Lowell High School,
Lowell, Massachusetts
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Introduction to Inspection Techniques for Civil Infrastructure

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Where Research Becomes Reality

Outline

- Deteriorated Civil Infrastructure

- Overview of Inspection Techniques
  - Optical/Visual Methods
  - Acoustic/Ultrasonic Methods
  - Thermal Methods
  - Magnetic Methods
  - Microwave/Radar Methods
  - Radiographic Methods
  - Liquid Penetrant Tests
  - Structural Health Monitoring

- Summary

Deteriorated Civil Infrastructure

- Deteriorated civil infrastructure systems and their sudden failures:
  - Significant impacts
  - Catastrophic results
- **Fact**: The U.S. infrastructure receives an overall grade of D, indicating that America has a infrastructure that is poorly maintained, unable to meet current and future demands, and in some cases, unsafe and suggesting a total cost of $2.2 trillion for repair.

(Source: ASCE 2009 Report Card for America's Infrastructure)

- Approaches to the problem:
  - Condition assessment of structures
  - Strengthening and repair of structures
- In both approaches, inspection and monitoring techniques are the pivotal capability in the success of these approaches.

Deteriorated Civil Infrastructure *(cont'd)*

- Sudden failures of civil infrastructure systems
  - Significant impacts
    - EX: I-35 Highway Bridge Collapse, Minneapolis, Minnesota (6:05pm, Wed., Aug. 1, 2007)

(Source: Security camera by the Army Corps of Engineers)

(Source: www.gettyimages.com)

Deteriorated Civil Infrastructure *(cont'd)*

- Sudden failures of civil infrastructure systems
  - Catastrophic results – I-35 Highway Bridge Collapse, Minnesota, MN
    - Causality: 13 deaths, 98 victims (Mn/DOT, Aug. 3,'07)
    - Cost of emergency response: $8 million from USDOT, $250 million from the Congress (Mn/DOT)
    - Business activities: $1.5 million to local small businesses (U.S. Small Business Administration, Aug. 24,'07)
    - Road-user cost due to detouring: $400,000/day (Mn/DOT, Office of Investment Management, Aug. 6,'07)
    - Rebuild cost: $234 million (awarded to the Flatiron-Manson and FIGG Bridge Engineers by Mn/DOT on Oct. 8,'07)
    - Other associated costs and expenses for the rehabilitation
  - Original cost of the bridge: $5.27 million (value in 1964)

[$32.11 million (current value) << Σ of the above costs]

Deteriorated Civil Infrastructure *(cont'd)*

- Strategies for deteriorated civil infrastructure:
  - Rebuild; if it is obvious. (Q: What if it is not obvious?)
  - Rehabilitation; strengthening and repair

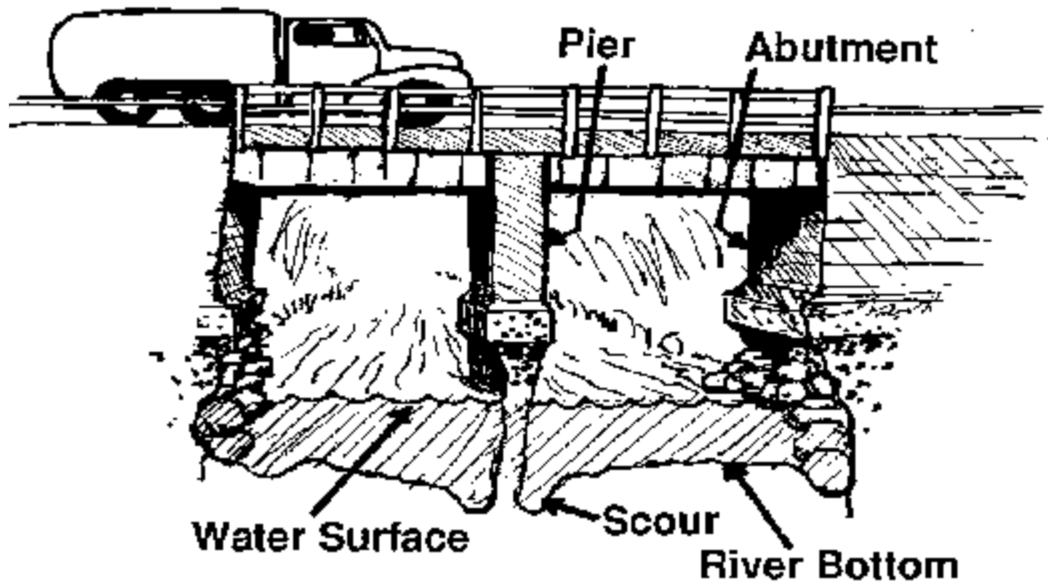
Deteriorated Civil Infrastructure *(cont'd)*

- Some damage levels are not easy to determine.

(Q: Rebuild or rehabilitate?)

Deteriorated Civil Infrastructure *(cont'd)*

- Some damages are not even visible; e.g., bridge scour problem



(Q: How do we detect/inspect it? And at what cost?)

Deteriorated Civil Infrastructure *(cont'd)*

- Condition assessment of structures
  - In addition to the I-35W bridge, there are approximately 75,000 other U.S. bridges also rated as "structurally deficient" in 2007.
    - Structurally deficient: "*The structure is deemed to have met minimum tolerable limits to be left in place as it is*."

→ Are these 75,000 structurally deficient bridges safe? How do we know for sure?

→ We need reliable (inspection results are creditable), efficient (inspection can be accomplished in time) condition assessment technologies for this challenging problem.

Deteriorated Civil Infrastructure *(cont'd)*

- Strengthening and repair of structures
  - For intact structures: To upgrade their design capacity
  - For damaged structures: To restore their design capacity
  - Novel composite materials (fiber reinforced polymer, FRP) have been widely used, such as glass FRP, carbon FRP, & aramid FRP.

→ How is an appropriate level of strengthening determined?

→ We need condition assessment technologies for (1) determining the level of strengthening and (2) evaluating the quality of strengthening.

