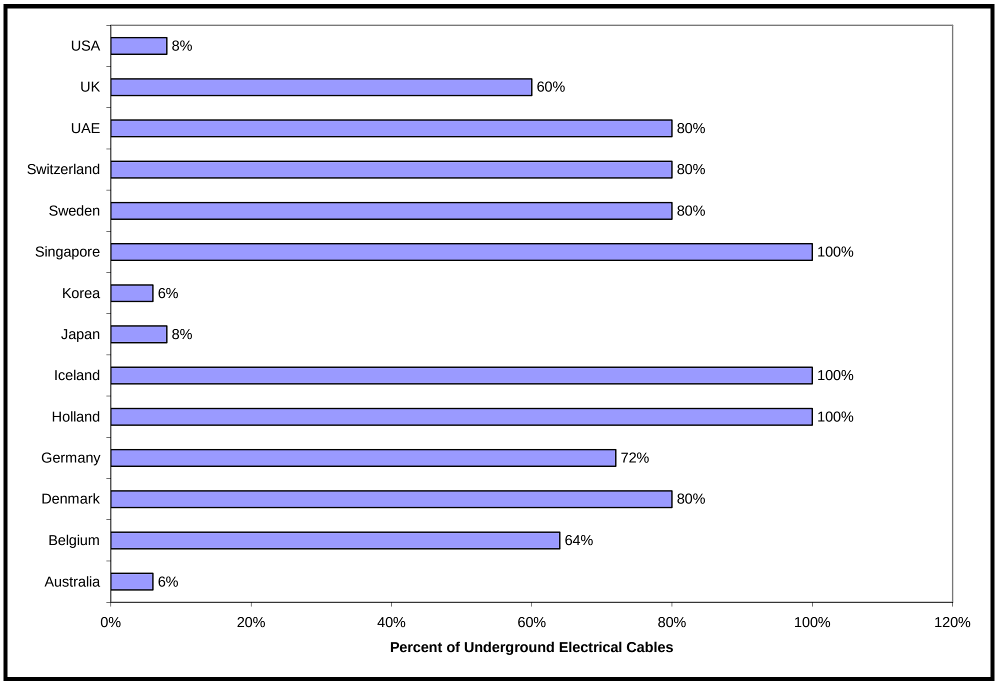

Figure 10 -- Percent of Buried Cables in Electrical System

Exploitation of utility corridors involves placing multiple utilities inside a common duct, or utilidor as illustrated in Figure 11. Utilidors can also be above ground as shown in Figure 12, which shows an utilidor bridge above a river.

Figure 11 -- Buried Utilidor System

Figure 12 -- Above Ground Utilidor System

Currently, there is a worldwide insurgence in the installation of broadband networks due to a technology age. Some of these telecommunication lines are being installed within existing utilities to reduce the utility corridor. These can be transported within a pipe through a liner (Figure 13), robots, pipe bursting, micro-duct blowing, and hooks within. Several standards exist related to utilities in existing pipes including C27D IEEE and ASTM F36.

Figure 13 -- Cables in a Liner

When engaging in exploitation of utility corridors, there are several considerations that must be undertaken in the planning and design stage. These include soil, drainage, lighting, ventilation, separation, storage, access, and security.

Breakout Questions & Answers

1. **What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?**

Statistics and case studies from existing utility corridor projects are important in gaining acceptance of the emerging technology. Providing magazine article and papers in conferences (APWA) can help in getting utility owners to agree to put their utilities together in a corridor.

2. **What are the key technical issues preventing further acceptance of the emerging technology?**

Coordination of utility providers is perhaps the key issue preventing further acceptance of exploitation of utility corridors. There are often logistics issues between dry and wet utility providers as to the order of installations and maintenance priorities. Additional issues include security concerns and costs.

3. **What organizations (public or private) could assist with the technology transfer process?**

Organizations such as FHWA and American Public Works Association (APWA) can play vital roles in assisting with technology transfers. Professional organizations that are involved in subsurface utility engineering (SUE) can be real proponents of exploitation of utility corridors. Additionally, technology vendors, municipalities, and academia are important.

4. **Are there any specific people who should be contacted to assist with the emerging technology?**

There are numerous individuals who should be contacted to assist with promoting exploitation of utility corridors including:

- Dr. Chris Rogers, University of Birmingham, U.K. (he currently has a major research grant for utilidors)
- Dr. Jeff Lew, Purdue University (conducts research in subsurface utility engineering)
- Municipal Permitting Departments (ROW engineers)

5. **Are there any funding sources that can be approached to assist in the implementation process?**

Potential funding sources to approach in assisting in the implementation process include the following:

- Federal Highway Administration (FWHA)
- State or Local governments

Conclusions and Recommendations

The ASCE Pipeline Research and Technology Transfer Symposium provided a venue for discussing and developing strategies to assist emerging technologies become accepted in the Marketplace. The Session 2 breakout session focused on “Exploitation of Utility Corridors” and “Geophysical Ground Imaging” technologies. Both of these areas are important considerations given the inherent risks associated with underground construction and the congested state of the nation’s utility space. Continued educational and research efforts are important steps in implementation and gaining acceptance of emerging technologies.

Session 3 Breakout Report

Condition Assessment Technologies for Water Mains

Sanjiv Gokhale, Vanderbilt University, Nashville, Tennessee

Breakout Participants

Facilitator: Tony Almeida, P.E., Halff Associates, Inc.
Participants: Brian Mergelas, PPIC, Ontario, Canada. Email: brain@ppic.com;
Mark Holley, Pure Technologies, Columbia, Maryland. Email: mark.holley@soundprint.com)
Recorder: Alhad Panwalkar, Graduate Student, Michigan State University

Introduction and Background

A water main break is the structural failure of the barrel or bell of the pipe. Water main breaks are caused when and where the loading on the pipe exceeds the pipe strength. Corrosion is a major cause of pipe strength deterioration. Corrosion can occur on either the interior or exterior of the pipe. Manufacturing flaws can also contribute to pipe strength deterioration.

Types of water main breaks include: (1) circumferential breaks; (2) longitudinal breaks; (3) holes caused by either corrosion or pressure/blowout; (4) split bells, including bell failure from sulphur compound joint materials; (5) sheared bells; and, (6) spiral cracks (O'Day et al., 1986; Makar et al., 2001). Water main breaks typically produce a substantial loss of pressure and flow at the point of the break and possibly elsewhere in the system, and therefore tend to be readily detectable and require immediate attention. In contrast, *water main leaks* often produce smaller, less easily detected, and less disruptive changes in pressure and flow that may go undetected and/or uncorrected for some time.

A 1994 estimate placed the number of main breaks in the United States at 237,600/year (Kirmeyer et al., 1994). This estimate was based on an estimated total length of water mains in the United States of 880,000 miles (excluding service lines) and a rate of 27 main breaks/100 miles/year. Variation is considerable between utilities. In one survey, main break repair rates ranged from 7.6 to 38.1 main break repairs/100 miles/year for 4 utilities. Seasonal variations in main break rates also occur, and northern cities tend to experience a substantial increase in main breaks during winter months. There are also significant differences in pipe material (Steel, PCCP, HDPE, Ductile Iron, Cast Iron, etc.), coating, and lining materials that may affect main break rates.

Emerging Technologies for Water Main Structural

Integrity Monitoring (SIM)

Structural integrity of water mains refers to the soundness of the pipe wall and joints for conveying water to its intended locations and preventing egress of water, loss of pressure, and entry of contaminants. SIM is the systematic detection, location, and quantification of pipe wall and pipe joint damage and deterioration (e.g., wall thinning, cracking, bending, crushing, mis-alignment, or joint separation) of installed drinking water mains. Effective SIM enables determination of the present condition and the deterioration rate of the pipe. Present condition for a particular pipe location is determined by a single measurement of a structural parameter. Deterioration rate for a particular pipe location is determined by periodic measurement of a structural parameter. If the measured parameter reaches a pre-determined unacceptable level, then actions can be taken such as (a) small repairs to forestall accelerated deterioration, and much larger repairs later or (b) repair, rehabilitation, or replacement (R) to prevent failures and associated damages.

Numerous SIM methods have been developed over the years. Some of the common SIM technologies are noted in Table 1, and described in more detail in other documents (e.g., Dingus, et al., 2002; Tafuri et al., 2001; Stone et al., 2002; Cromwell et al., 2001; O'Day et al., 1986; Deb et al., 2002; Lawrence, 2001; Fennell and Lawrence, 2000; Jackson et al., 1992; Hunaidi et al., 1999; Rajani et al., 2000; Smith et al., 2000; Bickerstaff et al., 2002).

Two technologies in particular were discussed during the ASCE Pipeline Research and Technology Transfer Symposium, July 30, 2006. A brief discussion regarding the capabilities of these techniques is included in the following sections.

Sahara® Leak Location System

The Sahara Leak Location system was originally developed for the detection and accurate location of leaks in live potable water mains while under pressure and in service.

In operation, a winch and cable drum control the forced deployment and retrieval of the neutrally buoyant probe and umbilical data cable that are disinfected before they enter into the pipe through any tap point 2" (50 mm) or greater in diameter. Normally, the system is then carried along the pipe by the flow of water (the flow rate must be greater than 0.3m/s or 1ft/sec) with a drag chute or "drogue". As the system travels through the pipe, the highly sensitive acoustic detector head continuously "listens" for the distinctive noise of a leak that is generated by the escape of under-pressure water. Leaks as small as 1L/hr (0.25 gallons/hr) are identified in real time by a processor at the insertion point (see Figure 14).

Once a leak has been detected, the sensor head can be stopped at the precise position of the leak. The magnitude of the leak is then estimated by the operator through quantification of the acoustic signal recorded by the sensor. The location of the leak within the main is surface located using TUE's PipeSpy2000™ precision locator unit and accurately marked for subsequent excavation and repair. The Sahara system is best suited to work in relatively straight pipelines where deployments of up to 2km from a single insertion point are possible.

Prestressed Concrete Cylinder Pipe (PCCP)

Integrity Monitoring System

The recent development and application of technologies to inspect and monitor prestressed concrete cylinder pipe has provided new opportunities to manage deterioration in these large-diameter water and wastewater pipelines. Previously, little information was available about the extent and rate of deterioration of the prestressing wires in this type of pipe. Engineers had to rely on visual inspection and corrosion surveys to try to identify pipes approaching a critical structural condition, which could then only be confirmed through excavation and forensic examination.

