April 1, 2006 – June 30, 2006

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Prepared for: U.S. DOT/RSPA

LONG-TERM MONITORING OF CASED PIPELINES USING LONG-RANGE GUIDED-WAVE TECHNIQUE

1st Quarterly Report

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July 31st, 2006

Public Page

This project started on 1 April 2006.

The SwRI Magnetostrictive Sensor (MsS) system is being developed and advanced along with a defect characterization model based on a partnership between PHMSA/OPS, NYSEARCH/NGA (gas industry research consortium and user group) and SwRI; a research contractor who has been investigating the use and application of MsS for many years. This program addresses development and testing of the MsS for use in cased crossings and is supported by industry sponsors through management by the NYSEARCH organization, cash cofunding, use of a separately-sponsored controlled test bed and testing at live field sites.

The MsS system is unlike other guided-wave inspection techniques and is unique because it applies a permanently-installed MagnetoStrictive Sensor (MsS) that permits testing of cased section of pipelines over time and without costly preparation. With a capability to both monitor activity over time and characterize the defects, the technology could potentially provide accurate tracking of defect growth with time and could give operators specific information to address inspection indications.

During the First Quarter, the project team initiated several tasks as outlined below.

This report addresses project tasks:

Task #M1 Kickoff Meeting
- Start date: 1 April 2006
- Scheduled completion date: 30 April 2006
- Status: Completed

Task #M2 Define/Finalize Utility Product Requirements
- Start Date: 1 April 2006
- Scheduled completion date: 30 June 2006
- Status: Partially completed; initial Product Specification has been drafted and reviewed. NYSEARCH Project Manager is of the opinion that more dialogue is needed to finalize.

Task #1 Refine and Validate Simulation Model
- Start date: 1 April 2006
- Scheduled completion date: 30 September 2006
- Status: Ongoing

Task #3 Improve Data Analysis Software for Inspecting
- Start Date: 1 April 2006
- Scheduled Completion Date: 31 January 2007
- Status: Ongoing

Task #M5 First Quarterly Report
- Start Date: 1 April 2006
- Scheduled Completion Date: 30 June 2006
- Status: Completed

Table of Contents

Technical Status

Task # M1 Kickoff Meeting Page 4

Task #M2 Define/Finalize Utility Product Req'ts Page 4

Task # 1 Refine and Validate Simulation Model Page 4

Task # 3 Improve Data Analysis Software for Pipeline Inspection Page 5

Task # 4 Evaluate Alternate Adhesives Page 5

RESEARCH FINDINGS AND DISCOVERIES

Task # 1 Refine and Validate Simulation Model Page 6

Business Status

Discussions with Operators and Potential Users of Technology Page 7

Plans for the Next Quarter Page 8

Appendices

Appendix A – NYSEARCH/NGA Presentation from Kickoff Meeting Page *9*

Appendix B – SwRI Presentation from Kickoff Meeting Page *12*

Technical Status

Task #M1 – Kickoff Meeting

Before the start of the project, at a meeting of the NYSEARCH/NGA funders in February, the final proposed project plans were provided to the funders. Given that initial review, the project was started and the formal kickoff meeting was deferred from April 1 until all parties were available to travel to San Antonio. A Kickoff Meeting with PHMSA/OPS, NYSEARCH Project Manager and SwRI Staff was then held in San Antonio at SwRI headquarters on June 28, 2006. Presentations from the Kickoff Meeting are attached in this report as Appendices A and B.

There were two action items that came from the Kickoff Meeting:

1) NYSEARCH/NGA sponsors need to identify and ship to SwRI sample pipes with various coatings for testing in the lab. SwRI is looking for lengths of coated pipe of 20' or better if possible. NYSEARCH will address this request in the second quarter.
2) When tasks are completed to optimize procedures for use of sensor and defect sizing, optimal procedures should be documented by SwRI.

Task #M2 – Define/Finalize Utility Product Requirements

NYSEARCH and SwRI team members communicated on a draft specification that was sent out to the NYSEARCH/NGA sponsors. The main variable in the draft product specification is the variety of pipe coatings (and coating thicknesses) that this inspection sensor needs to be able to address.

The draft specification was provided by SwRI for the CASED CROSSINGS application. Several NYSEARCH/NGA sponsors also provided feedback and added to range of coatings and thicknesses that need to be addressed. The draft specification incorporates the following parameters:

1) Applicable Pipe Sizes: any pipe sizes up to 48"
2) Pipe Wall thicknesses: any pipe wall thickness up to 1"
3) Pipe Material: any metallic material (the applicability to PE pipe has NOT been established but could be tested)
4) Sensor to withstand temperatures up to 100C. (Supporting system also needs to withstand such temperatures.)
5) Coatings and Coating thicknesses:
    - TGF-3 coal tar enamel thickness: 0.1875
    - Fusion Bonded Epoxies thickness: 12 to 20 mils
    - *Wax wrap thickness: up to 1"*
    - Shrink Sleeves thickness: 85 mils
    - Tapecoat thickness to 65 mils
    - Liquid Applied Epoxy thickness: 25 mils to 45 mils
    - High density PE thickness: 10 mils butyl rubber adhesive with 60 mils PE coating

Task #1 Refine and Validate Simulation Model

A preliminary software feature for putting in the various defect confirmation was added to the existing defect signal simulation program. The results of that effort are provided in the "Research Findings and Discoveries" section of this report.

Refinement of the simulation software began, including corrections for frequency dependence of the geometric shadow effects. To help determine way to implement the correctional schemes, a series of experimental measurements of defect signals from a 50-percent-deep circumferential notch was conducted on a bare 20-foot-long, 6-inch-OD, 0.28-inch-wall pipe sample – one of the four samples (three bare and one-bitumen coated) acquired at the beginning of the project for experimental purposes. Defect signal waveforms were measured at three frequencies (32, 64 and 128 KHz) while increasing the axial length of the notch (from 0.25 inch up to 4 inches at every 0.25-inch increment). In limited cases, measurements were also made after machining one edge of the notch to a 30-, 45-, and 60-degree slope from the vertical axis. Analysis of the experimental data is under way. Figure 1 shows the experimental setup for the measurement.

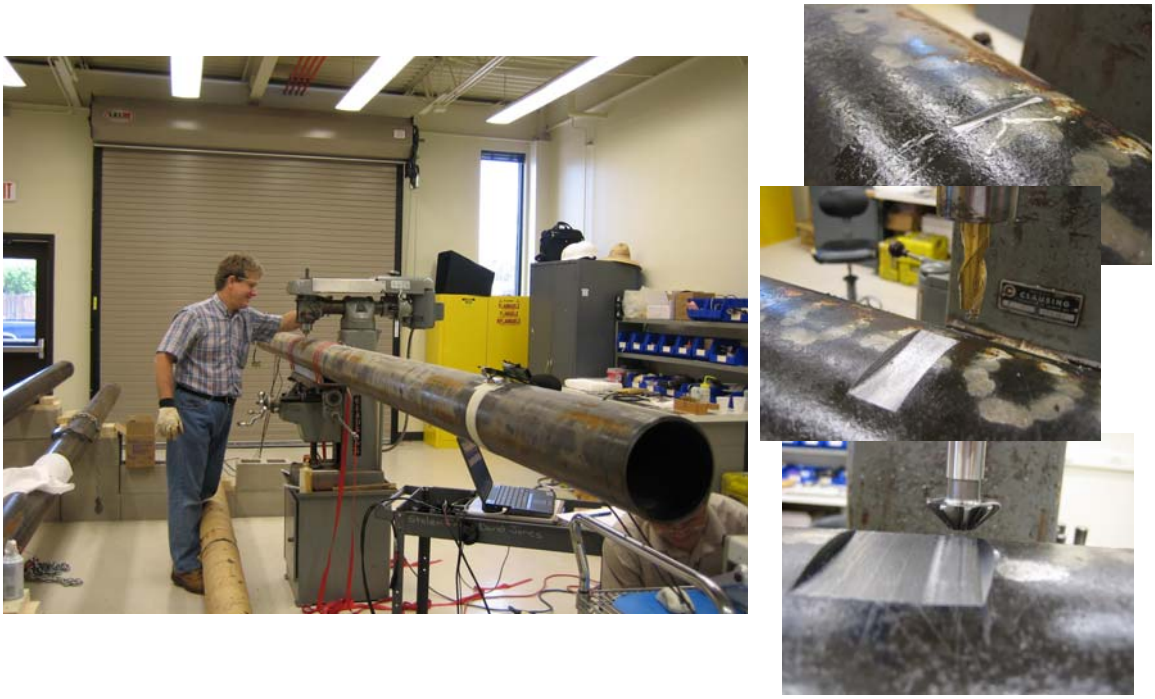

Figure 1. Experimental setup for defect signal measurements

Also at the beginning of the project, 10 pounds of iron-cobalt strip materials were ordered for use in the laboratory and field tests (expected to be delivered by July 2006).

Task # 3 – Improve Data Analysis Software for Pipeline Inspection

Improvement of the existing data analysis/reporting software for piping inspection began. A feature was added that allows the threshold level of detection to be varied with distance so that the signal-to-noise ratio at the threshold level is approximately the same as distances increase within the test range. Addition of a function that correlates the data taken from both sides of a cased section of pipelines is underway.

A phase-checking algorithm for automatic separation between defect and weld signals (one of the improvements identified in the proposal) was integrated into the existing software by SwRI prior to the start of the project.

Task #4 – Evaluate Alternate Adhesives

This task, originally scheduled for the second quarter, was initiated earlier than planned so that a suitable material could be found in ample time before the field evaluation of the long term monitoring of cased lines.

RESEARCH FINDINGS AND DISCOVERIES

Task # 1 – Refine and Validate Simulation Model

The new software feature can handle both OD and ID defects in either rounded or trapezoidal cross-sectional shapes with various axial length, width (in circumferential direction of the pipe), and depth. Examples of defect configurations that can be input are shown in Figure 2 for OD defects and Figure 3 for ID defects.