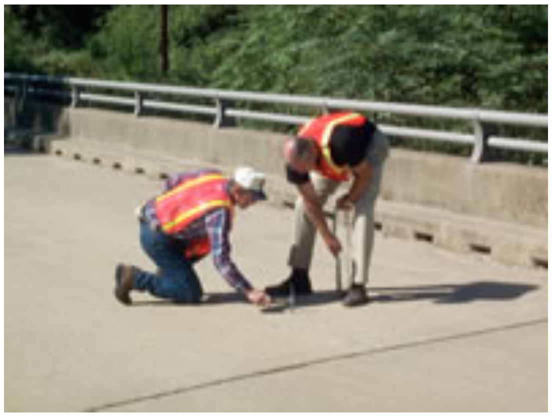
(Source: Fyfe Co. LLC, 2005)

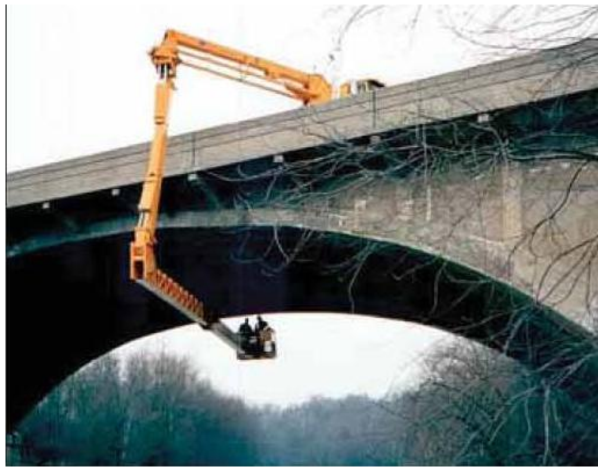
Overview of Inspection Techniques

Technique	Features
Optical/visual	– Distant inspection – Surface information
Acoustic/ultrasonic	– Contact or near-contact inspection – Sensitive to background vibration
Thermal/infrared	– Distant inspection – Sensitive to temperature variation
Radiographic	– Laboratory method
Electrical/magnetic	– Contact or near-contact inspection
Microwave/radar	– Near-field techniques use specially-designed antenna arrays or lens for mechanical focusing to obtain in-depth information. – Far-field techniques provide surface information only.

Optical/Visual Methods

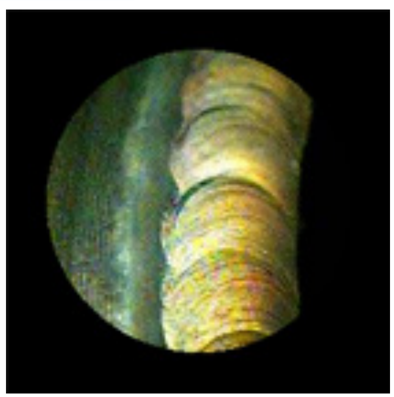
- Visual testing/inspection:





Optical/Visual Methods *(cont'd)*

- Probe-aided optical testing/insp
  - Rigid borescopes
  - Flexible borescopes



(Source: ITI, Inc.
3~12 mm diameter)

(Source: Lenox, Inc.
1~14 mm diameter)

Optical/Visual Methods *(cont'd)*

- Probe-aided optical testing/inspection:
  - Extended borescopes
  - Micro borescopes
  - Periscopes (underwater use)

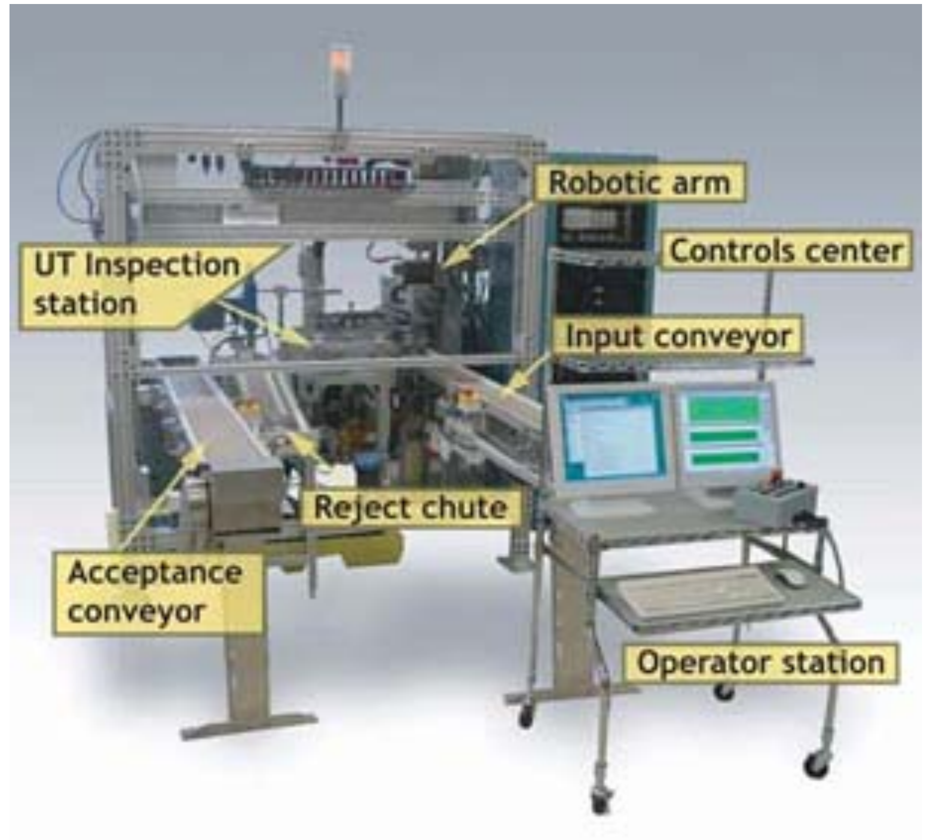
(Source: Extech, Inc., Model BR200, 0.5 mm diameter)

(Source: Eastern NDT, Inc.)

Optical/Visual Methods *(cont'd)*

- Robot-aided optical testing/inspection:

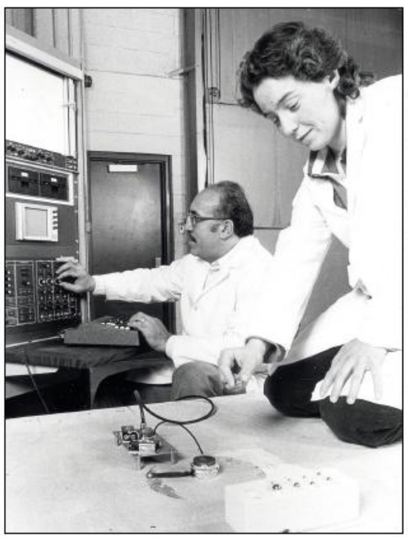
(Source: Everest VIT, Inc.)