Table 1: Structural Integrity Monitoring (SIM) Technologies for Water Mains

Summary of NDE-method Issues that Affect Technique Selection for Various Water Pipe Materials (Dingus et al., 2002)			
Inspection method	**Pipe material**	**Defect types**	**Notes**
Acoustic emission	Pretensioned or prestressed concrete pipe	Breaks in reinforcing steel Slippage of broken reinforcement Concrete cracking	Pipe not removed from service Hydrophones left in place for several days to weeks
Electromagnetic	All metallic pipe	Cracks	Commercial, off-the-shelf availability Detect environmental conditions that are likely to weaken pipe Does not directly inspect pipe Totally noninvasive
Impact echo	Concrete pipe containing steel	Delaminations and cracks at various concrete/mortar/steel interfaces	Requires dewatering and human access to interior of pipe Can be done externally if exterior access available
RFEC (Remote Field Eddy Current)	All metallic pipe	Changes in metal mass, graphitization Wall thinning Gouges Large cracks	Commercial, off-the-shelf availability Pig travels through pipe via water hydrants May require cleaning before inspection Pig may dislodge material from pipe wall, requiring flushing
Seismic	All concrete pipe	Reductions in concrete modulus because of aging Reductions in concrete compression as a result of breakage or slippage of reinforcing steel	Requires dewatering and human access to interior pipe
Ultrasonic	All metallic pipe	Detection of wall thinning	Not commercially available for water pipe Does not require dewatering of pipes Developed for inspecting oil or gas pipelines— systems are long, inflexible, and expensive

Now, however, electromagnetic inspection can provide a good approximation of the number of wires that have failed in a given pipe, and continuous acoustic monitoring can identify and locate wire breaks as they occur during the monitoring period. This information has been used to identify and replace severely distressed pipe and to assist in the development of repair or replacement programs. However, with few exceptions, this high-quality data is currently used only as part of a static approach, that is, information is collected from periodic electromagnetic inspection surveys or short term monitoring programs and decisions are made on the basis of an analytical or subjective assessment of risk of failure at that particular point in time. This can lead to the adoption of inadequate or over-conservative mitigation strategies.

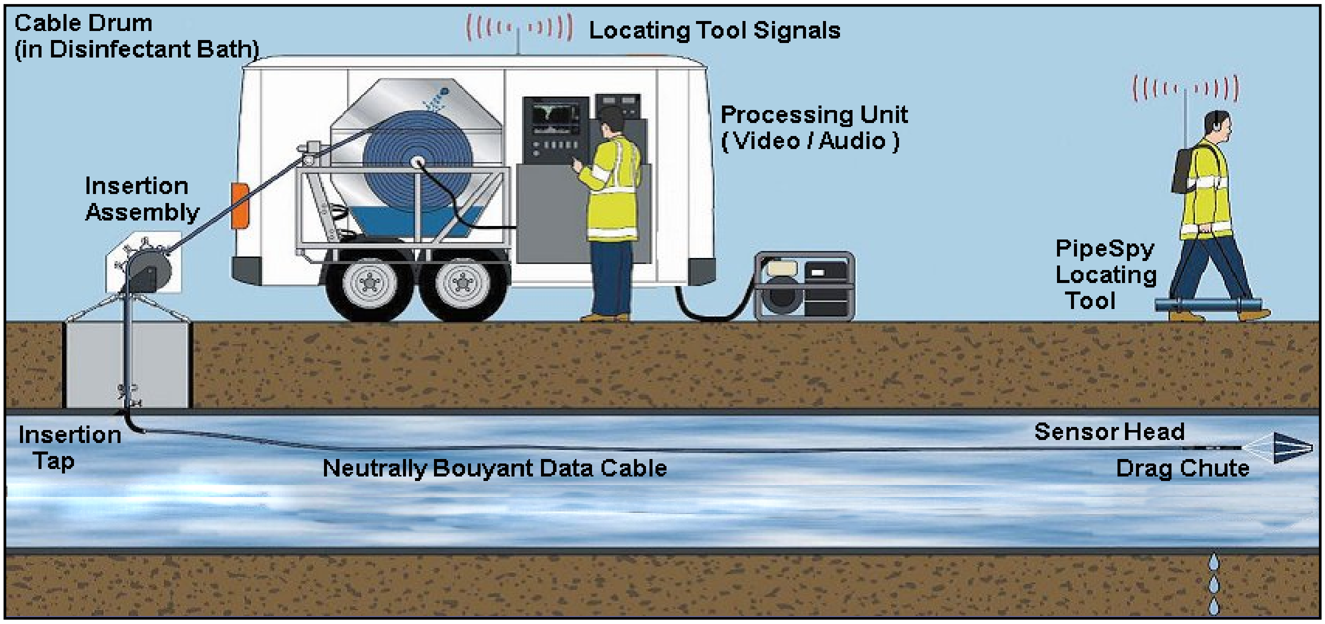

Figure 14 -- Sahara Leak Location Schematic

The combination of electromagnetic inspection, long-term acoustic monitoring and comprehensive risk management modeling provides an assessment of time to failure for each pipe while protecting against spontaneous rupture. The integration of this information into a comprehensive database with an intuitive interface allows agencies to optimize PCCP management and offers a more cost-effective solution to assuring pipeline integrity. A schematic of this process is shown in Figure 15.

Breakout Questions & Answers

During this session, five questions were addressed for each of the two technologies during the breakout session. These are presented in the following sections.

1. What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?

As with any new technology acceptance involves a lengthy period of evaluation and assessment. This is especially true in the public sector where the stake holders are averse to taking risks and quite rightfully so. The manager of a public asset has the singular responsibility to protect and maintain the asset in a cost effective manner. Strategies that have significant rewards, but also carry significant risks, are not always in the greater public interest especially as related to critical assets such as drinking water and wastewater.

Through the discussions in the Breakout Session the following action steps were recommended to assist new/emerging technologies in gaining widespread acceptance:

- Be clear as to the current state of the technology in terms of cost, performance, capabilities, and limitations.
  - Is the technology in the development/pilot stage, or is it ready for the market?
  - What are the limitations? (What can it do, and where would it be inappropriate to use the particular technology? Don't try to be everything to everyone)

- Independent Testing
    - Can the claims in terms of the technologies capabilities, cost, reliability, etc. be verified through independent testing protocol?
- Partner with a University/Professional Organization
    - Partner with a University or an organization like CERF (Civil Engineering Research Foundation) to develop, demonstrate, test, and assess the technology.
- “Flagship” projects
    - One of the best ways to gain market entry is to take on a select few, “flagship” projects to demonstrate the use of the technology.
    - The success of these projects can be touted through presentations, papers, publications at conferences, workshops, and the like.

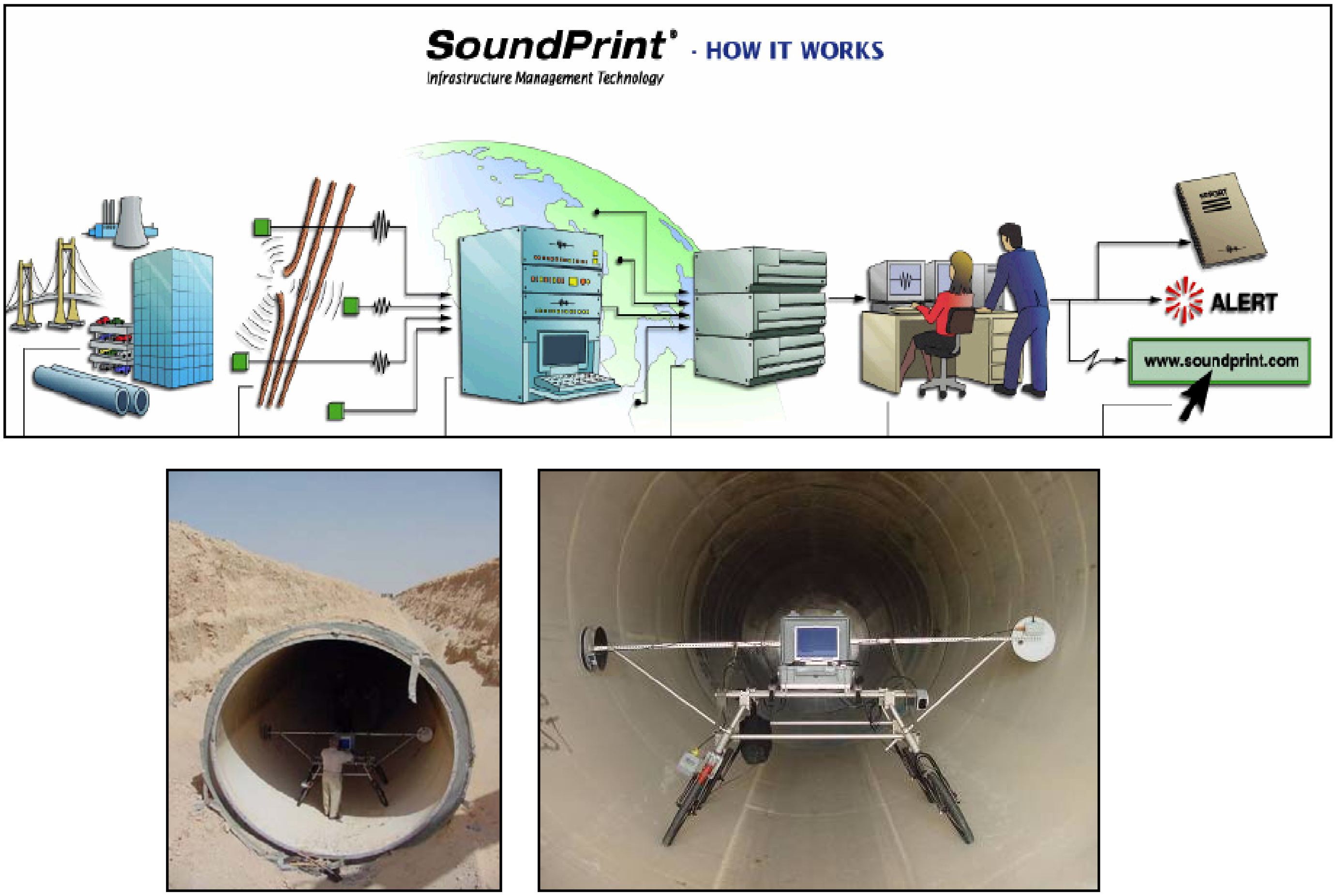

Figure 15 -- Electromagnetic Inspection and Acoustic Monitoring using Hydrophones

2. What are the key technical issues preventing acceptance of the emerging technology?

The “key” issue that emerged through the discussions in the Breakout Session regarding the technical issue preventing acceptance of new watermain inspection/assessment technologies, was the need to come up with a solution that allows testing “live lines”. Managers of assets were very strong in this opinion that taking a line out of service to carry out an inspection was not an option they could live with. The implication of this requirement is that the design standards must change in order to take into account the need for periodic evaluation e.g. size and location of taps/access points into the mains, limiting number of sharp bends in the pipeline, etc.

3. **What organizations (public or private) could assist with the Technology Transfer Process?**

There are many opportunities to interact with federal agencies and professional organizations to accelerate the evaluation and transfer of new technology for water pipeline applications.