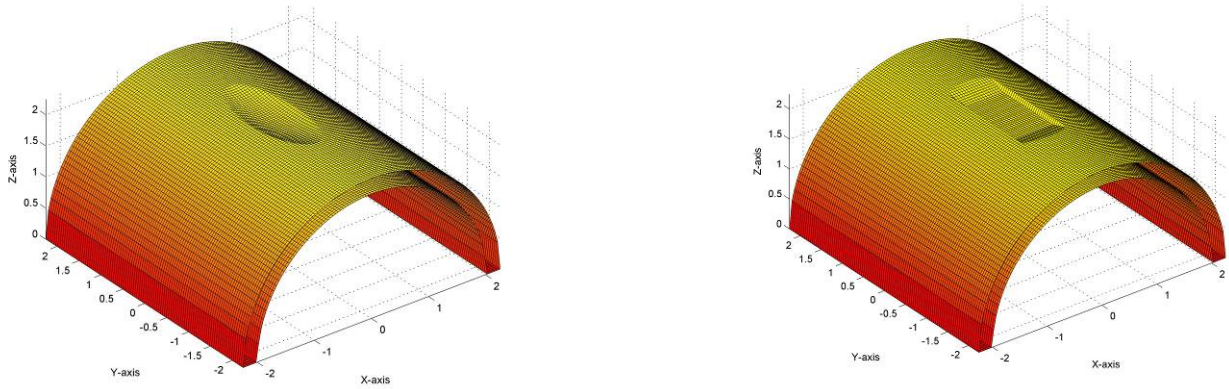

Figure 2. Example of OD defect configurations that can be input for simulation of defect signals

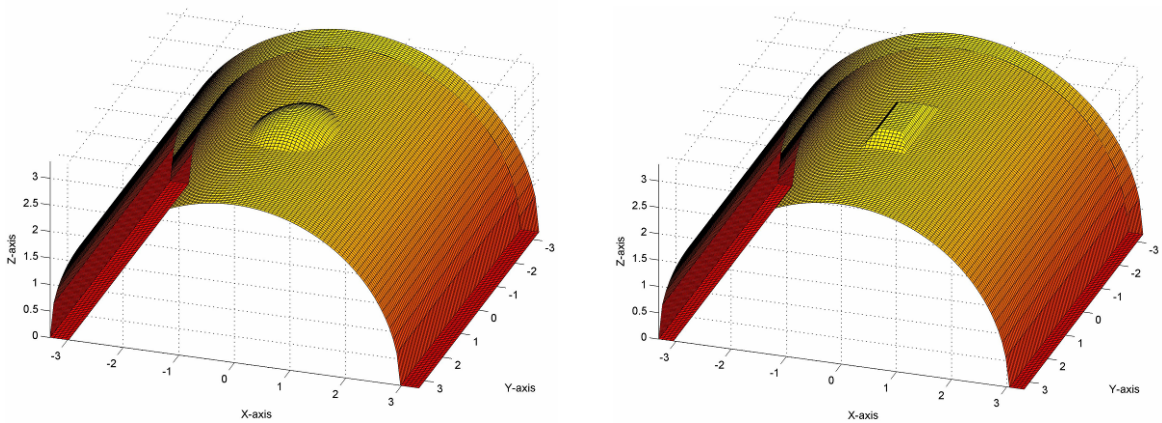

Figure 3. Example of ID defect configurations that can be input for simulation of defect signals

The defect confirmations feature was then integrated into the existing defect simulation software and a preliminary GUI (graphic user interface) version of the program was prepared for general use. A computer screen display of the simulation GUI program is shown in Figure 4. The display includes the defect configuration; defect cross section in axial and circumferential directions; controls for defect shape/type and their length, width, and depth; pipe OD and wall thickness; wave frequency; and the waveforms and spectra of both the transmitted and defect signals.

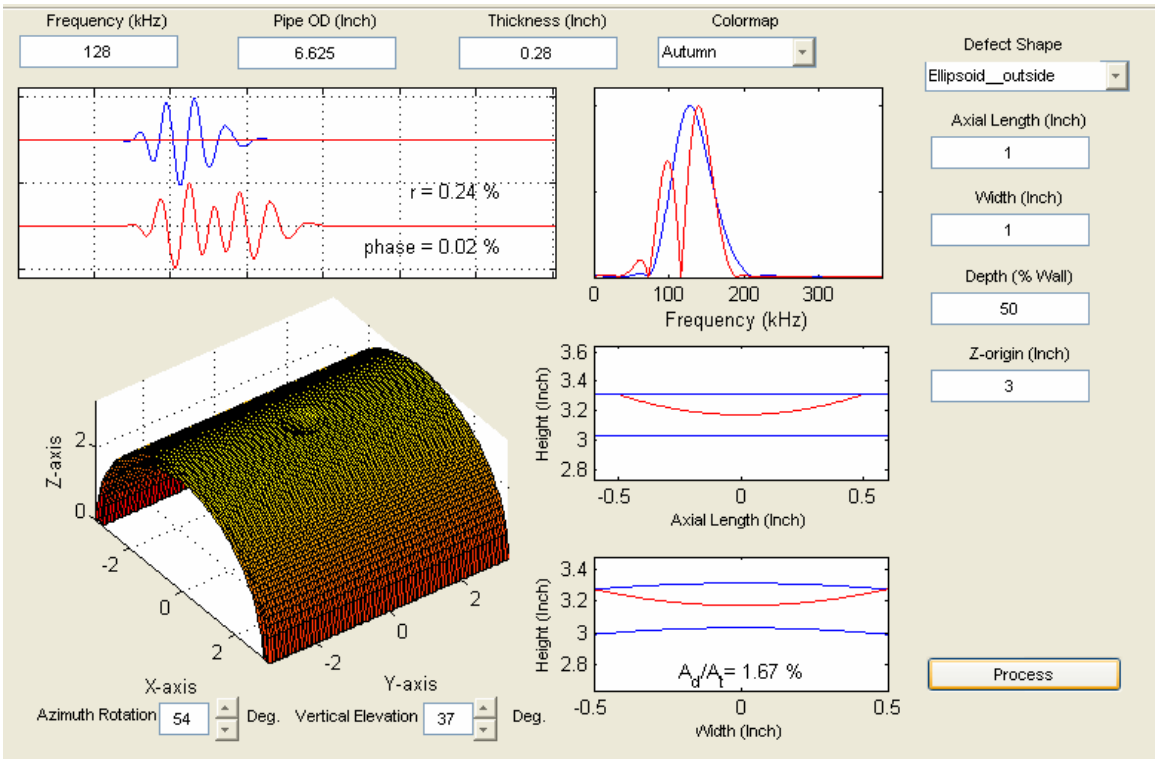

Figure 4. A computer screen display of the simulation GUI program

Task #4 – Evaluate Alternate Adhesives

Three flexible adhesive materials based on either epoxy or urethane were identified and evaluated. There were: (1) Epic Resin S7328, a polyurethane-cased adhesive; (2) Hysol U-10FL, a polyurethane-based adhesive; and (3) Epoxies Etc. 10-3216 Gray, an epoxy-based adhesive. All three were found to be good bonding materials for MsS operation. Materials (2) and (3), which seem suitable for field application, were subjected to a pressure test and found to still exhibit substantial pressure effects on MsS sensitivity. Other candidate materials that are more flexible are being identified for evaluation.

BUSINESS STATUS

Discussions with Operators and Potential Users of the Technology

There are (13) members/associate members of NYSEARCH/NGA who are funders of this Phase II project (NYSEARCH had previously sponsored a Phase I Proof-of-Concept project). Those members were provided information prior to the project and during the approval phase as well as after PHMSA/OPS decided to join. Their main concerns are practicality of the use of this sensor in a long-term monitoring system and how quickly it can be brought to market (many are anxious for alternatives to existing or new guided wave systems). Their main focus as operators is whether or not the sensor can be applied practically AND whether it can be installed on pipes with a variety of coating and coating thicknesses. Installation issues that are beyond what is addressed in the draft specification include whether or not there would be a blind spot near the sensor and exposed portions of pipe near the sensor.

The sponsors of this project are also sponsoring a similar Guided Wave project that NYSEARCH/NGA has with PHMSA/OPS. Thus, several pipe samples have already been found and shipped to those contractors for similar purpose. It may take longer for the sponsors to find additional samples for this project but the request will be addressed in the second quarter.

Notes in emails from sponsors indicate that various member company integrity management groups are keen on seeing whether this technology can become successful.

Plans for the Next Quarter

Task #M2 – Define/Finalize Product Utility Requirements

This task will be re-visited and discussed with sponsors and SwRI to ensure that it is complete. Pipe samples will be requested that incorporate as wide a range of coating effects as possible.

Task #1 – Refine and Validate Simulation Model

Based on the experimentally measured notch signal waveforms, schemes for correcting frequency dependence of the geometric shadow effects will be determined and implemented into the defect signal simulation software. A feature for correcting attenuation effects on the signal frequency content and, thus, on the apparent waveform detected (to account for its effects on signals detected in coated lines) will be added to the software, as well as a feature for mixing random background noise to the simulated defect signals (for evaluation of defect detectability and the impact of noise on defect characterization capability). Additional experimental measurements of defect signals using different defect types and shapes will be conducted to confirm the reliability of the simulation model.

Task # 2 - Develop Algorithm for Defect Characterization

Algorithm Development will begin. Feature parameters to be used for algorithm development will be selected. These include reflection coefficient, waveform duration, bandwidth, and spectral characteristics. Preliminary algorithms will be designed and tested using actual defect signals and simulated defect signals.

Task #3 - Improve Data Analysis Software for Pipeline Inspection

The addition of the function for correlating the data from both sides of the cased line to the data analysis/reporting software will be completed. Additional features will be added to the existing monitoring software to improve its performance and to make it user friendly. These include correcting variations in wave velocity, wave attenuation, and sensor sensitivity, correlating data from both sides of the cased line, and generating monitoring report.

Task #4 – Evaluate Alternate Adhesives

In Task 4, additional materials will be evaluated and, from the results, the best material and procedures for field applications will be determined.