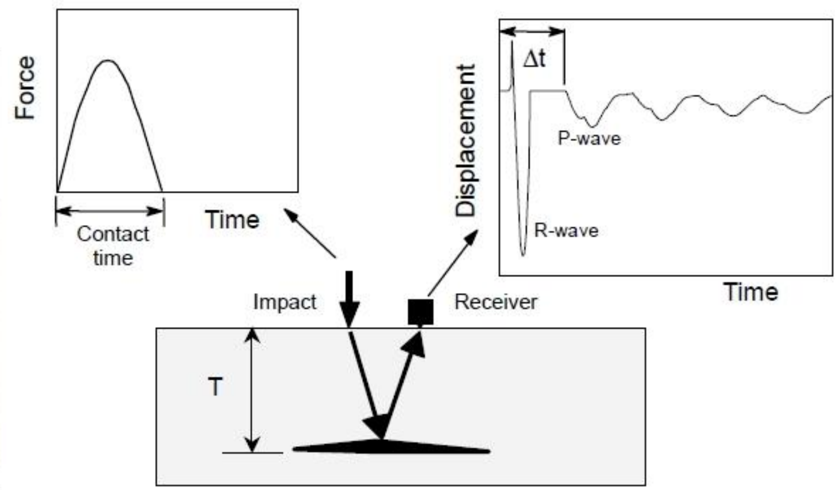


(Source: NDT Automation, Inc.)

Acoustic/Ultrasonic Methods

- Impact-echo:
  - Artificial excitation using steel balls (spherical surface); 4~15 mm in diameter
  - Impact speed: 2~10 m/s
  - Contact time: 15~80 μs (10^{-6} s)

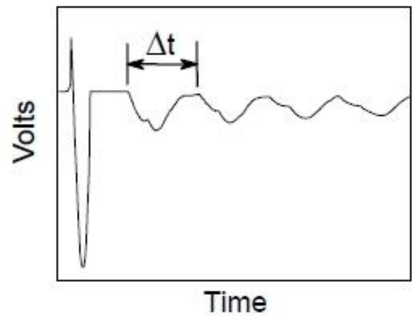


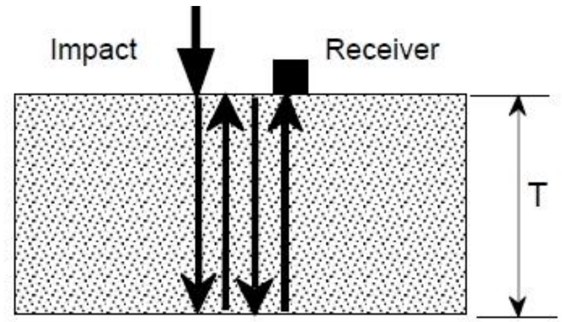


(source: Carino (2001))

Acoustic/Ultrasonic Methods *(cont'd)*

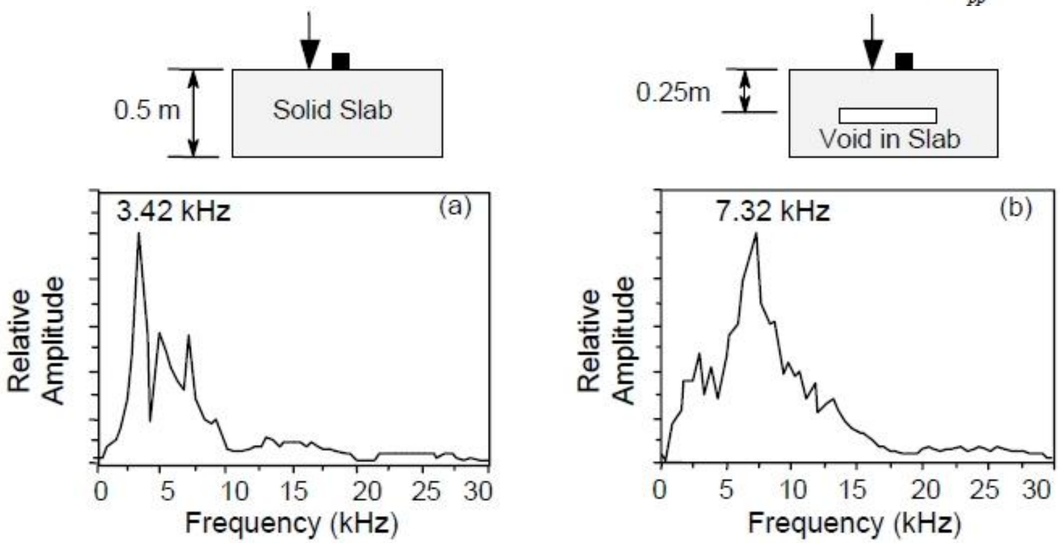
- Impact-echo: *(cont'd)*
  - Thickness determination
  - Flaw detection





$$\Delta t = \frac{2T}{C_{pp}}$$

$$f = \frac{1}{\Delta t} = \frac{C_{pp}}{2T}$$

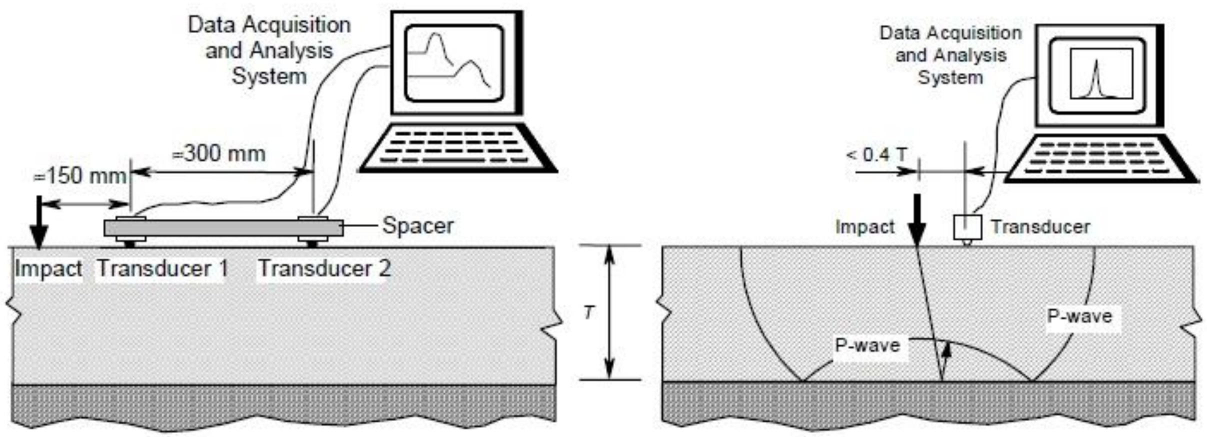


(Source: Carino (2001))