Many Federal agencies are conducting SIM research or have SIM research capability. However, their focus is usually not water pipeline applications, but rather natural gas or hazardous chemical pipelines, other structures, or other applications. Within EPA's Office of Research and Development (ORD), the National Risk Management Research Laboratories' (NRMRL) Water Supply and Water Resources Division (WSWRD) is responsible for distribution systems research. An important role for WSWRD can be to educate other agencies about research needs and priorities for water mains SIM research. EPA can also pursue collaboration on relevant SIM projects where common ground exists. EPA and the U.S. Department of Defense (DOD) recently completed one interagency agreement on intelligent systems for conveyance and storage systems. Opportunities for follow-up collaboration exist on related projects and programs with DOD (e.g., smart materials and pipelines), DOE (e.g., smart pipes, Intellipipe™, and smart cities), the National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce (DOC) (e.g., smart layer technologies), and DOT (e.g., intelligent pipelines for system reliability). The DOE's Strategic Center for Natural Gas and Oil (SCNGO) and the DOT's Office of Pipeline Safety (OPS), have leading roles in promoting, funding, and performing short-term and long-term SIM research, development, and demonstration projects for gas and hazardous liquid pipelines. Between DOE and DOT there are over 40 active structural integrity management technology projects. DOE's FY-03 budget for gas pipeline integrity research is about $7 million.

The National Science Foundation (NSF) is a major supporter of research to improve sensors for civil and other systems. Other federal agencies, such as DOD, NIST, and the National Aeronautics and Space Administration (NASA), are also funding or performing multiple research projects that are directly or indirectly applicable to improving structural integrity monitoring for pipelines or other structures. The U.S. Bureau of Reclamation (USBR) previously supported research on a subsequently commercialized system for acoustic monitoring of structural integrity of prestressing wires in prestressed concrete cylinder pipe (PCCP).

Complementing non-federal SIM technology research is another route for ORD/NRMRL/WSWRD to accelerate the evaluation or development of improved water main SIM technology. ORD/NRMRL/WSWRD can cooperate with the user community (e.g., AwwaRF, individual utilities) to define these requirements by expert workshop and/or survey. The expectation is that once the target performance and cost requirements are defined, it will become clear that: (1) achieving next-generation SIM requirements will require research activity that covers the full range of possibilities from fundamental research to verification of commercialized SIM technologies, (2) private sector research resources alone cannot address all high priority SIM approaches and pipe scenarios in an expeditious manner, and (3) ORD/NRMRL/WSWRD and other federal research resources (e.g., personnel, facilities, funding) can be invaluable for significantly accelerating the completion of SIM improvement research. Based on the consensus cost and performance targets, ORD/NRMRL/WSWRD can conduct complementary research and can also promote within the federal research sector the inclusion of next-generation SIM needs in federal research, development, demonstration or verification activities.

ORD/NRMRL/WSWRD can also work with non-federal organizations to investigate high-benefit technologies that are typically too high-risk for user community and other non-federal research programs. AwwaRF and specific utilities with active research programs are key user community research organizations, and their research focuses directly on water main applications. AwwaRF receives federal funding (e.g., $4.8 million in FY-04 from EPA) for research, but only a portion of these funds are applied to AwwaRF's infrastructure reliability (IR) program, and only a portion of the IR program addresses SIM evaluation or improvement. Given the range of unmet research needs, AwwaRF research support alone is insufficient to address SIM capability improvement. Foreign research efforts in water main inspection and condition assessment, particularly in Europe, Canada, and Australia offer collaboration opportunities.

The Water Environment Research Foundation (WERF) is another potential collaborator to the extent that common ground can be found between SIM research needs for wastewater mains and drinking water mains. AwwaRF, WERF, and EPA are currently cooperating to issue an RFP (Protocols for Assessing Condition and Performance of Water and Wastewater Assets, WERF Request for Proposals No. 03-CTS-20CO). Other relevant research entities include the private sector (e.g., inspection device manufacturers and service providers), academia, private research organizations, non-profit research organizations, and various partnerships and consortia that are producing and evaluating components or systems potentially relevant to drinking water mains SIM.

EPA/ORD already has several programs that can potentially support SIM research for water mains, but so far these programs have not been applied in a coordinated manner for that purpose. The ORD programs that are the prime candidates for collaborative efforts include ORD/NRMRL/WSWRD distribution system research program and the Environmental Technology Verification (ETV) program; the National Center for Environmental Research's (NCER) Small Business Innovation Research (SBIR) program; the National Homeland Security Research Center (NHSRC), and the Office of Science Policy's Federal Laboratory Consortium (FLC) project.

ASCE established its research affiliate, the Civil Engineering Research Foundation (CERF); in 1989 to *"facilitate, coordinate and integrate"* research for the civil engineering profession and the design and construction industry, and to help expedite the transfer of innovation into practice. In January 2006, ASCE re-engineered the mission of CERF to "strengthen the profession and industry through technical innovation and public policy," through the establishment of the Civil Engineering Forum for Innovation (CEFI). Recently Susan H. Skemp was appointed the executive vice president of the newly formed CEFI. Ms. Skemp will be responsible for leading the CEFI organization and developing programs and initiatives to support and expand the CEFI in its efforts to influence research and development initiatives within research agencies, private practice and academia.

4. **Are there any specific people who should be contacted to assist with the emerging technologies?**
   The discussions in the Breakout Session focused chiefly on organizations/agencies as opposed to specific individuals.

5. **Are there any funding sources that can be approached to assist in the implementation process?**

See Item 3.

Conclusions and Recommendations

- SIM capability improvements will provide multiple public benefits, so there are multiple reasons for public agencies to support Research, Development, Training, and Validation (RDTV) in this area.

  Substantial improvements to the state-of-the-art of structural integrity monitoring will yield health, water quality, water conservation, asset management, and economic benefits to water utilities and the public. These benefits will occur over both the short-term and the long-term. The most obvious health-related benefit will be reduction in preventable high risk water main breaks and their associated health risks from loss of pressure, which can cause backflow and intrusion of contaminants, and suspension of contaminated sediments. Reduction in high consequence main breaks also provides a substantial economic benefit from avoided response and damage costs. Another important benefit of improved SIM capability is more optimized Repair, Rehab, and Replacement (3R) scheduling, which helps to ensure that pipes are used as long as safely possible.

- Consensus, quantitative benefit, cost, and performance targets for SIM capability improvements would be useful.

  The adoption of new technologies for water main assessment can be accelerated by attracting more attention from the federal and non-federal research community. More attention to SIM research needs can be created by generating and publicizing consensus, quantitative performance-, benefit-, and cost-improvement targets for inspection and condition assessment technologies for various critical application scenarios. These targets must be developed in close coordination with the user community and technical experts. This topic is a good candidate for an EPA-AwwaRF collaborative effort.

- Advanced structural integrity monitoring technologies and procedures should be developed first for applications where they are most likely to have favorable benefit-cost ratios.

  These application scenarios include those where main breaks are expected to produce: high consequence of failure (e.g., major adverse effects on customers, utilities, or communities) and high frequency, moderate consequence failures (e.g., earthquake-prone areas, systems with a substantial amount of deteriorated pipes).

- Government research support can be critical for addressing fragmented problems whose solution will provide public benefits.

  The technology market is fragmented into numerous smaller problems and markets for a variety of reasons (e.g., various types of pipe materials, diameters, coatings, linings, configurations, and consequences of failure). Multiple SIM technologies and procedures will require improvement to substantially improve SIM capability on a national scale. Fragmentation reduces the potential return on research investment by the private sector. The federal government has previously played an instrumental role in supporting research that led, for example, to development of acoustic methods for monitoring PCCP deterioration, and for acoustic emission monitoring of leaks.

Session 4 Breakout Report

A. Pneumatic Capsule Pipeline (PCP)

B. Corrosion Prevention of Ductile Iron Pipelines

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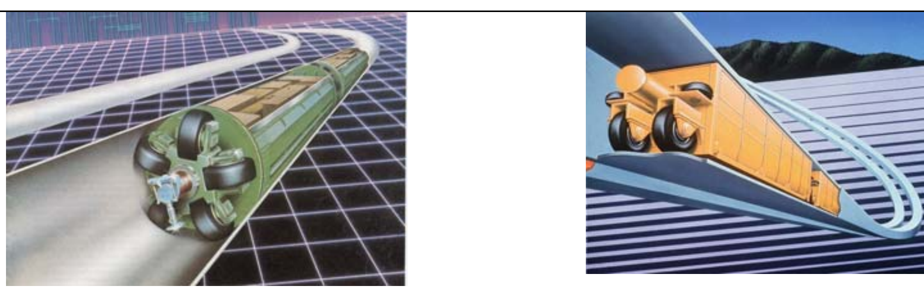
A. Pneumatic Capsule Pipeline (PCP)

Introduction & Background

Pneumatic capsule pipeline (PCP) is the modern version of the "pneumatic tube" system used commercially for over a century. Unlike the pneumatic tube, PCP uses wheeled capsules to carry heavy cargoes through large pipes or conduits, with each capsule capable of carrying more than a ton of cargo. Successful commercial use of such PCP systems in Japan since 1980 has demonstrated the technical and economic feasibility of PCP in a number of applications. Two types of PCP have been used successfully in Japan: round and rectangular – see Figure 16.



(a) Round (circular) PCP **(b) Rectangular or square PCP**

Figure 16 -- Pneumatic capsule pipeline (PCP) systems developed by and Used in Japan (Courtesy of Sumitomo Metal Industries, Ltd.)

PCP has been used successfully in Japan in several applications including: (1) transporting limestone to cement plant, (2) transporting materials in and out a large tunnel for bullet trains during construction of the tunnel, (3) transporting construction materials for highway construction, and (4) transporting solid wastes. Information on these applications and basic information on PCP are contained in various publications including a recent book [1], and an ASCE Task Committee Report [2].

All the current and past PCP systems, including those used in Japan, are driven by blowers or fans. Because capsules cannot pass through blowers or fans, such PCP system are complex in design and operation (must use complicated blower bypass or swinging pipes), and are rather limited in system throughput and maximum transportation distance. This problem was solved by researchers at the Capsule Pipeline Research Center (CPRC), University of Missouri-Columbia (UMC), through the invention of the electromagnetic capsule pump, based on the principle of linear induction model (LIM) [1-5]. The pump is non-intrusive (i.e., capsules can pass through it uninhibited), efficient, and simple. Figure 17 shows the concept of the LIM capsule pump; Figure 18 shows such a pump tested at UMC.