Appendix A NYSEARCH/NGA Presentation at 6/28/06 Kickoff Meeting

Long Term Monitoring of Cased Pipelines – MsS Inspection

NYSEARCH/NGA perspective

Kickoff Meeting

June 2006

NYSEARCH/NGA Objectives

- Identify and Develop technologies that can provide remote inspection capabilities for LDC-owned and transmission pipelines
  - Address a special challenge for Direct Assessment; Cased Crossings
- Validate products under development to determine qualitative and quantitative capabilities in controlled and real pipeline inspection environments

Phase I Accomplishments with SwRI MsS Approach

- Gained support and familiarization of novel approach by (12) NYSEARCH Industry sponsors
- Proved Concept
  - Ability to withstand wide range of pressure variations (with little modification)
  - Ability to withstand wide variation in CP current level
  - Ability to detect changes in defect size over time
- Phase I approach limited to assessment of defect by cross sectional area

Phase I Industry Issues

- Use of LT monitoring (permanent installation) measurement over time comes to a company policy decision
  - Likely that many companies will change procedures if technology works
- Installation of MsS strip sensor will need to be easy, minimal low cost and not require more than one gas technician
- Industry looking for technology that can quantify defect size (particularly wall loss) with high confidence
- Inspection technique needs to work with a variety of coatings

NYSEARCH/NGA Member Input

- Utility Requirements/Product Spec – feedback provide on product applicability; desired coatings
- Milestone Reviews; next NYSEARCH progress report (Month 6 – Sept)
- Planning/Implementation of Field Trials at Test Bed
- Planning/Implementation of Field Tests at member companies

NYSEARCH Management Tasks

- Program management/oversight
- Gain and communicate input by Utility Sponsors
- Plan, coordinate and prepare for Field Tests at Test Bed and Sponsoring Utilities
- Implement Field Tests
- Reporting and Financial Accounting

Appendix B SwRI Presentation at Kickoff Meeting

LONG-TERM MONITORING OF CASED PIPELINES USING LONG-RANGE GUIDED-WAVE TECHNIQUE

SwRI Project 14.12266
for
NYSEARCH/NGA and DOT/PHMSA

KICKOFF MEETING
June 28, 2006

Hegeon Kwun
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OUTLINE

- Direct Assessment Needs for Cased Pipelines at Road Crossings
- Project Goal
- Technical Background on Guided-Wave Technique and MsS
- Previous Work and Findings
- Project Objectives and Technical Approach
- Project Work Plan and Status
- Discussions

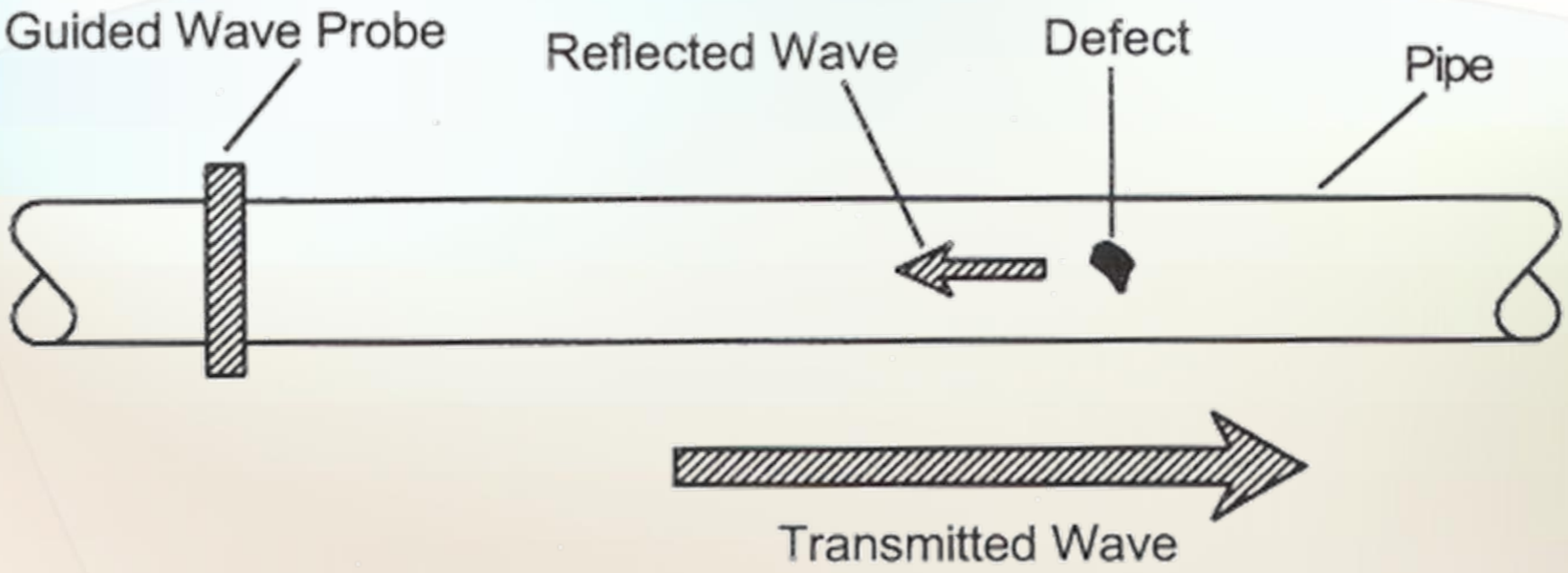
CASED LINES AT ROAD CROSSINGS

- Belong to high-consequence area
- Require direct assessment (DA) per Pipeline Safety Improvement Act
- Due to access difficulty, need remote inspection techniques for DA
- Potential solution
  - Long-Range Guided-Wave Testing

PROJECT GOAL

- Improve the effectiveness of the long-range guided-wave testing for DA of “cased crossings” by developing
  - Defect characterization capability
  - Long-term monitoring capability using permanently installed MsS

LONG-RANGE GUIDED-WAVE INSPECTION



MsS (MAGNETOSTRICTIVE SENSOR)

- MsS is a guided-wave probe that uses the magnetostrictive effects for wave generation and detection
- For pipeline testing and monitoring, T-mode MsS is used
  - Consisting of thin, ferromagnetic strips bonded around pipe and encircling coils over the strips
  - Inexpensive and suitable for long-term monitoring