(Source: Impact Echo Instruments, LLC)

Acoustic/Ultrasonic Methods *(cont'd)*

- Impact-echo: *(cont'd)*



Procedure A

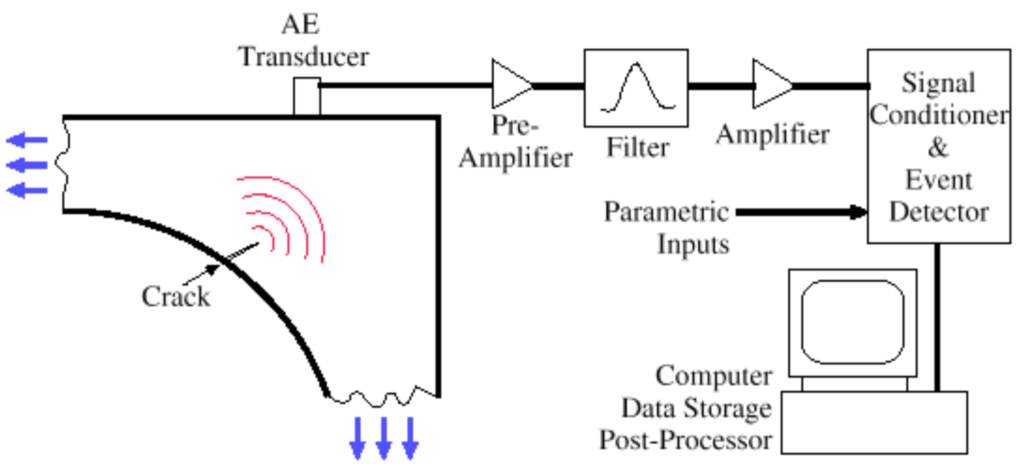
Procedure B

(Source: Carino (2001))

(Source: Impact-Echo Instrument, Inc.)

Acoustic/Ultrasonic Methods *(cont'd)*

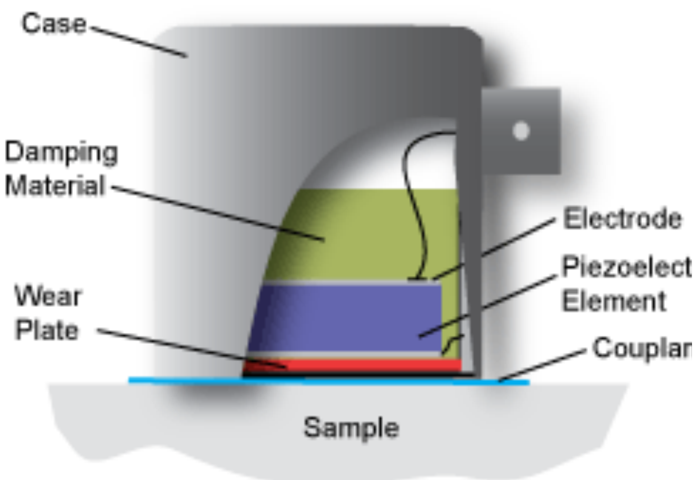
- Acoustic Emission (AE):
  - Based on the fact that material emits/releases minute pulses of elastic energy under stress.
  - Kaiser effect: No further AE would occur once a given load was applied and the AE associated with the release, unless the previous stress level was exceeded.
  - Continuous inspection/monitoring

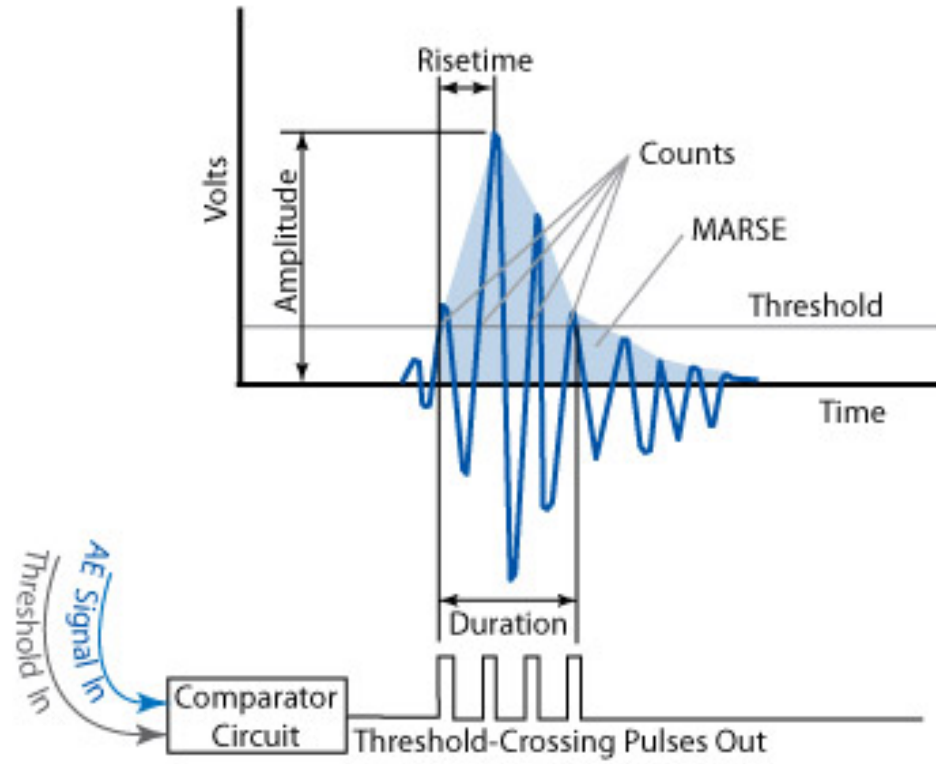


(Source: Physical Acoustics Corp.)