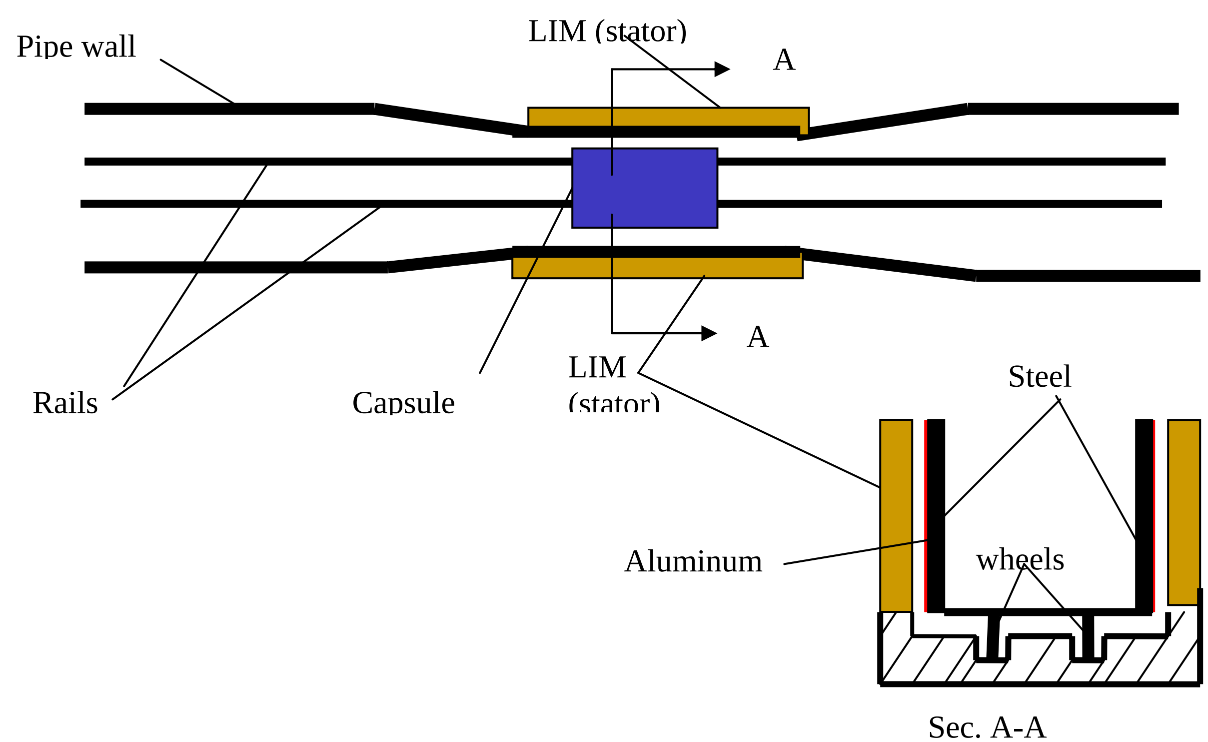


Figure 17 -- Use of LIM Capsule Pump in PCPS of Rectangular or Square Cross-Section

In 2003, the Freight Pipeline Company (FPC) in USA carried out a feasibility study of using PCP for underground freight transport in New York City [6]. Six potential applications were evaluated. While all six were found to be technically feasible, only five of the six cases were found cost-effective. The five cost-effective potential applications are: (1) tunnel construction, (2) transporting municipal solid waste, (3) transporting mail and parcels, (4) delivering goods on pallets, and (5) dispatching containers between seaports and an inland inspection/transfer station. Details of the study are reported in [6] and [7]. In 2005, FPC completed a study for the US Department of Energy (DOE), focused on an advanced PCP system that uses not only LIM capsule pump but also rails inside the conduit, with capsule running on the rails. The system, intended for transporting minerals and mine wastes, has the following advantages [8]: (1) low energy consumption – the system uses only one fourth of the energy of ordinary railroad trains and one tenth of the energy of trucks, for transporting the same cargo over the same distance; (2) can handle extremely large throughput – a PCP with 1m x 1m cross section can transport up to 50 million tons of cargo a year; (3) highly automatic, and (4) high safety and reliability.

The cost-effectiveness of the system depends mainly on throughput – high throughput makes the system cost-effective.

Figure 18 -- Test of PCP-LIM at the Power Electronic Laboratory of the University of Missouri-Columbia (From left to right, Professor Robert O'Connell and his former Ph.D student W. Plodpradista)

Sufficient knowledge and know-how exist today for the design and operation of PCP systems driven by both blowers and LIM capsule pumps. However, since PCP driven by LIM has not been used commercially and has not been demonstrated at full scale, a demonstration system must be built and tested using full-size capsules running in full-size pipe or conduits of a short length, at least a mile, before the technology can be and should be used commercially. Also, because PCP driven by LIM is a new technology, continued research to improve and optimize the technology is needed for many years to come. Research and commercial use should go hand-in-hand; there is no need to wait for the perfection of any new technology through research before using it. For instance, highway has been built and used for a century. Still, there is need for continued research to improve highway systems. When we are talking about technology transfer and commercialization of new pipeline technologies at this workshop, it would be wrong to say that "*the technology can now be used and hence needs no more research,*" nor should we say that "*let's do more research before we use this new technology.*"

The PCP technology is now ready for application in the United States in a number of applications including but not limited to the following:

- Transporting municipal and other types of solid wastes, including hazardous or even radioactive wastes.
- Transporting construction materials needed for or generated during tunnel construction.
- Transporting mail and parcels along major corridors such as between New York City and Washington, D. C.
- Transporting pallet goods in large metropolitan areas where surface transportation is congested and inefficient.
- Transporting standard containers to and from seaports to enhance port security and to reduce traffic jam, accidents and air pollution caused by trucks.

Use of PCP in the U.S. will benefit the nation in a number of ways including: (1) reduce the number of trucks that clog city streets; (2) reduce the air pollution, noise and accidents generated by trucks; (3) economic development and creating jobs; (4) increased transportation safety and security; (5). more rapid delivery of goods than trucks can; (6) greater reliability in delivering goods—unaffected by inclement weather, traffic jam, etc.; (7) energy conservation – PCP uses much less energy than trucks do; and (8) reduced dependence on foreign oil.

Breakout Questions & Answers

During this session, five questions were addressed for each of the two technologies during the breakout session. These are presented in the following sections.

1. **What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?**

Actions that will accelerate the implementation and the acceptance of PCP include:

- Increase dissemination of information on PCP not only within the pipeline industry but also to transportation planners, providers, and policy makers;
- Educate the general public about this new technology and how it can benefit the public;
- Lobby the Congress to establish an R & D program on PCP, or to include PCP in the R & D of “intelligent vehicles” for solving highway congestion problem;
- Encourage more professors to do research in PCP; and
- Persuade large construction companies such as Bechtel, Brown & Roots, or Jacob to take a strong interest in this new technology, and to set up an special group to implement it
- Find/create opportunities to use PCP in the US and around the world.
- Build partnership between large potential beneficiaries of implementing the PCP system, such as Wal-Mart, UPS, Federal Express, mines, quarries, port authorities, and Federal and state governments, to fund needed further R&D and demonstration.

2. **What are the key technical issues preventing further acceptance of the emerging technology?**

The advanced PCP system that uses linear induction motors (LIMs) and wheeled capsules running on rails in pipelines must first be demonstrated in a large project that will cost approximately from $10 to $20 million depending on project scope before the technology can be used successfully commercially. No such demo project has been conducted or planned so far. This is the single technical hurdle preventing the implementation of PCP commercially. Government sponsorship or co-sponsorship of such a costly project is necessary because the system, once demonstrated, will benefit the public in many ways. In addition, private companies alone will be reluctant to undertake such heavy investment without strong government involvement and support.

The stated reason by the US department of Transportation (DOT) for refusing to fund the needed PCP demo and R&D is that PCP will be used primarily by private firms. However, DOT funds R&D in roads and infrastructure that are used by both public and private sectors. In addition, PCP will be used as a common carrier to transport goods for both private sectors and the government (including military, US mail and parcels, etc.), and it brings the above-cited benefits for the public at large. It will create enormous new opportunities and new businesses to many sectors of the economy and significantly reduce our dependence on foreign oil.

3. **What organizations (public or private) could assist with the technology transfer process?**

ASCE can significantly help in bringing this new technology to commercial use; two things that through which ASCE can help are:

- Educating the public and the Congress about the capability and the benefits of using the PCP technology
- Lobbying the Congress for providing funding ($20 million) to the DOT budget to sponsor the aforementioned PCP demo project, and to sponsor a parallel research program on PCP ($10 million).

ASCE should not only assist but become the leader or champion of this new technology because: (1) This is an important new technology in transportation infrastructure, an area that belongs to civil engineering profession, (2) use of this technology in the future will greatly benefit the public, and (3) use of this new technology in the future will greatly benefit the civil engineering profession. It will create enormous new opportunities and new businesses to many sectors of the civil engineering profession such as pipeline, construction, tunneling, trenchless technology, geotechnical engineering, structures, and transportation planning.

4. **Are there any specific people who should be contacted to assist with the emerging technology?**

The President of ASCE (Dennis Martenson), the President Elect of ASCE (William Marcuson III), and the Executive Vice President of the Engineering Forum for Innovation (CEFI) (Susan Skemp), should be contacted and made aware of the need for enlisting their help to bring the PCP technology to the attention of the Congress and DOT officials.

5. **Are there any funding sources that can be approached to assist in the implementation process?**

The ASCE endorsement to such technology is significant; this endorsement provides credibility that facilitates the interaction with potential funding entities to sponsor a demonstration project of the advanced PCP system. After this endorsement, the U.S. Department of Transportation, port authorities, and high volume shipping entities in the US and overseas should be approached to form a funding coalition for such high initial cost and high impact technology.

Conclusions and Recommendations

Pneumatic capsule pipeline (PCP) can play a major role not only in freight transportation but also in solving a major transportation problem that faces the nation: traffic jam and accidents on highways and streets, and the resulting air pollution and waste of energy and time generated by stalled or slow-moving surface vehicles. The conventional PCP systems driven by blowers has only limited potential for commercial application in the U.S. because capsules cannot pass through the blowers, which renders the PCP systems inefficient and not cost-competitive with trucks and railroads in most circumstances. In the last two decades, a revolutionized PCP system driven by linear induction motor (LIM) has been developed in the U.S., which greatly enhances the capability and the cost-effectiveness of PCP systems. However, the technology cannot yet be used without first being demonstrated at full-scale, which is costly and risky business for private companies to undertake without government sponsorship or partnership. Therefore, for this new technology to be first used in the U.S., it is necessary for the U.S. government (i.e., the Congress and the U.S. Department of Transportation) to sponsor a demonstration project of such an advanced PCP system, costing about $20 million. A complimentary research program of $10 million is also needed to assist in the commercialization of this new technology. ASCE leadership is needed in bringing this new technology to the attention of the Congress, transportation officials, and the general public.

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B. Corrosion Prevention of Ductile Iron Pipelines

Introduction & Background

After nearly three years of collaborative work, a nine member team of engineers from Corrpro Companies, Inc. (Corrpro), the Ductile Iron Pipe Research Association (DIPRA), and DIPRA's member companies have developed a new technology/tool referred to as the Design Decision Model™ (DDM™) for defining corrosion protection requirements for ductile iron pipelines. While the subject of corrosion protection of iron piping has been a sometimes contentious industry issue for many years, the feeling of the industry leaders involved was that utility owners, the engineering community, and the public would benefit from some significant meeting of the minds regarding this issue. The Design Decision Model that resulted is basically a "consequence" vs. "likelihood" (contemporary risk matrix) model that, in specific areas, goes into more detail than the current analyses and recommendations of related ANSI/AWWA, ISO and ASTM standards (e.g. refer to the appendix to ANSI/AWWA C105/A21.5, Polyethylene Encasement for Ductile-Iron Pipe Systems).