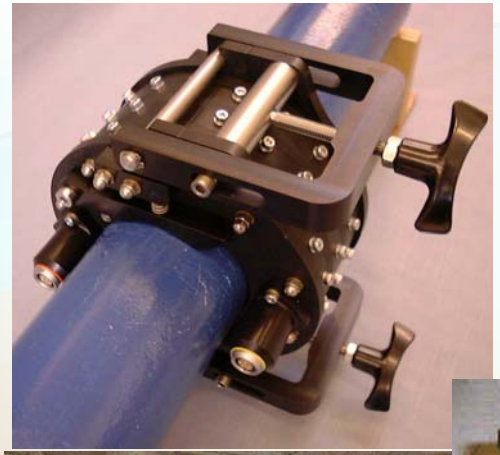
T-MODE MsS PROBE

Magnetostrictive Strip: Iron-Cobalt

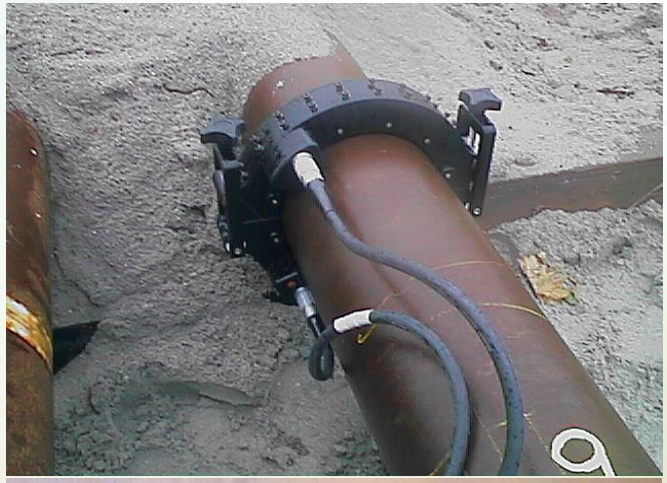
Ribbon Coils Placed Over the Strip

OTHER GUIDED-WAVE SYSTEMS
PIEZOELECTRIC TRANSDUCER RING

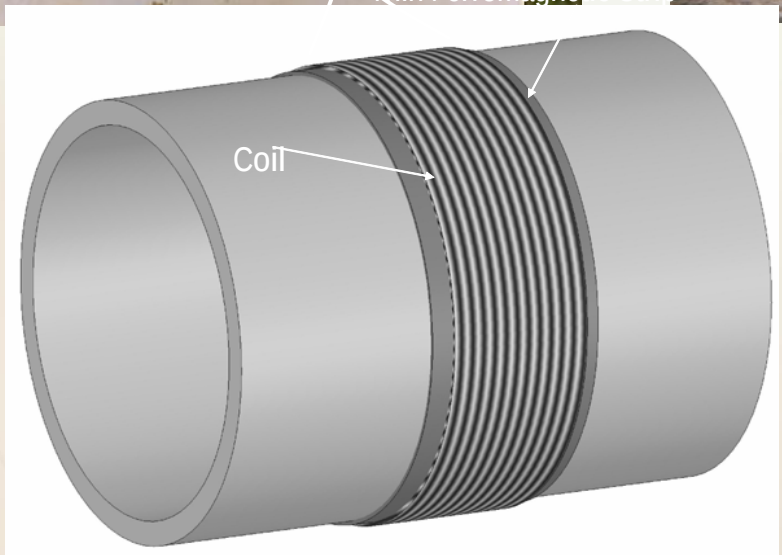
Teletest



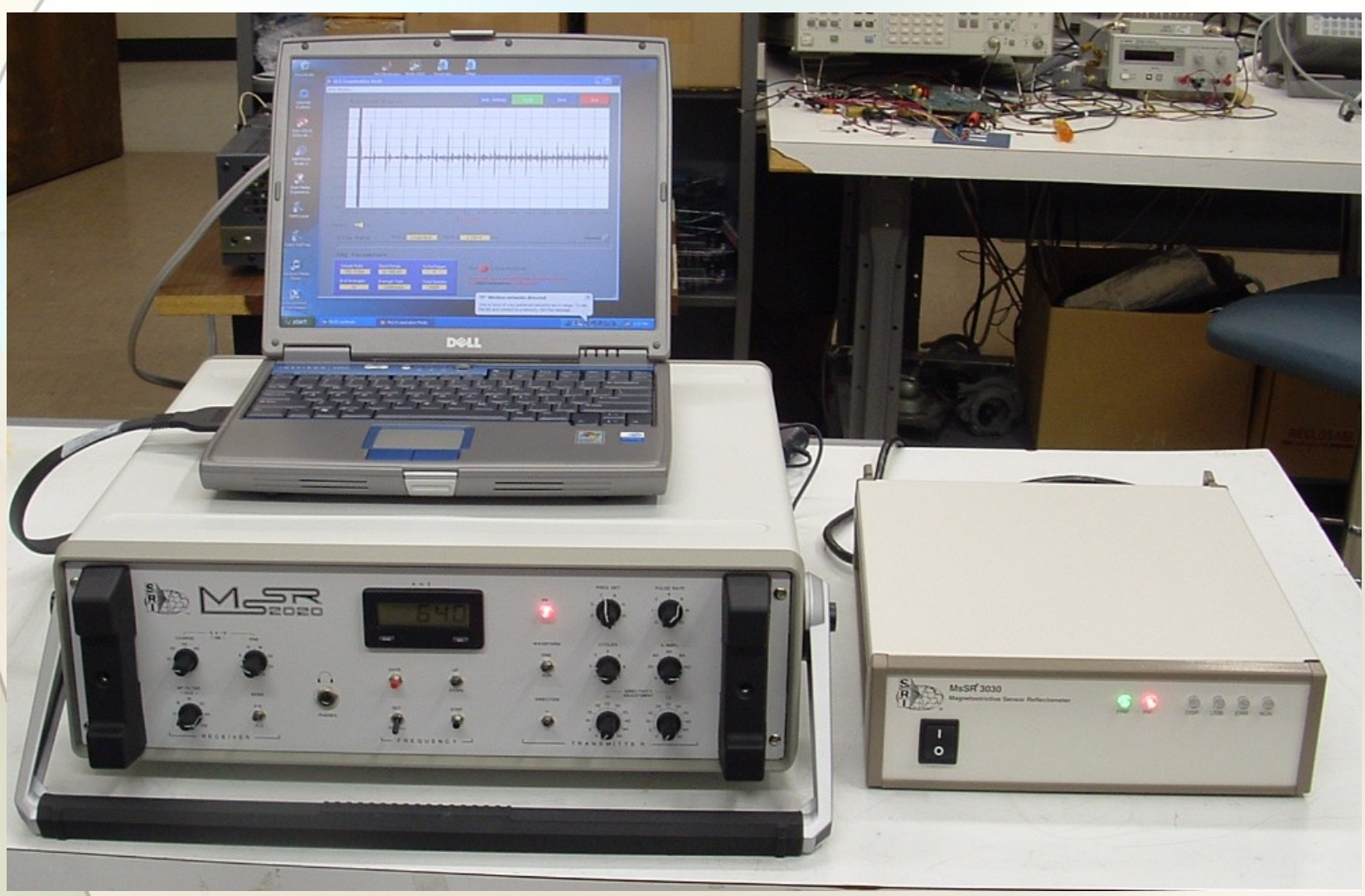
Wavemaker



PERMANENT MsS FOR LONG-TERM MONITORING



MsS INSTRUMENTS (MsSR 2020 and 3030)



MsS DEVELOPMENT HISTORY

- 1991: Concept conceived for bridge cable inspection
- 1992: Feasibility of cable inspection proven in lab
- 1993: Feasibility proven on pipe/tube using L-wave
- 1996-1998: Field instrument (MsSR-1000) developed under industry support
- 2001: Thin-nickel-strip T-wave developed, instrument upgraded (MsSR-2020), and commercial use began
- 2003-2005: High-power T-wave developed under PHMSA program, instrument upgraded (MsSR-3030)
- 2005: Feasibility of cased-line monitoring proven under NYSEARCH/NGA funding (Phase 1)
- 2006: System software upgraded, the present NGA/PHMSA project (Phase 2) began

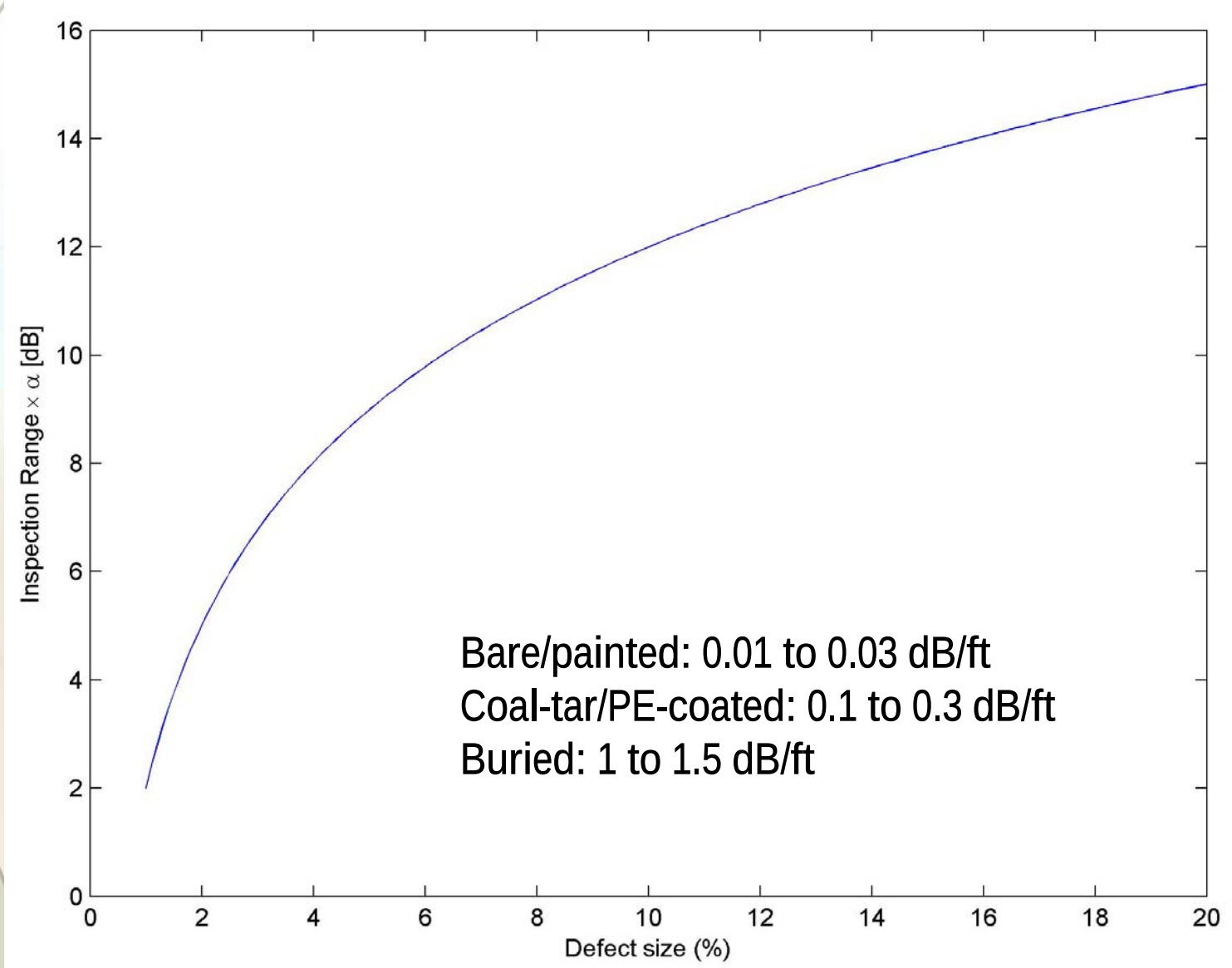
PREVIOUS WORK AND FINDINGS

- Along with MsS technology R&D, SwRI has conducted extensive laboratory and field testing/ evaluation of guided waves on pipes
- Findings include:
  - Good for detecting and locating defects such as corrosion metal loss areas, circumference cracks, and deep (over 70% wall) axial cracks
  - Can roughly estimate defect size; needs more R&D to achieve defect characterization
  - Can inspect over 500-foot length of piping in one direction for detection of 2 to 3% defects on straight bare or painted lines (here, % means defect's circumferential cross-sectional area relative to total pipewall cross section)