Acoustic/Ultrasonic Methods *(cont'd)*

- Acoustic Emission: *(cont'd)*

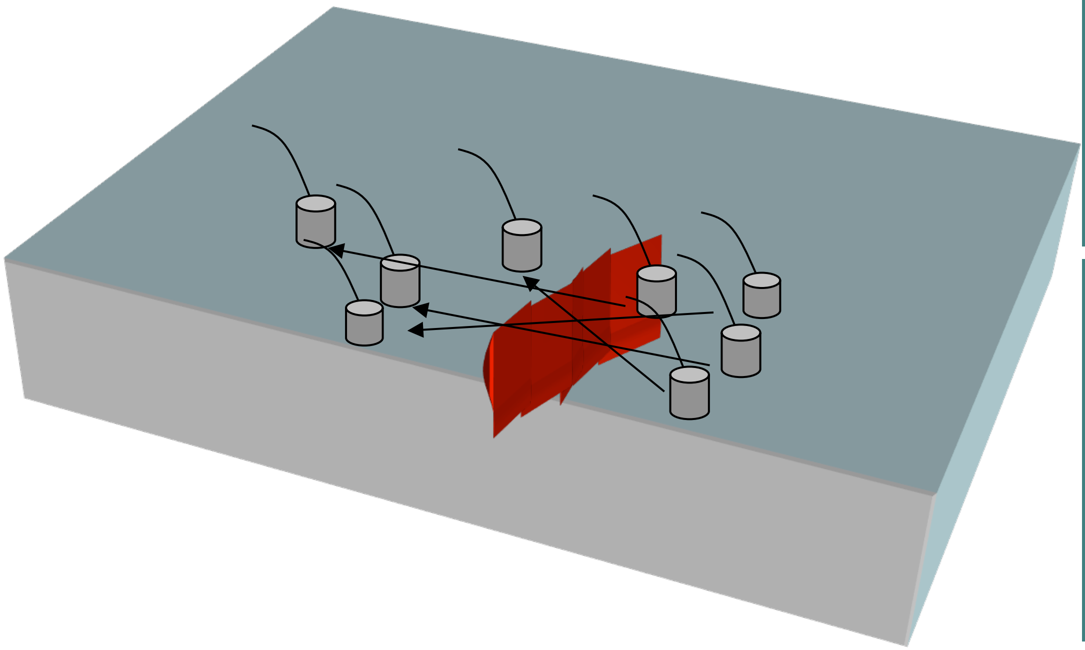


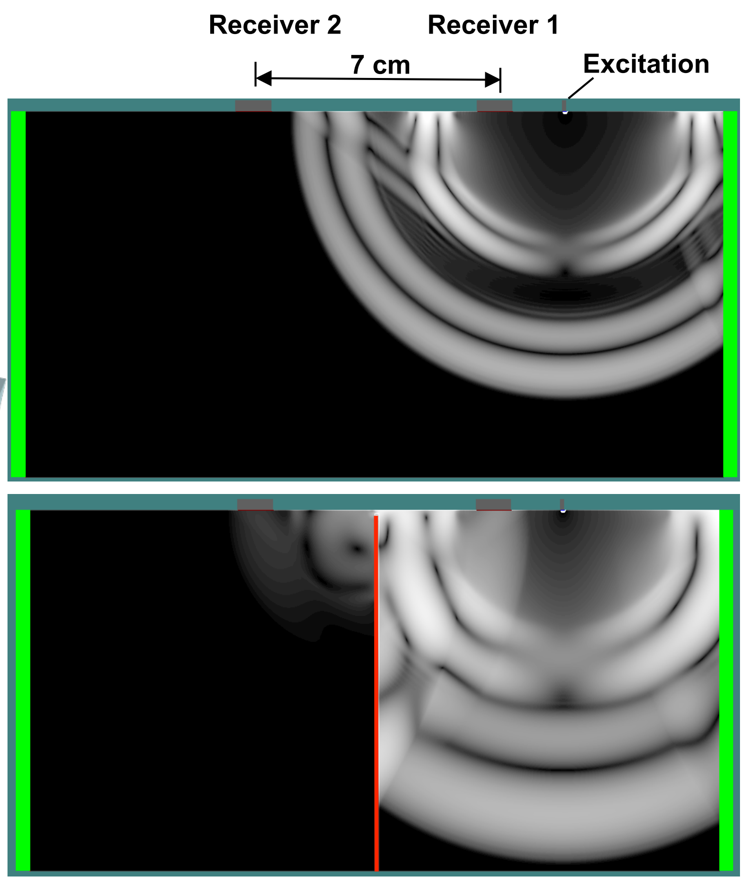


(Source: NDT Resource Center)

Acoustic/Ultrasonic Methods *(cont'd)*

- Acoustic Emission: *(cont'd)*





(Source: Aggelis & Makitas (2009))

Acoustic/Ultrasonic Methods *(cont'd)*

- Ultrasonic testing (UT):
  - Utilizing the propagation and reflection of ultrasonic waves produced by ultrasound transducers
  - Conventional UT sensors operate in 200 kHz and 5 MHz.
  - Coupling is usually needed to overcome the attenuation of ultrasounds in air; some non-contact UT sensors can operate at a distance of 10 mm.

(Source: Material Testing Equipments, Inc)

Acoustic/Ultrasonic Methods *(cont'd)*

- UT: *(cont'd)*
  - Ultrasounds travel in long distances in solids.
  - Ultrasounds travel in well-defined sonic beams.
  - Wave velocity changes when transmitting through material interfaces.
  - Can be used to measure thickness of pipelines and vessels
  - Can be used to detect flaws and their size, shape, and location

(Source: Material Testing Equipments, Inc)

Thermal Methods

- Contact temperature measurement
- Non-contact temperature measurement
- Damage detection
- Traffic monitoring
- Aircraft deicing
- Quality assurance/control