The Design Decision Model was built essentially on decades of data and experience of Corrpro, DIPRA, and member companies (both in the laboratory and, perhaps more importantly, the field) It was also built on hundreds of years of combined individual experience of the team members and an experienced third-party statistician. This research included digesting new and definitive research on corrosion rates and innovative concept research dealing with "life extension" corrosion protection currents. The research demonstrates that ductile iron pipe can be effectively protected in some corrosive environments with a much lower magnitude of design current density than commonly applied to steel oil and gas pipes.

After full analysis of available data, research, and experience, the team agreed that there are important and basic technical and logistical differences between cast ductile iron pipes used typically for water/sewer and the mill-rolled and fabricated steel pipes used typically for regulated petro-chemical and gas pipelines. The differences in products include the nature of the external surface and corrosion-resistance value of the annealing oxide layer on ductile iron pipe, as well as the nature of the AWWA standard asphaltic coating for ductile iron pipe compared to the standard offerings for steel pipe. It was also further understood that, in general, very aggressive surface preparations, e.g., as commonly required for bonded coatings on steel pipes, can cause prohibitive bonded coating problems when attempted on the exterior of ductile iron pipes (due to the annealing oxide layer). Difficulties also are found in the application of certain bonded coatings because of the prominent peen pattern found on the outside surface of cast ductile iron pipe.

All of this past and present research was considered and led to the development of the DDM. Defined "likelihood factors" considered in the DDM include soil properties of resistivity /conductivity, moisture content, groundwater influence, pH, chloride ion concentration, sulfide ion concentration, redox potential, presence of bi-metallic connections and other known corrosive environments such as stray currents etc. DDM "consequence factors" include pipe diameter/size, pipe repair considerations, depth of cover, as well as availability of alternate water supply/looping etc.

According to DDM decision matrix input/results, the resulting corrosion protection scenarios for a minimum of 100 years of useful service life for ductile iron pipelines include:

- Standard Coating (AWWA C151 Asphaltic)
- Polyethylene Encasement (per AWWA C105)
- C105 Wrap + Bonded Joints
- Bonded Joints + Life-Extension Current (with or w/o C105 Wrap)
- Cathodic Protection

1. What actions/steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?

- Education in the area of differences in applications (water/sewer and petro-chemical and gas pipelines) and between ductile iron and steel pipe, necessitating different approaches to problem.
- Eventual incorporation in a standard or revision to standard of the aspects of DDM not now covered in existing standards

2. What are the key technical issues preventing further acceptance of the emerging technology?

- Overcoming the paradigms of some corrosion engineers or other authorities built on conventional training developed in the regulated pipeline (oil and gas) environment, poor experiences with unprotected pipelines installed in corrosive environment without any corrosion protection, or experience with steel pipes etc.
- Lack of experience in some areas with ductile iron pipes.

3. What Organizations Might Assist With Technology Transfer Process?

- Interested Utilities/Cities/Organizations
- Educational Institutions
- Asset Management/Asset Managers
- DIPRA and Member Companies
- Corrpro

4. Are there any specific people who should be contacted to assist with the emerging technology?

- Mr. Dale Lindemuth, Director of Engineering of Corrpro E-mail: dlindemuth@Corrpro.com ph: 713/460-6000 fax: 713/460-6060
- Mr. Richard Bonds, Research and Technical Director of DIPRA E-mail: rbonds@dipra.org ph: 205/402-8700 fax: 205/402-8730

5. Are there any funding sources that can be approached to assist in the implementation process?

- Research and development work to date has been funded by Corrpro and DIPRA, and the method is currently proprietary.
- Implementation of some aspects of the DDM in some circumstances could involve some engineering and maintenance services of value to Owners and the public; therefore, future sources of funding might be explored as required for such services.

Conclusions and Recommendations

The Design Decision Model (DDM) for establishing corrosion protection requirements for ductile iron pipelines is a new tool. DDM is partially based on new corrosion-related research; however, it is also based on many decades of research and experience of the parties involved.

References

In addition to the above-cited contact individuals, the following papers provide more details:

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Session 5 Breakout Report

Horizontal Directional Drilling and Alternative Pipe Materials for Trenchless Technology

Brian Dorwart, PE, PG, Vice President, Haley & Aldrich, Inc., Manchester, NH

Breakout Participants

Facilitators: Brian Dorwart and Collins Orton
Report Leader: Mohammad Najafi (The University of Texas at Arlington)
Recorder: Maryam Ajami (Graduate Student at Michigan State University)
Participants: Shahrzad Namini and Mark Trujillo

Introduction and Background

Based a review of Horizontal Directional Drilling (HDD), completed projects with owners and contractors indicating significant problems in more than 50% of the projects, it is apparent that HDD is still an emerging technology although there is approximately 40 years of construction experience in certain applications with this technique. The purpose of this portion of the symposium was to assess present conditions and develop areas and techniques for improvement to assist in further development of the technology.

Problems include: different performance expectations between the owner, the engineer, and the contractor; project permit conditions that can not be met HDD technology; lack or proper or limited pipe material choices, un-constructible or inappropriate designs; difficulties with locating existing utilities and characterizing subsurface conditions; lack of contractor and inspector training and certification, poor contract documents and technical specifications, and contractors who do not follow project specifications and contract documents properly. Results include disputes and legal actions, loss of future HDD work in certain areas, regulatory fines, and additional cost to owners. Since the telecom boom of the 80's and 90's, manufacturers, contractors, and a few engineers, have developed a significant tool box of equipment and techniques to address problems and to reduce project risks. However, there is still considerable learning required amongst all parties before HDD is no longer considered an emerging technology.

Current practices and a presentation of new developments preceded discussions regarding further research needed for acceptance of HDD in the general market. In summary:

1. HDD as a construction method may be considered in any application where a small tunnel is needed to provide a pathway for a conduit. Present industries that use HDD include:
    a. Gas and oil pipeline transmission,
    b. Power transmission,
    c. Communications
    d. Municipalities for water, and sewer, and
    e. Industrial applications

2. HDD is an underground project therefore it is a high-risk operation resulting from increased chance of occurrence for potentially expensive issues such as:
    a. Change conditions as the majority of the project is out of sight and through subsurface conditions difficult to economically characterize,
    b. Product design for short and long term loads.
    c. Adherence to permit conditions.
    d. Damage prevention to surrounding utilities, adjacent structures, and environment.

3. New areas of research for HDD technology include:
    a. Intersect casing and drill path drilling to extend the length of an installation,
    b. The concept of Annular Pressure Curves and Formation analyses and curve development to manage drill fluid loss during construction.
    c. Tracking accuracy,
    d. Drill rig capabilities,
    e. Drilling methods to match the ground and project conditions,
    f. Drilling tools and equipment such as drill bits, hole openers, and drill fluids,
    g. Grouting technology to fill HDD abandoned boreholes, and annular spaces, and more accurate Subsurface Utility Engineering (SUE) for utility locates.
    h. Development of new pipe materials which is currently limited to steel, HDPE, PVC, and in some cases clay, polymer concrete and fiberglass pipe.
    i. Training and certification courses for engineers, inspectors and contractors (specifically HDD operators).

Discussion & Results

The symposium focused on five questions to help define the present conditions and problems, determine available resources, and suggest areas of further study to expedite the successful development of the technique. This report provides a summary of thoughts associated with these five questions based on the experience, thoughts, and comments of the attendees.

Breakout Questions & Answers

During this session, five questions were addressed for each of the two technologies during the breakout session. These are presented in the following sections.

1. **What Actions/Steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?**
   Educations of owners, engineers, contractors, permit engineers, and regulators regarding the HDD process.

2. **What are the key technical issues preventing further acceptance of an emerging technology?**
    1. Technical failure of projects that have resulted in environmental damage, product failures, not meeting expectations of project owners, and other difficulties.
    2. New technology requirements with respect to public works projects, such as gravity installations, and accuracy requirements.
    3. Cost estimating failures during the planning phase resulting in significant budget overruns.
    4. Lack of owner and engineer training and experience.
    5. Poor contracting practices including appropriate risk allocation.
    6. HDD and other emerging technologies are currently considered by many engineers and project owners to be more expensive than traditional technologies (such as open-cut) and this mind set has led to elimination of these technologies at the planning and design stage of the project. However, HDD and other emerging technologies, provide less "social costs," which if considered during the planning and design phase, they may become more cost-effective than traditional methods. Therefore, alternative bidding strategies are needed to include accepted procedure for assessing social impact and environmental costs and provide a "life-cycle-cost" approach to project planning, design and budgetary and cost estimation of the project.

3. **What organizations, both public and private, could assist with the technology transfer process?**
    1. ASCE
    2. AWWA
    3. Universities and Research Centers such as TTC and CUIRE
    4. IEEE
    5. EPA and NSF
    6. State environmental agencies
    7. Federal and State DOT's
    8. Municipal employee technical support organizations
    9. CGA
    10. TTC
    11. ASTM
    12. ASME
    13. CUIRE
    14. Construction Insurance Industry
    15. Construction Bonding Industry
    16. Material Supplier Organizations like PPI etc.
    17. NASTT and associated organizations
    18. AGC
    19. State and Local Governments -- Municipalities
    20. NUCA

4. **Are there any specific people who should be contacted to assist with the emerging technology?**

    The specific individuals that would have a significant impact would include: Dr. Tom Iseley, Dr. Ray Sterling, EPA, state DOT's, NSF and professional and trade associations, such as ASCE directors.

5. **Are there any funding sources that can be approached to assist in the implementation process?**
    1. EPRI
    2. FHWA & TRB
    3. COE
    4. EPA
    5. ASCE
    6. NSF
    7. US DOT and state DOT's

Conclusions and Recommendations

Pipe Selection – This is a difficult problem for many engineers as owners often control the selection process and selected products have different issues with regard to installation with HDD methods and other emerging technologies. Owners, due to many reasons, that may include technical or non-technical issues (owner's culture, previous use and experience with a specific type of pipe material, ease of use, previous failures, etc.) may promote or ban a specific type of pipe material. However, there is no document that provides a reasonable comparison of the pipe products that may be installed by HDD, the limitations of the various pipe materials, or the appropriate design method for assessing short- and long-term loads applied to a pipe material.

Qualifications – There are many inexperienced engineers and contractors offering HDD services. Many of these projects can have significant problems. The owner needs to be educated in the importance of having a qualified project team and how to interview and pre-qualify engineers and contractors for their project.