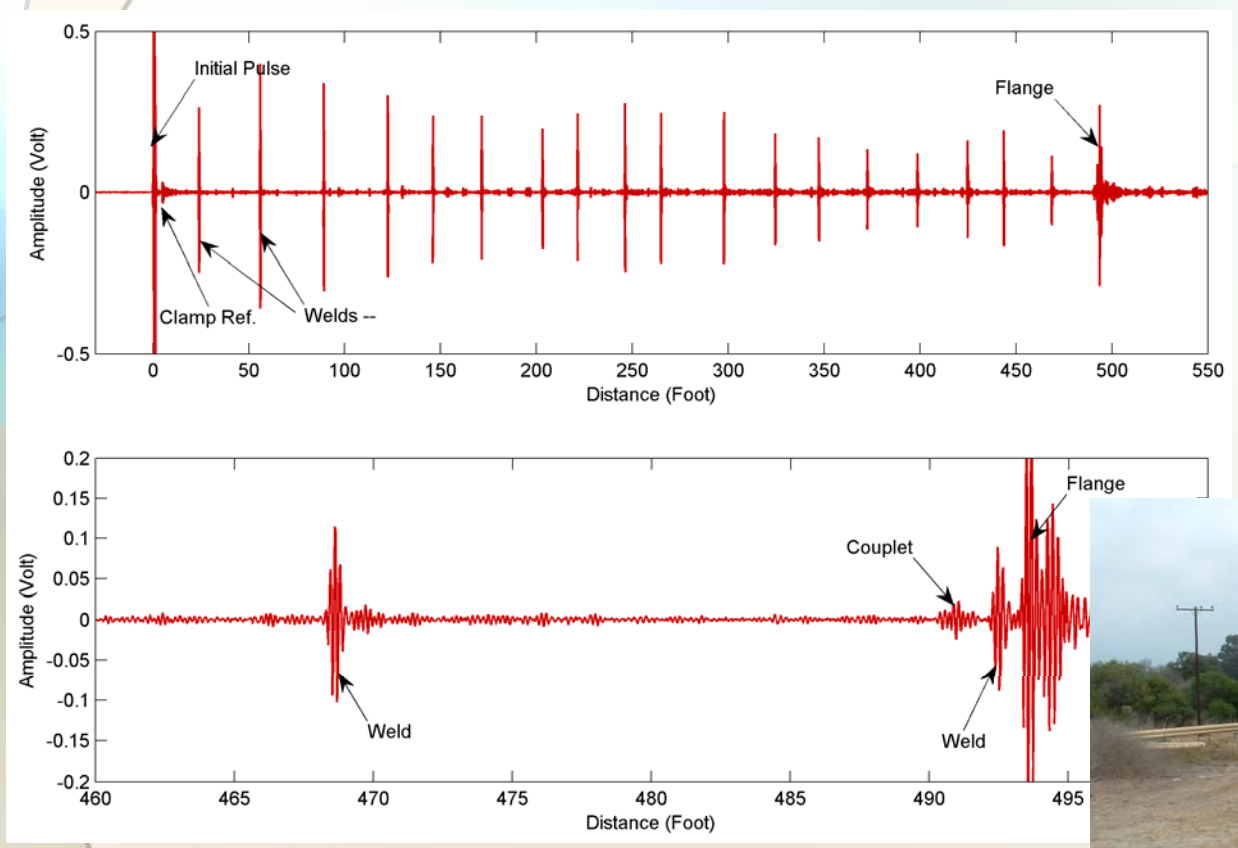
FINDINGS (CONT'D)

- Factors that reduce or limit inspection capability
  - Line features such as short-radius elbows, tees, flanges, and clamps
  - Coating such as coal tar enamel or PE
    - Increases wave attenuation and reduces inspection range (to about 50 to 100 feet for detection of 5% defects in one direction)
  - Surrounding soil
    - Significantly increases wave attenuation and shortens inspection range (to about 10 feet for detection of 5% defects)
- Monitoring cased carrier lines at road crossings using permanently installed MsS is feasible

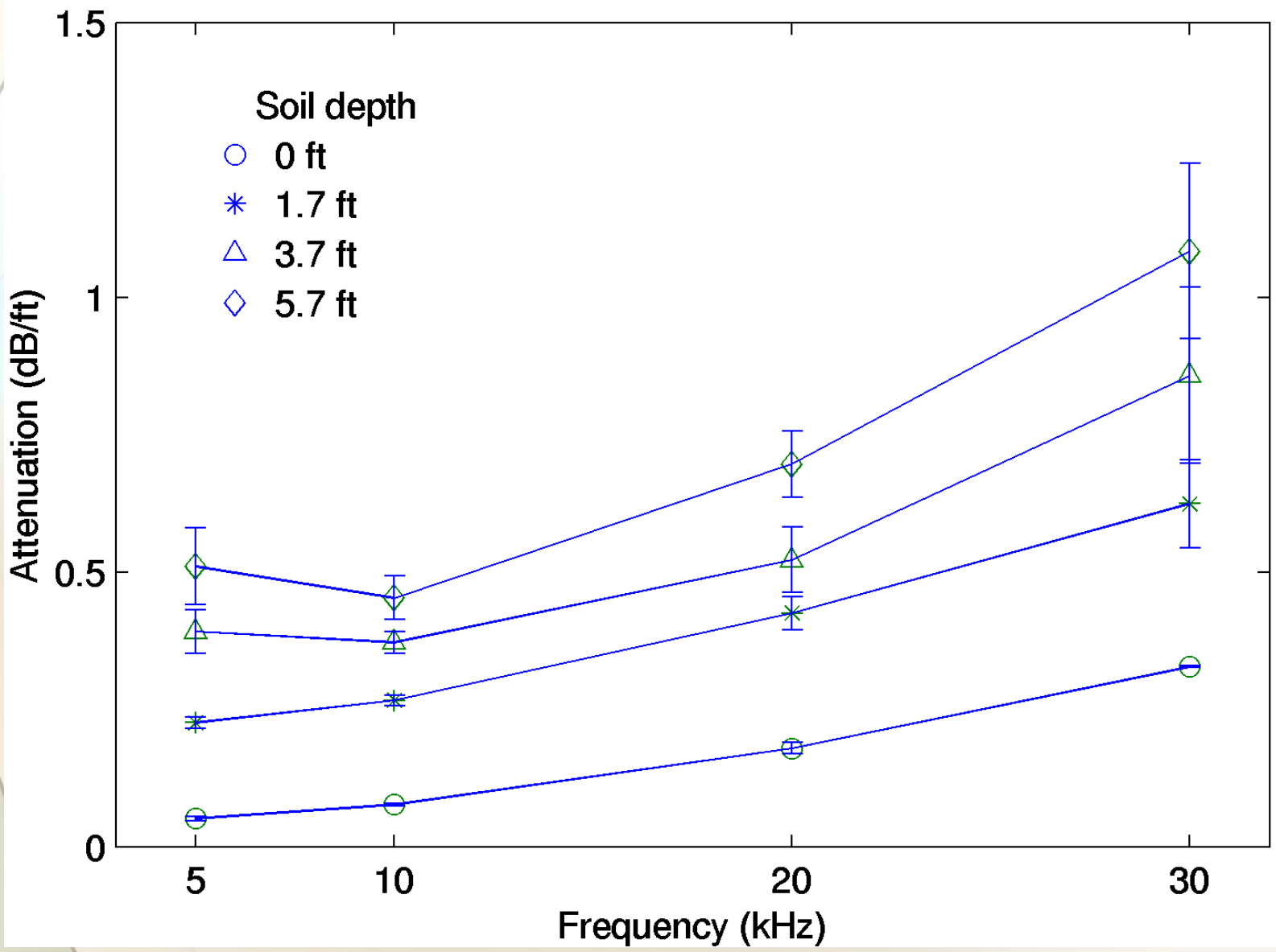
DEPENDENCE OF INSPECTION RANGE ON DEFECT SIZE AND ATTENUATION



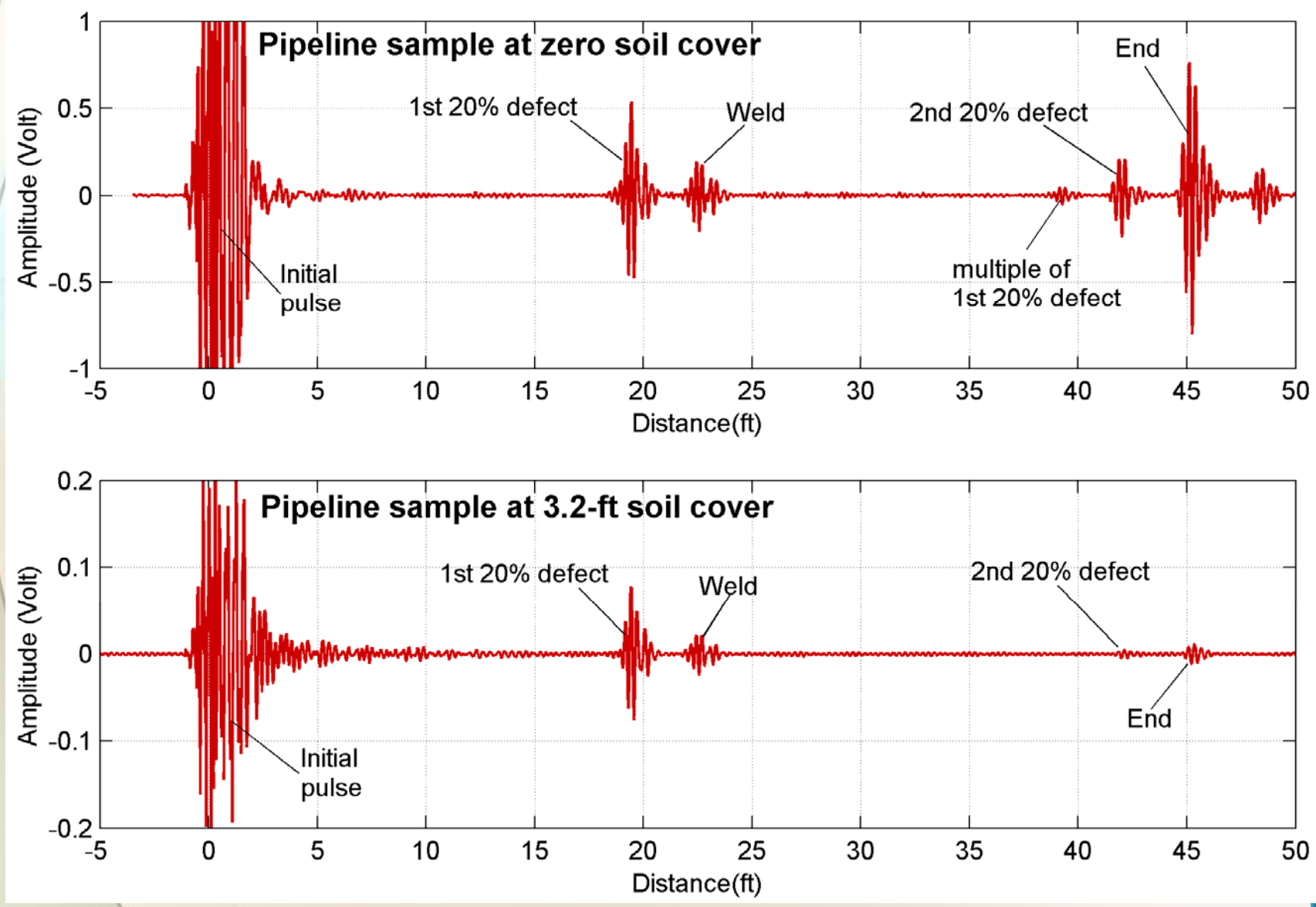
EXAMPLE FROM STRAIGHT ABOVE-GROUND 16-IN. GAS TRANSMISSION LINE



T-WAVE ATTENUATION IN 4.5" OD COAL-TAR-ENAMEL-COATED PIPE AT VARIOUS SOIL COVER DEPTHS (from EPRI report)