Fluke FLK-T140 IR camera

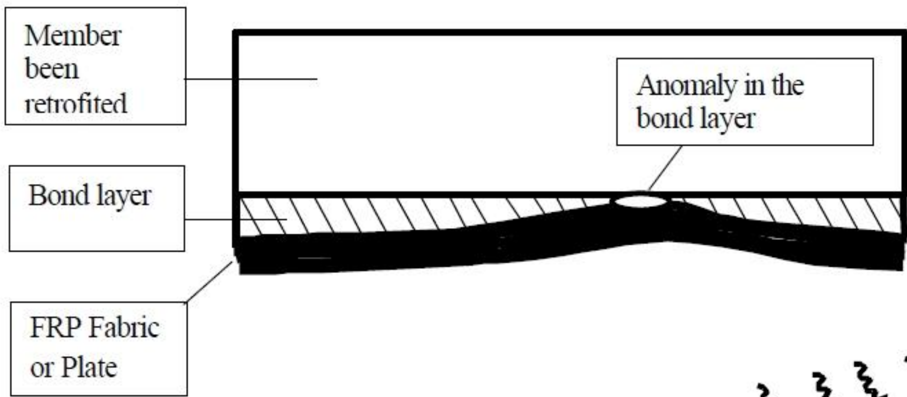
FLIR ThermaCAM B-CAM

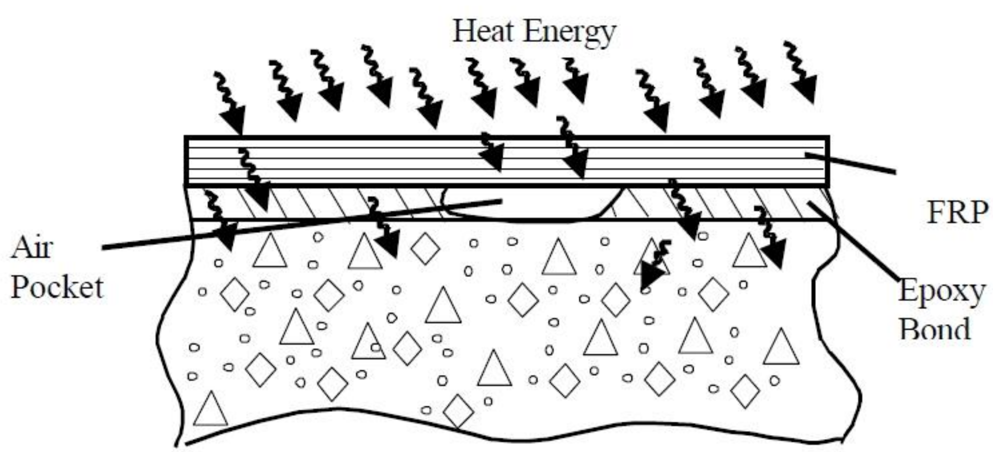
RAK IR camera

Nikon IR camera

Thermal Methods *(cont'd)*

- Damage detection:
  - 1) Debonding detection of fiber reinforced polymer (FRP)-concrete systems

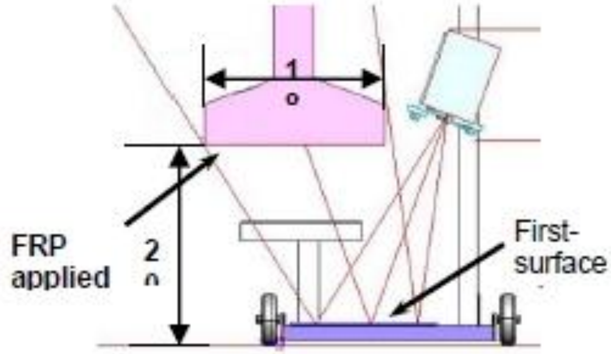


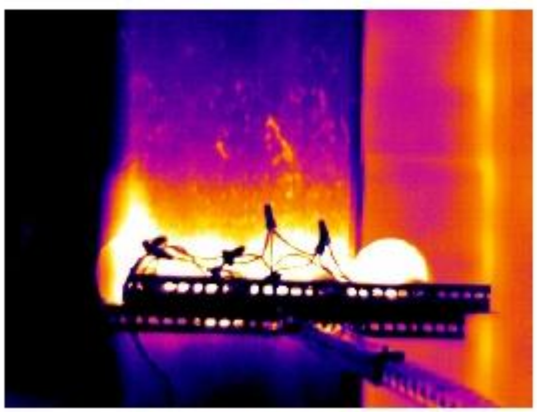


(Source: Mtenga *et al.* (2001))

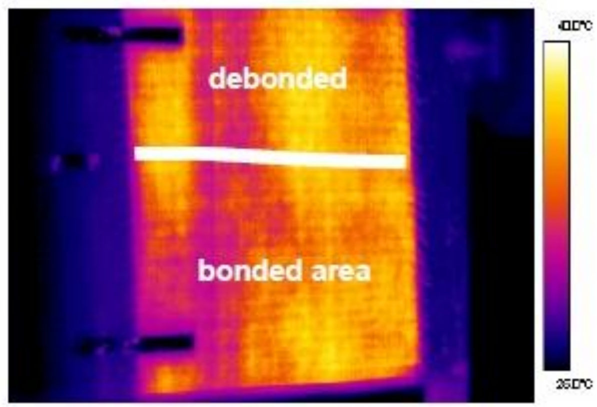
Thermal Methods *(cont'd)*

- Damage detection: 2) Laboratory fiberglass-concrete system





(a) Carbon-fiber – Epoxy System (during application)

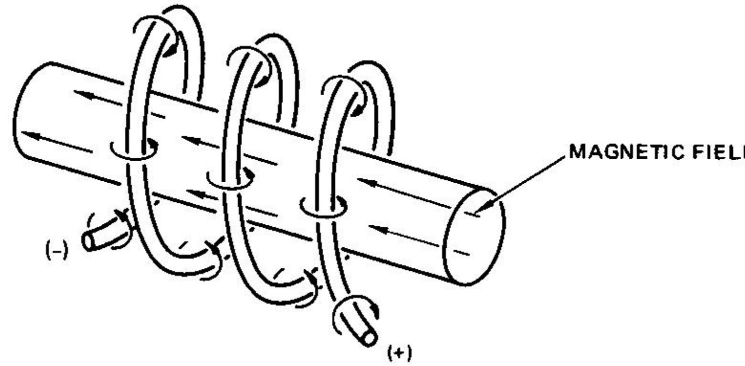


(b) Carbon – Polyurethane System (after failure)

(Source: Brown and Hamilton (2003))

Magnetic Methods

- Magnetic Testing (MT) or Magnetic Particle Inspection (MPI):
  - Induced magnetic fields: **Longitudinal**