Training – There are a few training opportunities available for contractors, engineers and inspectors, but no uniform and centralized training and certification process are available. Many engineers and contactors do not get involved with training of other engineers and contractors because of "competition issues," and keeping "business secrets." Universities should be encouraged to offer pipeline engineering courses for current engineers, contractors, regulators and the engineering students. Experienced organizations, such as ASCE, should be encouraged to target selected owner organizations for offering training and technical presentations in a generic format for HDD and other emerging technologies. Engineers should be encouraged to educate owners and regulators regarding realistic expectations for an HDD project. Experienced organizations should encourage creating a library of case studies that represent real situations but are sufficiently generic to protect participants. The ASCE has developed a series of case studies that would provide excellent examples of how to set up these case studies. These studies could then be distributed to various owner and regulator organizations as examples of what can happen with an inexperience project team. The objective is to develop realistic expectations and to provide a basis for defining reasonable and prudent owner, engineer, and contractor practices.

Social Costs – Social costs are often associated with managing a risk based design and considering the life-cycle-costs of a project. It would be very desirable to develop a risk based design process for HDD that includes life-cycle-costs and social cost assessment of the project. This approach may lead to alternative biding strategies by contractors.

No Design Standards or Standard Engineering Approach – Except for ASCE Manual of Practice No. 108, there is no other design standards or planning approach for HDD projects. Different industries have significantly different requirements for creating a successful project. Each industry should have a design guideline available to permit better project planning and uniformity in design and construction.

Performance Specifications – The HDD method is very specialized. While method determination is best determined by an experienced engineer, engineers should not get involved in the selection of means and methods of construction. Performance specifications should be the recommended procedure for guiding a contractor for the work not method specifications. It would be good to develop an outline of accepted performance specification for each industry that could possibly be used similar to CSI format for writing specifications. As a part of performance specifications, it would be desirable for a team of representatives from all concerned project team members, including insurance and bonding, to develop a series of measurable items for the specifications to ensure quality and performance specific for a specific industry.

Appendices

Appendix 1:
Symposium Speakers and Facilitators

Speakers and Facilitators for the ASCE Research and Technology Transfer Symposium

Session	Name & Address	Presentation	Role
1	Michael Welch BRB Contractors, Inc. 3805 NW 25th St. Topeka, KS 66675 785.290.1125 mike.welch@brbcontractors.com	Exploitation of Utility Corridors	Speaker
1	Dr. Henry Liu Freight Pipeline Company 2601 Maguire Blvd. Columbia, MO 65201 573.442.0080 fpc.liuh@yahoo.com	Freight Pipelines	Speaker
1	Michael Yen Sekisui SPR America 2243 Jefferson Drive Atlanta, GA 30350 770.396.1246 Michael.yen@sekisui-spr.com	SPR Technology for Pipe Rehabilitation	Speaker
1	Grant Jameson Entec 24, 12110 40th St. SE Calgary, Alberta T2Z 4K6 CANADA 410.319.0443, ext. 1 Grant.jameson@entec.com	Enhancements to Horizontal Directional Drilling Equipment	Speaker
1	Steven Kramer Jacobs 1100 North Glebe Rd., Suite 500 Arlington, VA 22201 571.218.1446 steven.kramer@jacobs.com		Moderator & Symposium Chairperson
2	Dr. Brian Mergelas Pressure Pipe Inspection Co. 4700 Dixie Rd. Mississauga, Ontario L4W 2R1 CANADA 905.624.1040 Mergelas@ppic.com Mark Holley Pure Technologies 10015 Old Columbia Rd., Suite B-215 Columbia, MD 21045 410.309.7050 Mark.Holley@soundprint.com	Condition Assessment:	Speakers
2	Collins Orton TT Technologies 2020 E. New York St. Aurora, IL 60502 800.533.2078 pipedr96@aol.cm	Alternative Pipe Materials for Trenchless Technology	Speaker

Session	Name & Address	Presentation	Role
	Dr. Sam Ariaratnam Arizona State University P.O. Box 0204 Tempe, AZ 85287 480.965.7399 Ariaratnam@asu.edu		
2	Paul Fisk NDT Engineering 67 Millbrook St. Worcester, MA 01606 508.754.0417 Paul.fisk@ndtcorporation.com	Geophysical Ground Imaging	Speaker
2	David Kroon Corrpro 7000 B Hollister Houston, TX 77040 713.460.6000 dhkroon@corrpro.com	Corrosion Prevention of Ductile Iron Pipelines	Speaker
3 & 4	Dennis Doherty Jacobs Two Center Plaza Boston, MA 02108 617.742.8060 dennis.doherty@jacobs.com		Facilitator
3 & 4	Paul Savard Jacobs Two Center Plaza Boston, MA 02108 617.742.8060 paul.savard@jacobs.com		Facilitator
3 & 4	Tony Almeida Halff Associates, Inc. 8616 Northwest Plaza Dr. Dallas, TX 75225 214.346.6345 talmedia@halff.com		Facilitator
3 & 4	Randy Conner American Cast Iron Pipe Co. P.O. Box 2727 Birmingham, AL 35202 205.325.7946 rconner@acipco.com		Facilitator
3 & 4	Brian Dorwart Haley & Aldrich 340 Granite St., 3rd Floor Manchester, NH 03102 603.391.3329 bcd@haleyaldrich.com		Facilitator
3 & 4	Dr. Jey Jeyapalan 9 Sundance Rd. New Milford, CT 06776-3840 860.874.7345 jkjeyapalan@earthlink.net		Facilitator

Session	Name & Address	Presentation	Role
3 & 4	Dr. Mohammad Najafi, P.E. Director, Center for Underground Infrastructure Research & Education (CUIRE) Coordinator, Construction Engineering & Management Department of Civil & Environmental Engineering The University of Texas at Arlington Box 19308 -- 438 Nedderman Hall Arlington, TX 76019-0308 Phone: 817-272-0507, Fax: 817-272-2630 Email: najafi@uta.edu www.cuire.org		Facilitator & Editor
3 & 4	James Chae Jacobs 600 108th Ave., NE, Suite 700 Bellevue, WA 98004 425.452.8000 james.chae@jacobs.com		Facilitator
3 & 4	Collins Orton Product Specialist TT Technologies 2020 E. New York Street Aurora, Il 60502 800.533.2078 pipedr96@aol.cm		Facilitator
3 & 4	Dr. Henry Liu, P.E. Freight Pipeline Company 2601 Maguire Blvd. Columbia, MO 65201 573.442.0080 fpc.liuh@yahoo.com		Facilitator
3 & 4	Dr. Anil Misra, P.E. Professor of Civil Engineering University of Missouri-Kansas City 350H Flarsheim Hall 5100 Rockhill Road Kansas City, MO 64110 816.235.1285 Misraa@umkc.edu		Report Leader
3 & 4	Dr. Samuel T. Ariaratnam, P.E. Associate Professor Ira A. Fulton School of Engineering Arizona State University P.O. Box 870204 Tempe, Arizona 85287-0204 (480) 965-7399 samuel.ariaratnam@asu.edu		Report Leader
3 & 4	Dr. Sanjiv Gokhale, P.E. Professor/Dir. of Construction Management Program Department of Civil & Environmental Engineering Vanderbilt University VU StaB 351831, Nashville, TN 37235 615.322.5919 s.gokhale@vanderbilt.edu		Report Leader

Appendix 2:
Participant Guidelines

Participant Guidelines

ASCE Pipeline Research and Technology Transfer Symposium

Sheraton Hotel, Chicago, IL

Sunday, July 30, 2006

1) In the morning sessions (Sessions 1 and 2), each speaker will provide a 15 minute overview of his emerging technology and answer questions. These will be fast paced presentations to give attendees a general understanding of the technologies. A PowerPoint presentation is recommended. It is also suggested that each presentation be about 10 minutes with 5 minutes for follow-up questions.

2) A symposium summary will be provided to attendees that includes brief abstracts on the emerging technologies. Full papers are not required from presenters. Copies of PowerPoint presentations on the emerging technologies are desired as handouts for use during the afternoon breakout sessions.

3) In the afternoon sessions (Sessions 3 and 4), the attendees will be divided into five re breakout groups. Two emerging technologies will be discussed in each breakout session. It is desirable to have about 10 people per breakout session. Two Facilitators, a Report Leader and a university student to serve as Recorder are assigned to each breakout session. The facilitators will be responsible for leading a discussion on the following:

- What actions/steps are needed to assist in the implementation and acceptance of the emerging technology into the marketplace?
- What are the key technical issues preventing further acceptance of the emerging technology?
- What organizations (public or private) could assist with the technology transfer process?
- Are there any specific people who should be contacted to assist with the emerging technology?
- Are there any funding sources that can be approached to assist in the implementation process?

The Recorder's responsibility is to assist the facilitators in capturing the key ideas generated during the breakout session on flipcharts and in more detailed notes if appropriate.

The Report Leader is responsible for summarizing the breakout session in a concise report to be prepared after the symposium. Approximately a 10 page report should be prepared for each breakout session.

4) During Session 4, Facilitators will present the results of their breakout session in a mini presentation to all attendees. Depending on available time, the Facilitators will use flipcharts or PowerPoint for their presentations. The presentations will last 15 minutes. The presentations will also be summarized in the post symposium notes.

5) Post Symposium – Within 45 days after the Symposium (September 15, 2006), the Report Leaders should submit their draft reports to Steven Kramer and Mohammed Najafi by e-mail. (steven.kramer@jacobs.com and Najafi@msu.edu)

Appendix 3:
Abstracts on Presented Emerging Technologies

Fiber Reinforced Polymer Reinforcement for Pipelines

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Fiber reinforced polymer reinforcements (FRPs) are polymers reinforced with fibers that may be composed of polyester, glass, high strength carbon, and other materials. FRPs have been developed for three principal applications: 1) cast-in-place pipe (CIPP) linings to reinforce *in situ* aging pipelines and conduits, 2) crack arrestors to stop propagating ductile or brittle fractures in high pressure oil and gas pipelines, and 3) external wrap to reinforce transmission and trunk lines against external forces and/or reduced capacity in hoop stress. Each principal application involves different types of polymers, fibers, and installation techniques. A description of all three applications will be given. Emphasis will be placed on full-scale test results for CIPP linings and external FRP wrap for seismic strengthening. The application of CIPP linings in cast iron pipelines is a promising application of the technology. Reinforcing cast iron mains with FRP linings provides an internal reinforcing system that can seal the pipeline against corrosion deterioration and joint leakage, and can provide continuity of flow even when brittle cast iron mains are damaged by round cracks related to ground deformation, stress concentrations generated by external contact, and earthquake deformation.