EXAMPLE OF SOIL EFFECT — 20-kHz T-MODE DATA FROM 4.5" COAL-TAR-ENAMEL-COATED PIPE SAMPLE (from EPRI report)



GUIDED-WAVE MONITORING OF CASED LINES AT CROSSINGS

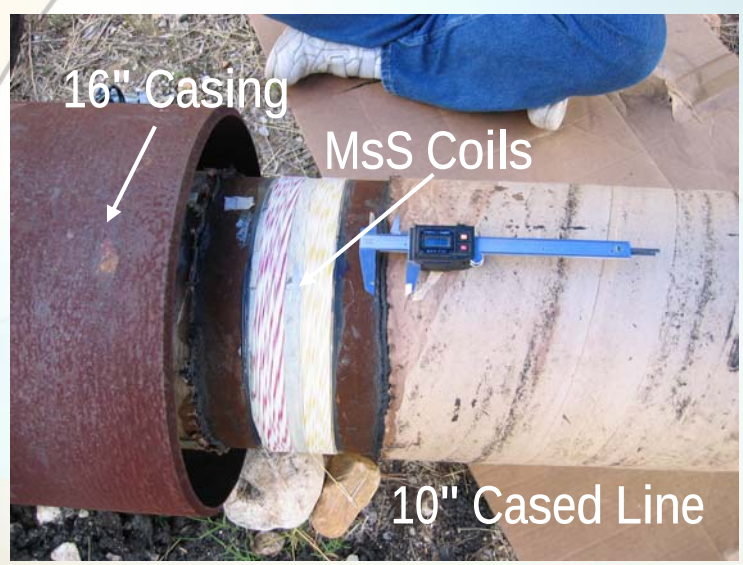
- Why guided wave monitoring?
  - The cased section of the carrier line can be examined from a location outside casing for ICDA and ECDA
  - Periodic monitoring with permanently installed probe allows accurate tracking of the structural condition change for appropriate maintenance decisions and prevention of unexpected failure
- The feasibility was proven on a mockup in a recently completed NYSEARCH/ NGA project (Phase 1)

NYSEARCH/NGA PHASE 1 WORK AND FINDINGS

- Cased-line mockup
  - Carrier line — 63-ft-long, bitumen-coated, 10" OD, 0.365 wall pipe
  - Casing — 42-ft-long, 16" OD pipe
  - Seven spacers of different types along cased section of the carrier line (per feedback from NGA members)
  - Three 12" access windows on casing for placement of defects in the carrier line
  - MsS installed on the carrier line for 20-kHz operation just outside of both ends of casing

CARRIER-LINE PREPARATION

MsS TEST SETUP ON A CASED-LINE MOCKUP



WORK CONDUCTED IN PHASE 1 AND FINDINGS

- Investigated effects of cathodic protection current on sensor stability
  - Up to 6 amperes of current, no measurable effects

CP Rectifier

CP Ground Connection

WORK CONDUCTED IN PHASE 1 AND FINDINGS

- Demonstrated the capability of long-term monitoring on the cased-line mockup
  - Procedures
    - Take baseline data
    - Place defects (1% size*) in the carrier line, take data, and compare with the baseline
    - Increase defect size (to 2% and 3%) and repeat the process

* Here, the defect size refers to its circumferential cross-sectional area relative to the total pipewall cross section

THREE DEFECT TYPES PLACED IN CASED-LINE MOCKUP

d1

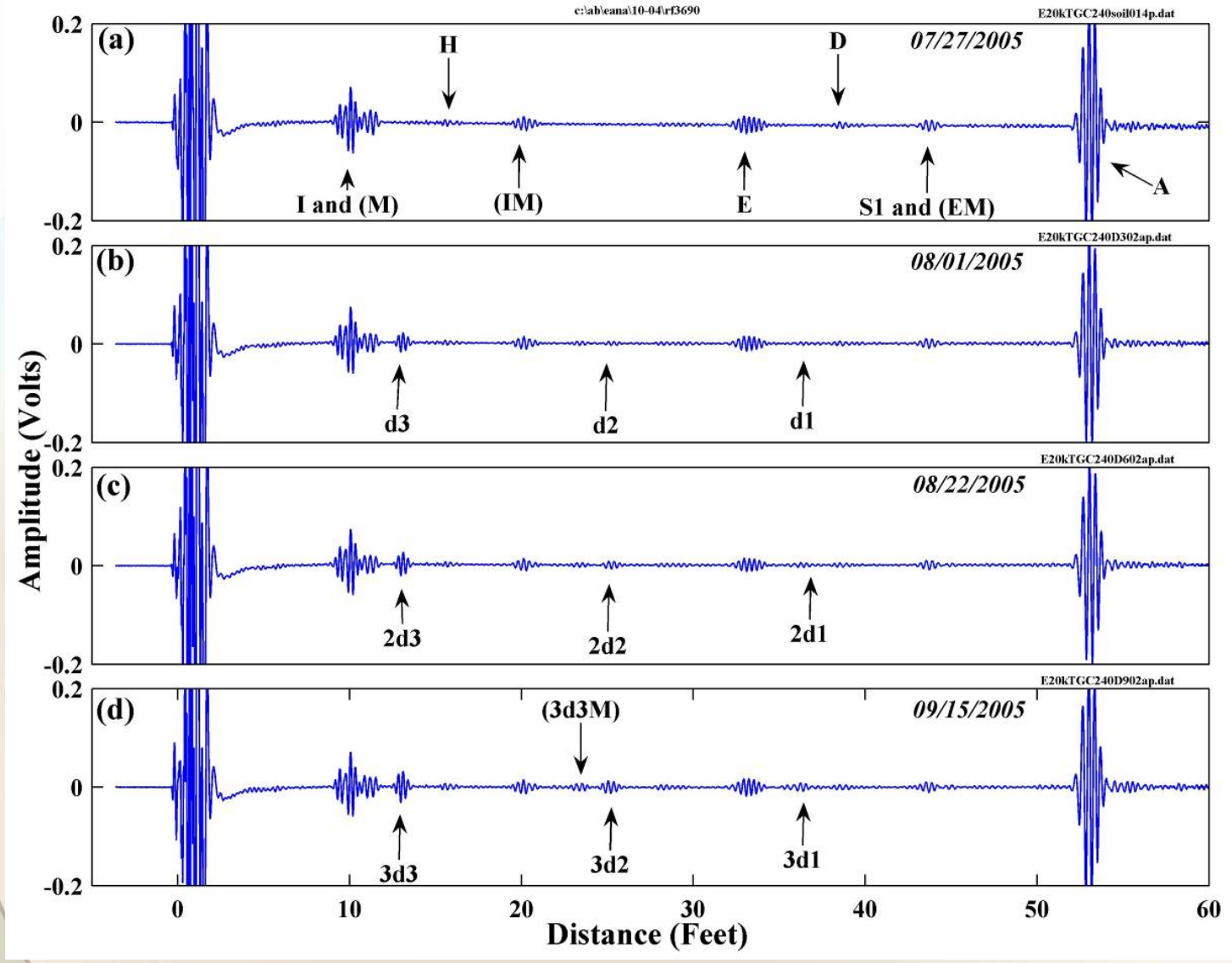
d2

d3

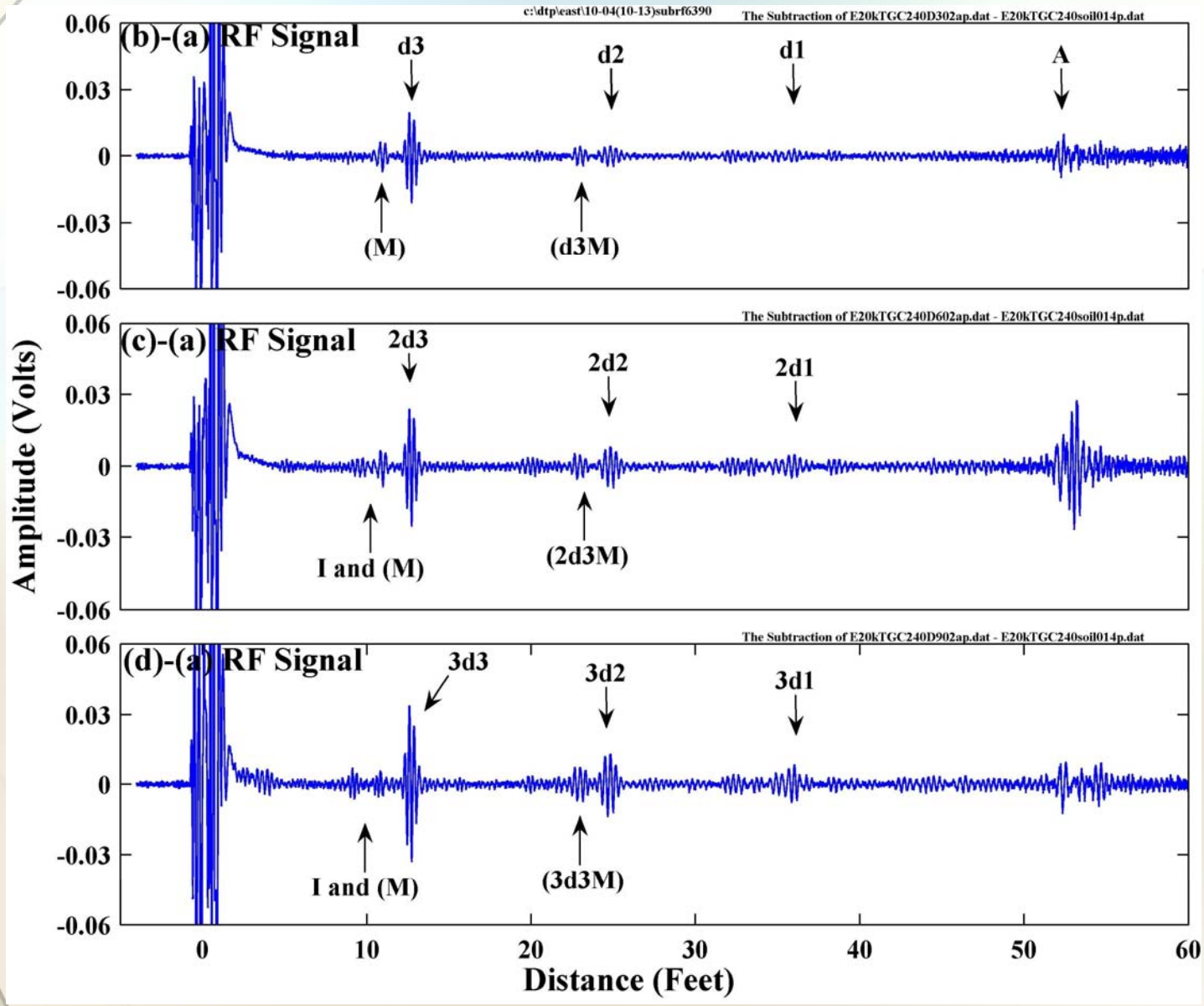
Types chosen per suggestions from NGA user's group