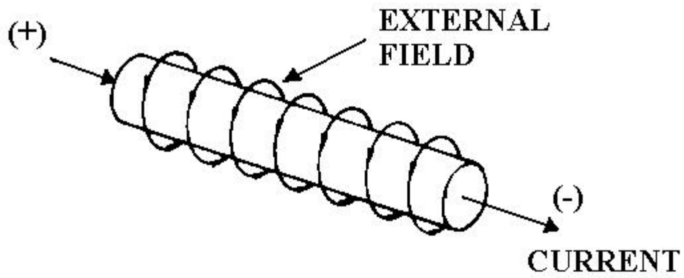
Coil on Wet Horizontal Inspection Unit

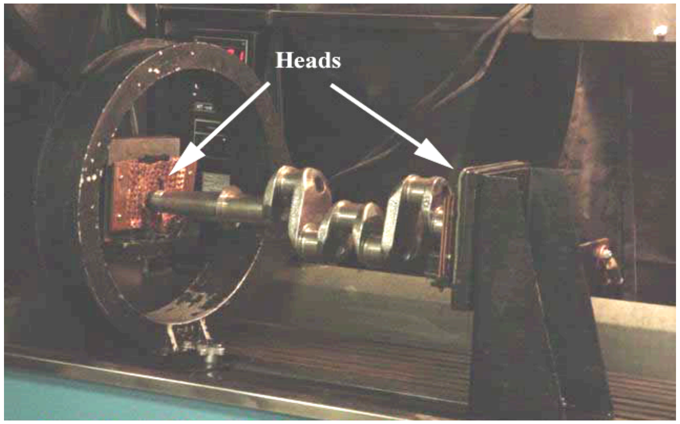
Portable Coil

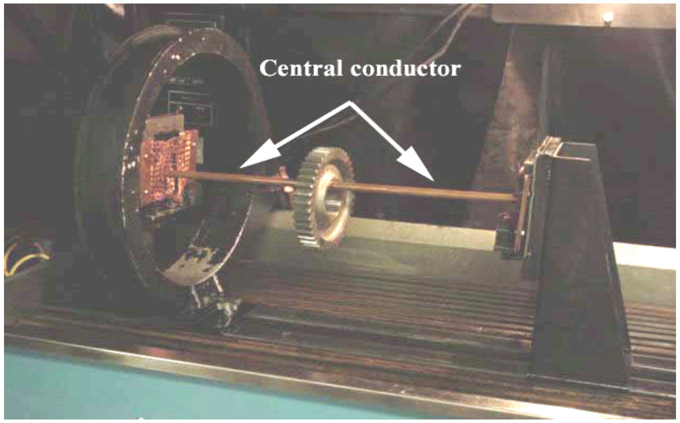
(source: Larson, Iowa State Univ.)

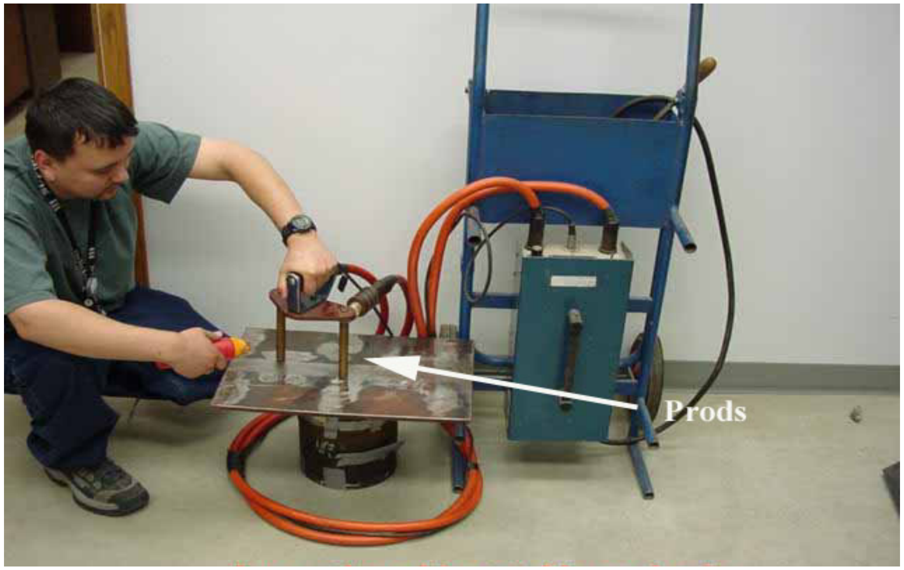
Magnetic Methods *(cont'd)*

- MT or MPI:
  - Induced magnetic fields: **Circular**





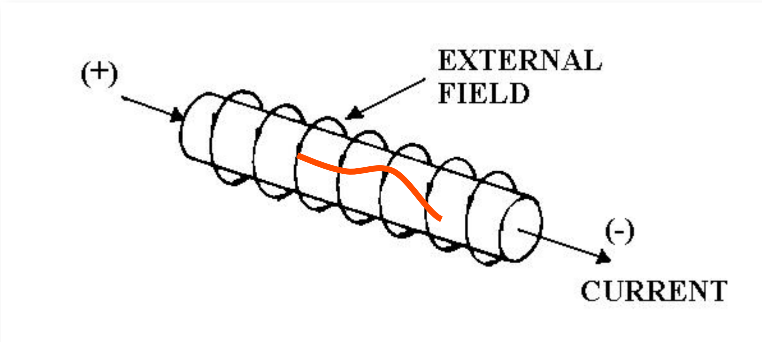




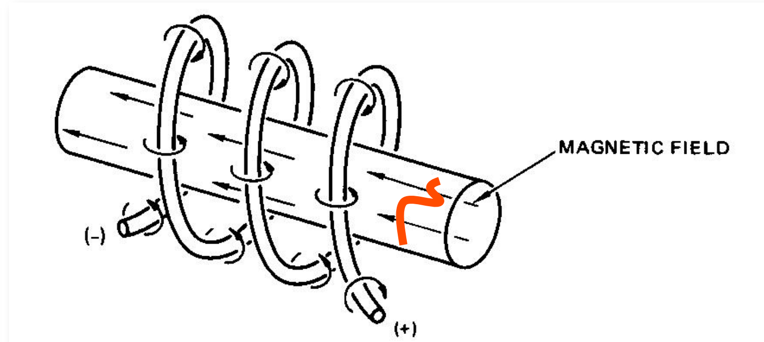
(source: Larson, Iowa State Univ.)