Full-scale test results for three different types of CIPP systems will be used to illustrate and quantify improvements, and to identify key features of enhanced performance when CIPPs are applied as reinforcement against potential damage and cracking of cast iron mains. The test results and key characteristics of behavior will be drawn from research performed for the gas industry. The application of FRP reinforcement for enhancing seismic performance is illustrated in the accompanying slide (see attached PowerPoint), which shows both compressive damage to a water trunk line during the 1994 Northridge earthquake and the application of an external FRP wrap to resist outward buckling at a typical joint in water supply pipelines. Critical water transmission and trunk pipelines are constructed with welded slip joints, each of which consist of a cold-formed bell connected with a circumferential fillet weld to the spigot end of the connecting pipe. The geometry of the joint promotes local buckling that can reduce the axial compressive capacity of the pipeline to 40% of a straight section. Tests performed on large diameter water trunk lines for the Los Angeles Department of Water and Power will be presented showing that FRP external wrap restores the load carrying capacity of a pipeline with welded slip joints to 100% of the compressive capacity of a straight section.

Exploitation of Utility Corridors

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Public will benefit greatly when we exploit the power of utility corridors. They are tired of each utility designing, installing, operating, and maintaining their own trench for their service. Take for example, the cost of civil works in the last mile/FTTH, most experts quote to be in the range of 70 to 85% of the total deployment, but not if you choose the construction materials and methods right. We know how to do it a lot faster and much cheaper. Building optical fiber in dedicated conduits placed in open cut ditches to solve the last mile and the fiber glut problem cannot be done due to excessive delays, lack of permits to open cut, disruption to traffic in highly populated areas, and the enormous cost of construction. The very governmental, commercial, and residential end users who are craving for true broadband coming into their premises already have sanitary sewers, storm drains, drinking water pipes, and natural gas lines reaching their premises to meet their needs. They also have roads and electrical conduits reaching them. The fat pipe to carry infinite voice/video/data from multiple providers could be housed in these utilities by forming creative business partnerships among optical fiber owners, service providers, utility pipe owners, and vendors. Fiber could also be installed in micro-road cuts and micro-ducts. Municipalities and energy companies could even take the lead in this new paradigm in some situations, given they own and manage most these underground assets for the public. By them taking the initiatives for building the last mile fiber, they could meet the needs of FTTX, renovation of their aging pipeline infrastructure, and improved sensing, surveillance, and security of vital lifelines. The speaker will outline the pros and cons of such utility corridors and will point to several areas that need our attention to speed up acceptance of this concept of utility corridors.

Mike Welch is a civil engineering graduate from the University of Kansas and has been in underground construction for over 40 years, serves on the Board of Directors of AGC, ASTM, and several other companies and public service organizations.

Freight Pipelines

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To promote research, development and technology transfer of freight pipeline (more specifically, pneumatic capsule pipeline) for transporting various cargoes in different applications, in order to bring the technology to use in the United States as soon as possible.

Pneumatic capsule pipeline (PCP) is the modern version of "tube transport" in which large diameter pipelines (usually 1 m or larger) are used to transport cargoes that are normally transported by conveyor belts, trucks or train. It has been used quite successfully in several applications in Japan, but not in other nations. Even in Japan, so far the applications are rather limited in the number of projects using PCP, in pipeline length, and in the types of cargoes transported. This is due to a major weakness of the current systems of PCP: they all use electric fans or blowers to drive the air through the pipe. Because fans and blowers block the passage of capsules, complicated flow switching is necessary to allow capsules to bypass the fans/blowers. This not only increase the system cost but also sharply limits the capsule/cargo throughput. The linefill rate of PCP systems used in Japan is less than 3%. This means less than 3% of the pipeline is filled with cargo-laden capsules; over 97% of the line is empty. In most commercial applications, cost-effective use of PCP requires much higher linefill – over 10%, which is difficult to achieve by using fans or blowers. However, a new type of capsule pump, based on the principle of linear induction motor (LIM), has been invented in recent years for use to drive PCPs in lieu of using fans/blowers. LIM is the same principle used for magnetic-levitated trains, and newer versions of roller coasters. The LIM capsule pump is non-intrusive; it allows both air and capsules to pass through unhindered. With PCPs driven by LIMs, the linefill rate can exceed 30%, enabling the PCPs to transport ten times more capsules and hence ten times more cargoes than conventional PCPs driven by fans/blowers. It also eliminates the need for using capsule flow switch devices, thereby simplifying system designs.

A 2004 study sponsored by the New York State Energy Research and Development Authority (NYSERDA) investigated six potential applications of PCP for underground freight transport in New York City (NYC). It found that five of the six investigated cases were cost-effective (i.e., it cost less to transport freight by PCP than by current modes of freight transport in NYC). The five applications include: (1) conveying excavation materials during tunnel construction, (2) transporting municipal solid waste from transfer stations to a disposal/processing site in a rural area, (3) transporting mail and parcels between New York City and Washington D.C., including cities along the corridor, (4) transporting containers between New York Harbors and an inland container inspection/transfer station, and (5) transporting pallet goods within NYC. Such usages of PCP in NYC can bring huge benefits to the City, the State and the Region in enhancing freight transport, reducing traffic jams, lessening air pollution, and bringing about higher transportation safety and security. For instance, the 4th application mentioned above will enable all the containers arriving NYC from overseas to be dispatched through an underground tunnel/conduit to a rural area for inspection/processing, thereby allowing 100% of containers to be inspected, and greatly reducing the risk of having a container carrying explosives or a nuclear bomb detonated in the NYC Harbor.

Because PCP driven by LIM is an emerging technology that has not yet been used commercially, R&D and demonstration of this new technology are required before it will be accepted for commercial use. Technology transfer is also needed -- to transfer the technology from the developers which are either universities or small businesses to users, which are either existing pipeline companies that will design and construct the pipelines for clients, or transportation planner, who need to consider the technology for inclusion in transportation planning. Therefore, R & D, technology demonstration, and technology transfer are all important to future use of PCP in the U.S. and other nations.

During the breakout session of the Symposium, the Freight Pipeline Group will have a round-table meeting to discuss PCP focused on the following:

- Identify critical needs for R&D, technology demonstration and technology transfer in PCP.
- Identify government programs/agencies that may support the R&D, technology demonstration, and technology transfer of PCP. The role of ASCE and other engineering societies in helping to educate transportation professionals and the public about this new technology will also be explored.
- How can industry and universities form partnership or consortiums to bring the PCP technology to early commercial use.

Dr. Henry Liu is President, Freight Pipeline Company, located in Columbia, Missouri, USA. He is a former Engineering Professor and Director of Capsule Pipeline Research Center (CPRC), University of Missouri-Columbia. CPRC was a center of excellence founded by National Science Foundation (NSF) for eight years. Dr. Liu served in many leadership positions in Professional Organizations including: Chairman of both the Aerospace Division and the Pipeline Research Committee of ASCE (American Society of Civil Engineers), President of International Freight Pipeline Society (IFPS), and Chairman of Steering Committee of the International Symposium of Underground Freight Transport (ISUFT). He has received seven research awards including the Bechtel Pipeline Engineering Award and the Aerospace Technology Applications Award of ASCE. He has seven U.S. patents, and has published more than 100 technical papers and two books: PIPELINE ENGINEERING, CRC Press (Taylor & Francis Publisher), 2003, and WIND ENGINEERING, Prentice Hall, 1991.

SPR Technology for Pipe Rehabilitation

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The Sekisui SPR method consists of a rigid PVC profile which is spirally wound into an existing pipeline. Successive wraps of profile are locked together and the annular space between the liner and the existing pipe is grouted. The result is a strong composite pipe integrated with the existing pipeline. The Sekisui-SPR process has the ability to rehabilitate gravity pipe-work systems without surface excavation and with some pipeline flow. A typical entry point into the system will be from a manhole or outfall location.

The Sekisui-SPR lining process, for the rehabilitation of gravity pipe lines and culverts, utilizes an extruded poly vinyl chloride (PVC) profile strip that is machine spiral wound into an existing gravity system host pipe. The system provides precise control of the internal diameter of the newly formed PVC pipe ensuring the designed annular grout space is maintained throughout the renewal length.

The extruded profile is mechanically locked together by virtue of the profile design and the use of the Sekisui proprietary winding machine. In-built into the finished profile are joint sealing strips that prevent external and internal leakage during the installation process. The newly formed pipe-within-a-pipe is then grouted in place using a Sekisui proprietary cementitious mortar. A range of PVC profiles are available to suit a variety of host pipe sizes and shapes. For the larger sizes the PVC profile is reinforced with a steel strip and for pipeline curvatures of tight radius a specially designed PVC profile is available. The PVC profile range come with differing profile rib and thickness configurations to match project design requirements.

When completed, the spiral wound profile liner pipe shall extend from end-to-end of the section being lined as a continuous pipe-within-a-pipe. The finished specification will either a) provide a structural rehabilitation solution with improved flow coefficients and chemical resistance characteristics or b) provide improved chemical resistance characteristics with improved flow coefficients.

Enhancements to Horizontal Directional Drilling Equipment

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The HDD design objective is to produce a technically defensible design that can result in a successful drill for all parties including regulators, owners, and contractors. New technologies and a better understanding of the mechanics associated with HDD construction have significantly improved the chances of a successful drill providing they are used by an experienced designer and the contractor is experienced. The design concepts have been presented to regulatory agencies in both the US and Canada and to Owners with a warm response from all parties.

Design involves an understanding of drill engineering principals and equipment capabilities. Furthermore, innovations in equipment have significantly improved the chances for successful drills when followed. Innovations have included:

- Development of a planning and design process that incorporates all the aspects of a project: finances, engineering, construction, and regulatory conditions.
- Implementation of updated drilling processes and techniques into the drilling specifications.
- Pressure Managed Drilling including drill fluid design and management methods including the Annular Pressure Curve to manage risk of drill fluid loss and pressure controls for drill fluid such as under balanced drilling.
- Tracking improvements that permit intersect drill designs for complex situations or for extended drill lengths,
- Project specific engineering geological assessment of ground conditions that impact drill performance and risk of drill fluid loss including formation confinement pressure.
- Construction planning with an emphasis on due diligence, emergency response planning, contingency strategies and documented on-site compliance.

Condition Assessment of Water Transmission Pipelines

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Water infrastructure in the USA is aging and it is becoming more and more important to understand the condition of water pipelines when making capital planning decisions. Because to the high cost of pipeline replacement, major utilities around the world are using innovative assessment technologies. Prestressed concrete pressure pipe may be inspected using RFEC/TC an electromagnetic technique to examine the structural prestressing wires or AET a system able to monitor ongoing loss of prestress within the pipeline. The Sahara system is cable of detecting leaks as small as 1L/h in pipelines 300 mm in diameter and greater. This session will present an overview of existing proven technologies to assess the condition of water transmission pipelines and will make mention of some new technologies that might offer solutions in the future. In addition specific case studies sharing the experience of key clients in utilizing assessment technology to save money through prioritized repairs, deferred capital investment and ongoing maintenance will be presented.

PCCP Integrity Management

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The recent development and application of technologies to inspect and monitor prestressed concrete cylinder pipe has provided new opportunities to manage deterioration in these large-diameter water and wastewater pipelines. Previously, little information was available about the extent and rate of deterioration of the prestressing wires in this type of pipe. Engineers had to rely on visual inspection and corrosion surveys to try to identify pipes approaching a critical structural condition, which could then only be confirmed through excavation and forensic examination.