*Circumferential cross section of defects is approx. 1% of pipe wall cross section

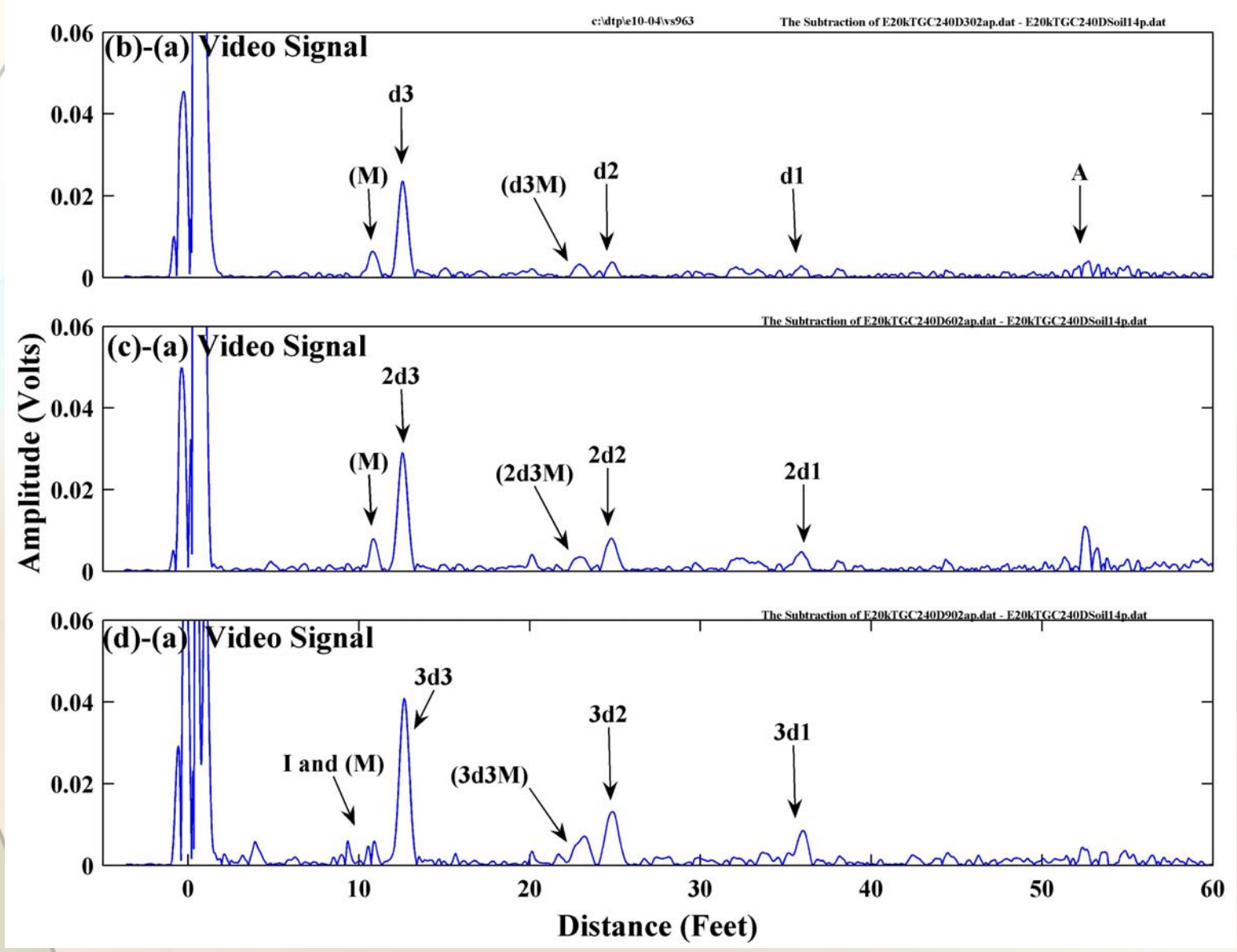
20-kHz TEST DATA ACQUIRED PERIODICALLY BEFORE & AFTER PLACEMENT OF DEFECTS



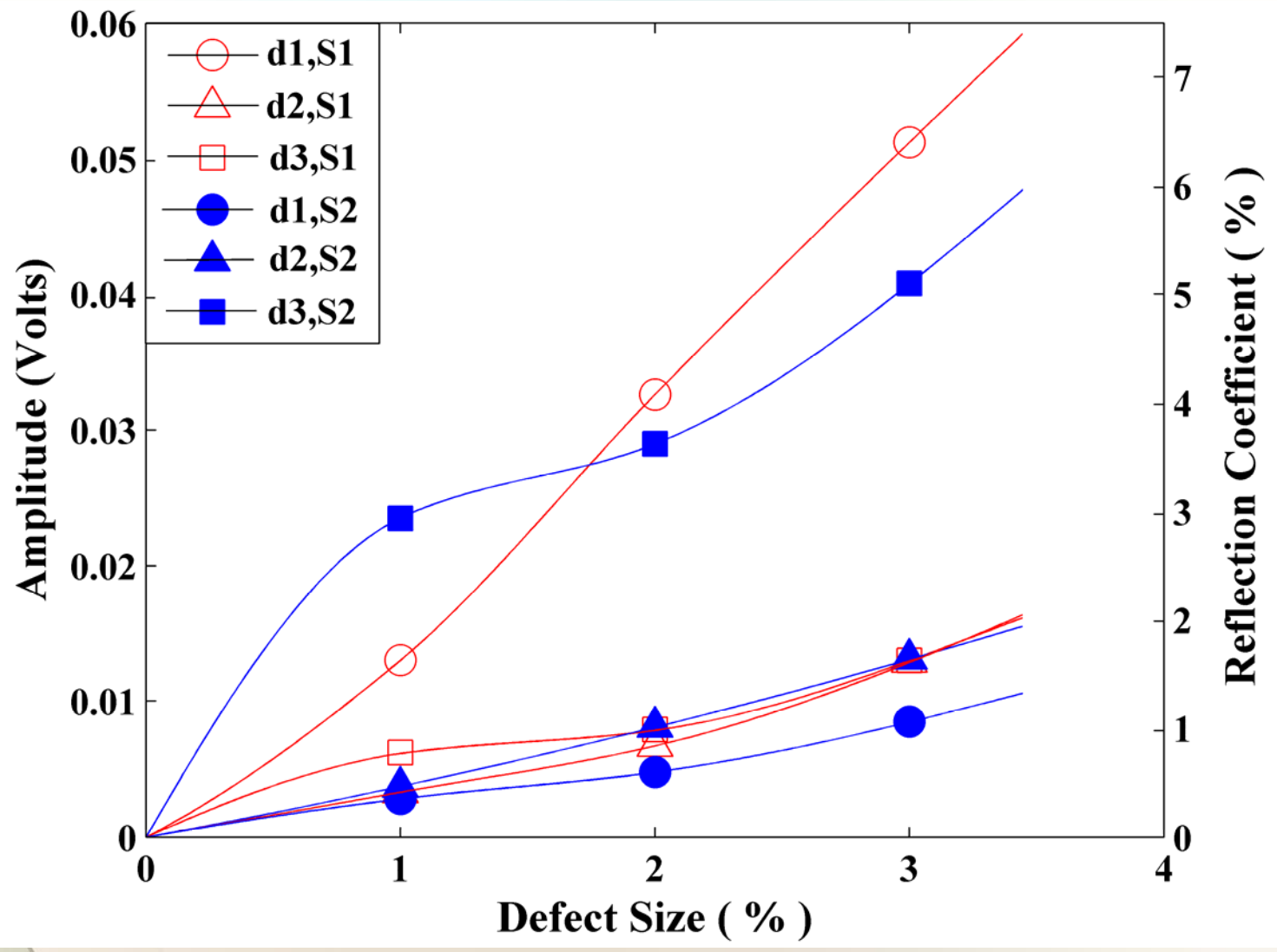
DIFFERENCE DATA IN RF SIGNALS



DIFFERENCE DATA IN VIDEO SIGNALS



DEFECT SIGNAL AMPLITUDE VERSUS DEFECT SIZE



WORK CONDUCTED IN PHASE 1 AND FINDINGS

- Results from cased-line mockup testing
  - 1% defects produced detectable signals over 35-foot distance
  - Due to data variations caused by environmental effects on sensor and mockup, reliably detectable defect size was approximately 2%
- Long-term monitoring of the entire cased sections of pipelines at road crossings is feasible using permanently installed probes