Now, however, electromagnetic inspection can provide a good approximation of the number of wires that have failed in a given pipe, and continuous acoustic monitoring can identify and locate wire breaks as they occur during the monitoring period. This information has been used to identify and replace severely distressed pipe and to assist in the development of repair or replacement programs. However, with few exceptions, this high-quality data is currently used only as part of a static approach, that is, information is collected from periodic electromagnetic inspection surveys or short term monitoring programs and decisions are made on the basis of an analytical or subjective assessment of risk of failure at that particular point in time. This can lead to the adoption of inadequate or over-conservative mitigation strategies.

The combination of electromagnetic inspection, long-term acoustic monitoring and comprehensive dynamic risk management modeling provides an assessment of remaining time to failure for each pipe while protecting against spontaneous rupture. The integration of this information into a comprehensive database with an intuitive interface allows the City of Tucson to optimize PCCP management and offers a far more sophisticated and cost-effective solution to assuring pipeline integrity than current practice. This presentation describes how such a strategy can be implemented and presents a case study on how the City of Tucson is adopting this approach to manage its PCCP inventory.

Alternative Pipe Materials for Trenchless Technology

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Pipe material can be a very volatile subject. It has been a stumbling block to the use of pipe bursting technologies and horizontal directional drilling (HDD) with some utilities around the country. Many of these utilities are so invested in certain pipe materials that it is almost impossible for them to consider other piping materials. While there is a high level of familiarity with the application of HDPE pipe in pipe bursting and directional drilling, there is still considerable interest, in other pipe materials, by owners, engineers and contractors. A short list of these pipe materials for pipe bursting and HDD includes ductile iron pipe with restrained joints or special Jacking type joints and C-900 PVC pipe with restrained joints or a new Fusion Welded PVC pipe joint. Many of the pipe manufacturers have identified pipe bursting and HDD applications as an extension of their market for pipe sold into the open cut world. Adapting these alternative pipe materials into real world trenchless applications is a definite challenge.

Many of these pipe materials are beginning to find their way into the Pipe Bursting and HDD field. Various pipe manufacturers are working diligently with pipe bursting equipment developers and manufacturers of HDD equipment to find real world ways to adapt their pipe products to the rigors of pipe bursting and HDD installations. It takes the extensive experience of these parties to find suitable ways to install what is best described as sectional, gasketed pipe in the pipe bursting and HDD process. There are many factors to consider and this paper will describe in detail what is necessary for these pipe materials to work in pipe bursting and HDD applications.

Geophysical Ground Imaging

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Geophysical survey methods can be an effective tool to assist in the planning, designing and costing of directional drilling, micro-tunneling or tunneling projects by providing an assessment of soil and bedrock conditions and identification of potential obstructions, or even archeological artifacts. Geophysical methods can be cost effectively applied to both land and marine projects. Geophysical methods commonly used for these investigations include but are not limited to seismic refraction, seismic reflection, and cross-hole and down-hole tomography. The geophysical results are correlated with and enhance traditional boring data by filling the gap between borings and in some cases providing data where it is not possible, too expensive or time consuming to obtain boring data.

Several geophysical studies will be used to illustrate the use of these geophysical survey methods.

> A seismic down-hole (VSP) tomography program was conducted between borings spaced approximately 100 feet apart to image the subsurface ground conditions along a proposed tunnel alignment in Miami Florida. The survey produced two dimensional tomographic images of the ground conditions between borings to help identify weak rock areas that could affect tunneling operations.
>
> Seismic refraction data were obtained at 12 proposed river crossings of the Middletown to Norwalk Connecticut 345 KV transmission line to determine the approximate depth to bedrock and general identification of the materials overlying the bedrock. Seismic refraction data was acquired quickly and provide the necessary subsurface information for permit applications without the environmental, public awareness and access problems that conventional drilling would have encountered.
>
> A marine seismic reflection and side scan sonar investigation was conducted along a proposed directional drilling project in Boston Harbor. The seismic reflection data was used to map subsurface soil and bedrock changes. Side scan sonar was use to evaluate bottom conditions identifying organic bottom areas, bulkheads and submerged piles that could be a conduit for drilling fluids to leak through. Additionally, a magnetic survey was used to assess bottom magnetic anomalies that would interfere with magnetic tracking equipment and to assess the area for potential magnetic artifacts such as sunken ships.

Geophysical ground imaging methods are a cost affective way of managing risks associated with directional drilling and tunneling projects by mapping changes in soil or bedrock conditions, providing an understanding of actual stratigraphic conditions between test borings, and identifying potential man made obstructions.

Corrosion Prevention of Ductile Iron Pipelines

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The results of a study of corrosion and corrosion protection characteristics of ductile iron pipe are presented. Included are field and laboratory evaluations related to short term and long term polarization rates under varying conditions; corrosion rate reduction and corresponding cathodic current criterion; and the corrosion protection benefits of the traditional, standard asphaltic shop coating. This information was analyzed in conjunction with an extensive database from 1379 physical inspections of buried iron water lines. The result of the study is a risk based corrosion protection design strategy (Design Decision Model) for buried ductile iron pipelines. . Example approaches to corrosion protection are provided with guidance to ensure cost-effective solutions. These include: shop coated pipe, shop coated pipe with polyethylene encasement, joint bonding and corrosion monitoring systems, stray current control, life extension cathodic currents, cathodic protection with polyethylene encasement, cathodic protection of shop coated pipe and cathodic protection of pipe with a wax tape coating. Life-cycle cost analyses of alternative strategies are presented."

Large-Scale Laboratory Validation of Field Behavior, New Products, and Advanced Sensors

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There have been substantial advances in large-scale laboratory experiments for validation of pipeline performance, products, and advanced sensing technologies. A notable example is the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) that is supported by the US National Science Foundation (NSF) http://nees.cornell.edu/basic/index.htm.

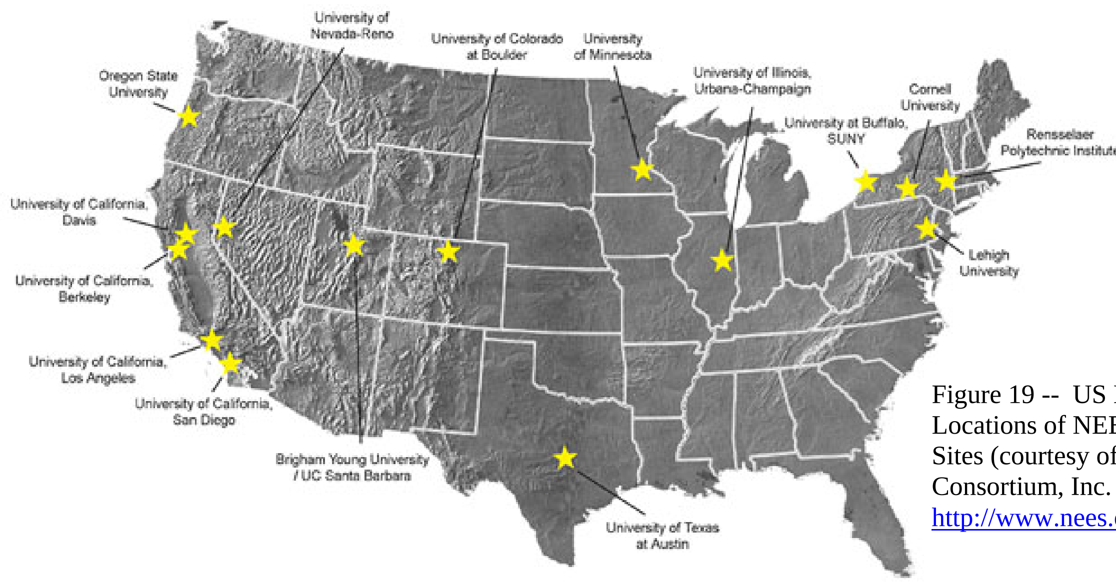

Figure 19 -- US Map Showing Locations of NEES Equipment Sites (courtesy of NEES Consortium, Inc. http://www.nees.org/index.php).

As illustrated in Figure 19, NEES is a nationwide resource of advanced research equipment sites networked through the high performance Internet. The network is focused on improving the seismic design and performance of public and private works through advances in the technologies applied in civil, mechanical, and telecommunication systems. It uses state-of-the-art experimental and numerical simulation capabilities to understand the behavior of critical facilities under complex loadings and to test and validate the analytical and computer models needed for effective engineering. NEES links sites throughout the U.S. and globally to create a shared resource that benefits from open access and the contributions of leading researchers at multiple locations.

Researchers using the NEES equipment site at Cornell University are simulating earthquake fault rupture effects on critical underground pipelines that are used to carry natural gas or water at high pressures. The experiments involve the largest laboratory tests ever performed on pipeline response to ground rupture. Approximately 100 tons of soil are sheared and ruptured, displacing 1.2m (4 ft) at the center of a 400-mm diameter pipeline composed of high density polyethylene. Pipelines, made of polyethylene, represent an important class of conduits with high ductility and the capacity to stretch and deform without rupture under extreme loading conditions. The tests not only demonstrate the ability of such facilities to accommodate severe movement, but provide important data about strain concentrations, changes in shape, and soil-structure interaction – all of which will improve analytical models to evaluate polyethylene piping and its performance during extreme events. The tests provide information essential for design and construction in response to earthquakes, floods, landslides, large deformation induced by tunneling and deep excavations, and subsidence caused by severe dewatering or withdrawal of minerals and fluids during mining and oil production. Such loading conditions are increasingly important as technologies are developed to cope with natural hazards, human threats, and construction in congested urban environments. The tests are being performed in unison with experiments at Renssalaer Polytechnic Institute using its 150 g-ton NEES facility to perform nearly identical experiments at 1/12th scale. The combined tests are exploring the characteristics of modeling complex soil-structure interactions at both full size and reduced scales. They provide valuable information about physical testing at multiple scales to understand complex loading effects, polymer product performance, and the intricacies of soil-pipe interaction under large plastic, irrecoverable deformation of both the soil and piping.

The experiments also provide a vehicle for demonstrating the capabilities of and improvements for advanced sensors for pipeline systems. The experiments at Cornell and RPI are being performed with tactile force sensors that consist of a matrix of piezometric sensors in a flexible fabric that covers the pipeline like an exterior wrap. The sensors provide detailed measurements of the soil pressures imposed around the pipeline during relative displacement between the pipeline and soil during ground rupture. At Cornell, the full-scale tests are being conducted with a pipeline robot equipped with a laser profiling device that measures the cross-sectional deformation of the pipe during ground deformation. Thus, the experimental pipelines are equipped with external and internal sensors to assess soil pressures and corresponding ovaling of the pipe. Validation of the sensors at full-scale under severe loading conditions helps advance the technology and confirm applications of use for industry.