TECHNICAL OBJECTIVES OF PRESENT PROJECT (PHASE 2)

- Develop capability of characterizing defect from guided-wave signals
- Develop long-term condition monitoring capability
- Evaluate and validate capability in the field

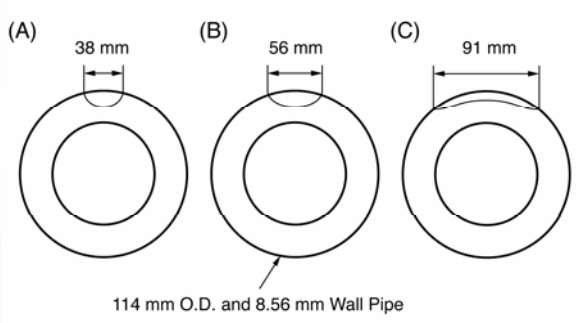
TECHNICAL APPROACH

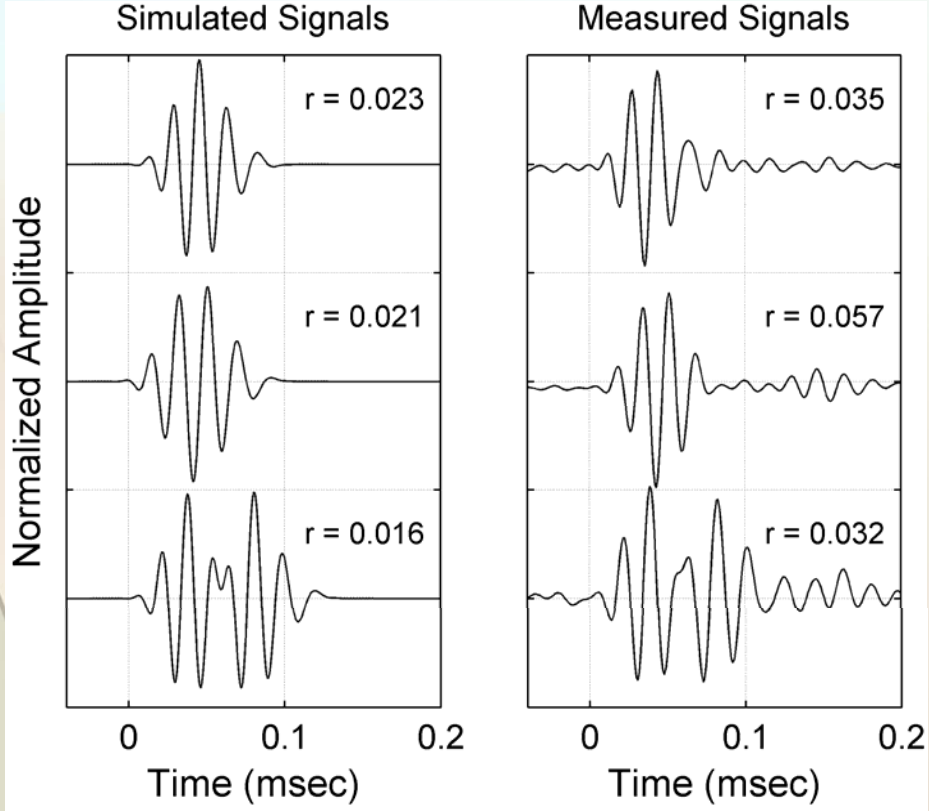
- Defect characterization
  - Refine and validate defect signal simulation model (based on transmission line model)
  - Simulate defect signals of various configurations
  - Develop algorithms for defect characterization
- Long-term condition monitoring
  - Develop procedures for permanently installing T-mode MsS on carrier lines at road crossings
  - Conduct periodic testing and track condition changes (defect growth and initiation) with time
    - NYSEARCH test bed at Binghamton, NY
    - Other cased lines at road crossings

TRANSMISSION LINE MODEL FOR DEFECT SIGNAL SIMULATION

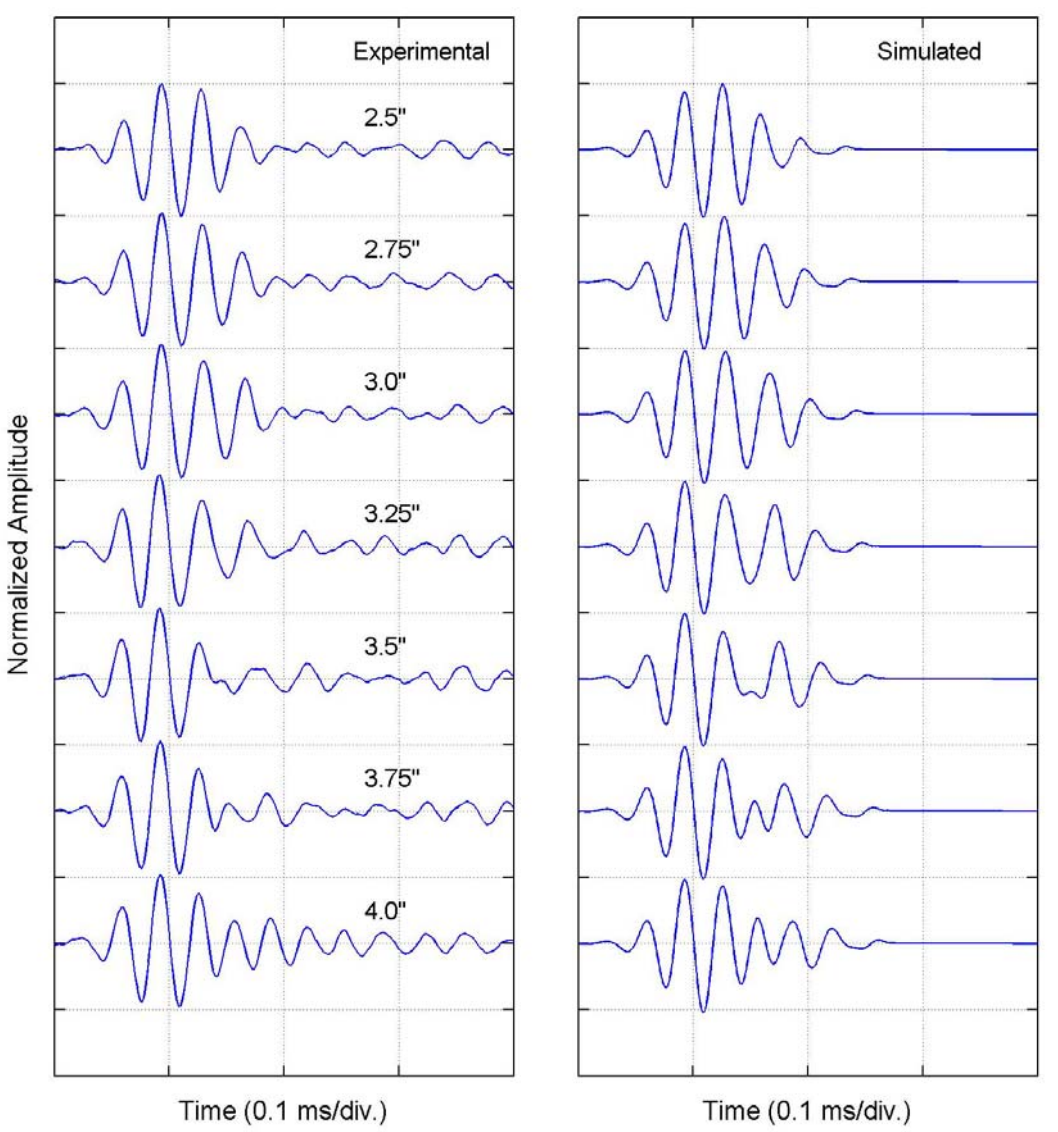
- An analytical model developed at SwRI (patent pending)
- Very effective in simulating defect waveforms; numerical accuracy of signal amplitude within about a factor of 2
- Improvement needs (being addressed in this project)
  - Correction for frequency-dependent shadow effects
  - Validation for T-mode defect signals

EXAMPLES OF EXPERIMENTAL & SIMULATED DEFECT SIGNALS (1)





EXAMPLE OF EXPERIMENTAL & SIMULATED DEFECT SIGNALS (2)



PHASE 2 WORK PLAN

- Task 1 — Defect Signal Modeling Refinement and Experimental Validation
- Task 2 — Algorithm Development for Defect Characterization
- Task 3 — Improvement of Data Analysis Software for Pipeline Inspection and Monitoring
- Task 4 — Adhesive Bonding Material Testing
- Task 5 — Testing on NYSEARCH Test Bed
- Task 6 — Field Validation

OVERALL DURATION AND BUDGET

- Over 24 months (started in April 2006)
  - Tasks 1 through 5 — 14 months
  - Task 6 (field validation) — 9 months
- Budget — Approximately $1,000,000
  - From DOT/PHMSA — $500,000
  - From NYSEARCH/NGA — $500,000

PROJECT STATUS (as of June 23, 2006)

- Task 1 — Defect Signal Modeling Refinement and Experimental Validation
  - Added a feature for inputting various defect configurations to the existing modeling program
  - Made a preliminary GUI version of the program
  - Began experimental measurement of defect signals for correction and validation of the simulation model
    - Measurements with notch-shaped defect completed

EXPERIMENTAL SETUP FOR DEFECT SIGNAL MEASUREMENTS

PROJECT STATUS (Cont'd)

- Task 3 – Improvement of Data Analysis Software for Pipeline Inspection and Monitoring
  - Added a variable threshold level feature
  - Adding a feature that correlates the data acquired from both ends of the cased section of the carrier line
  - A phase-checking algorithm for automatic separation between defect and weld signals was integrated into the system software prior to the start of the project

PROJECT STATUS (Cont'd)

- Task 4 – Adhesive Bonding Material Testing
  - Identified and evaluated three flexible adhesive materials (epoxy and urethane based); found not satisfactory
  - Looking for other candidate materials
- So far, the project is on schedule and under budget

Thank you for your support.

We look forward to successful completion of the project work.

Any questions?