Magnetic Methods *(cont'd)*

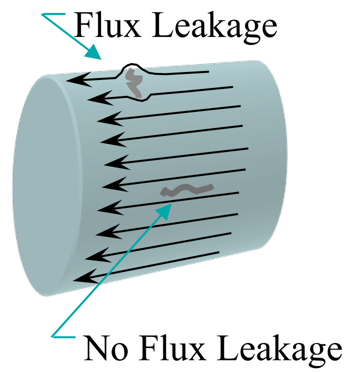
- MT or MPI:



Longitudinal (along the axis)



Transverse (perpendicular the axis)

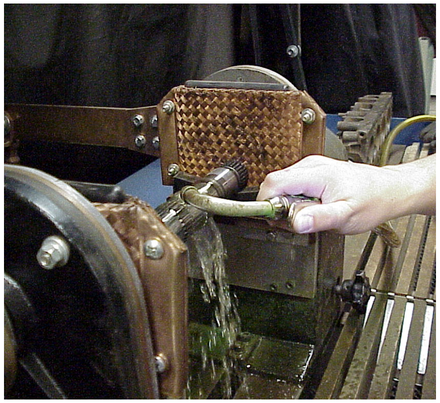
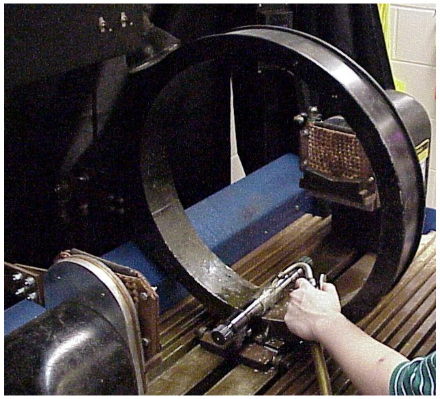


(source: Larson, Iowa State Univ.)

  – Inspection effectiveness depends on the defect orientation with respect to the magnetic fields.

Magnetic Methods *(cont'd)*

- Magnetic Testing (MT) or Magnetic Particle Inspection (MPI):

Dry method

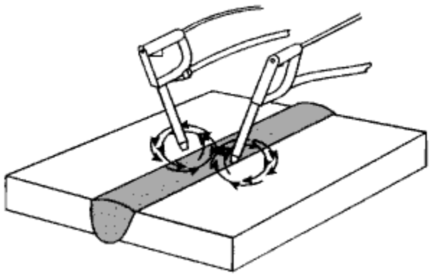
(source: Larson, Iowa State Univ.)

Wet method

(source: Lacey *et al.*, Univ. Illinois Chicago)

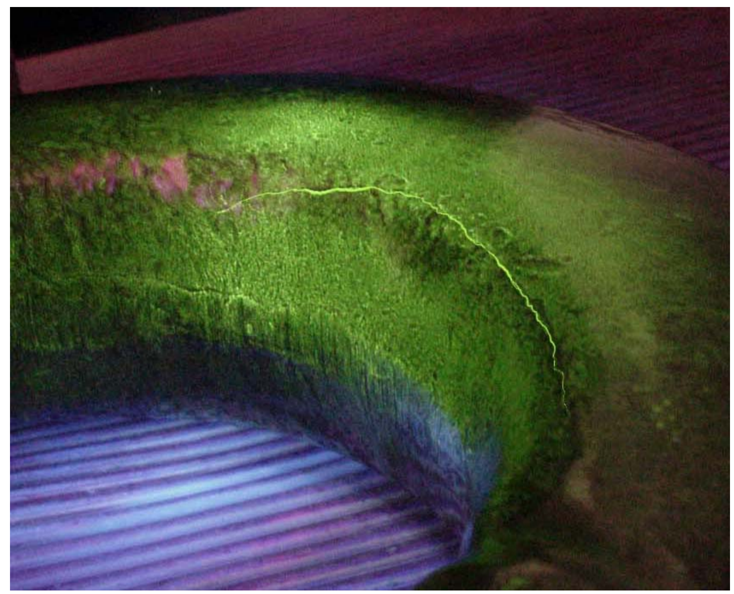
Magnetic Methods *(cont'd)*

- MT or MPI:
  - Dry method



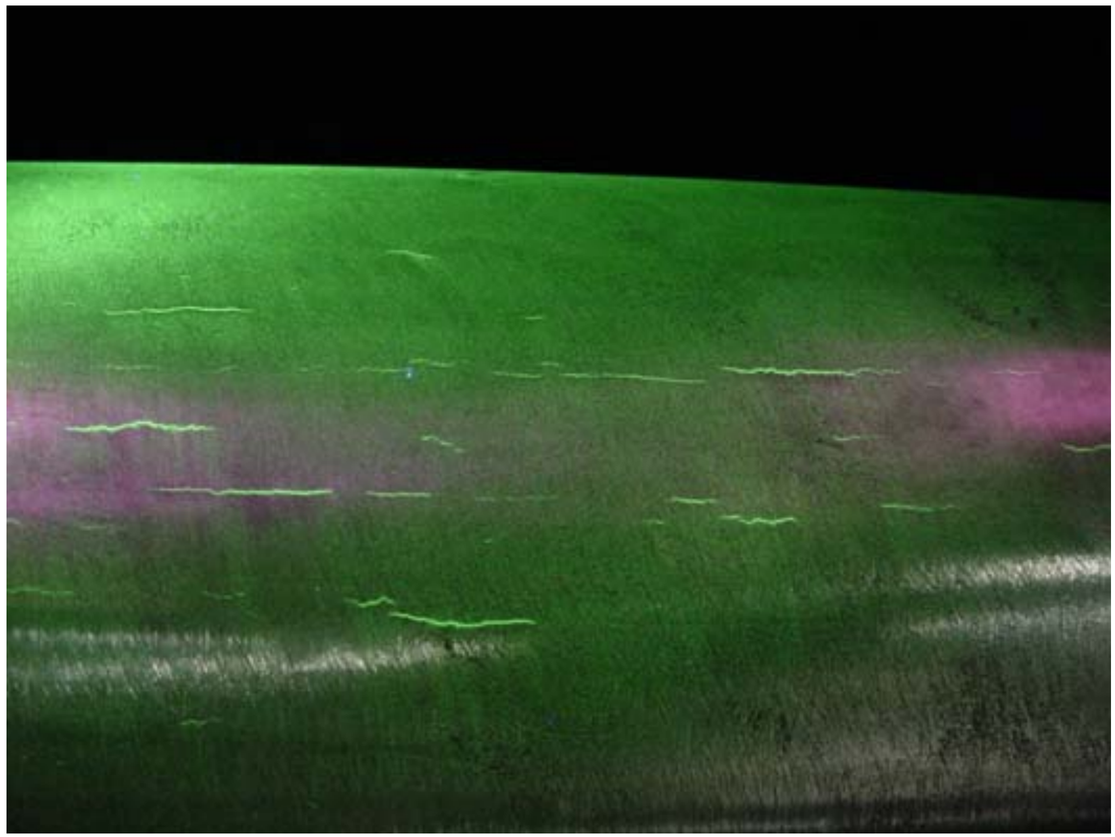
(source: Larson, Iowa State Univ.)

  - Wet method



Magnetic Methods *(cont'd)*

- MT or MPI:
  - Wet method



Fluorescent wet magnetic particles

(source: Larson, Iowa State Univ.)

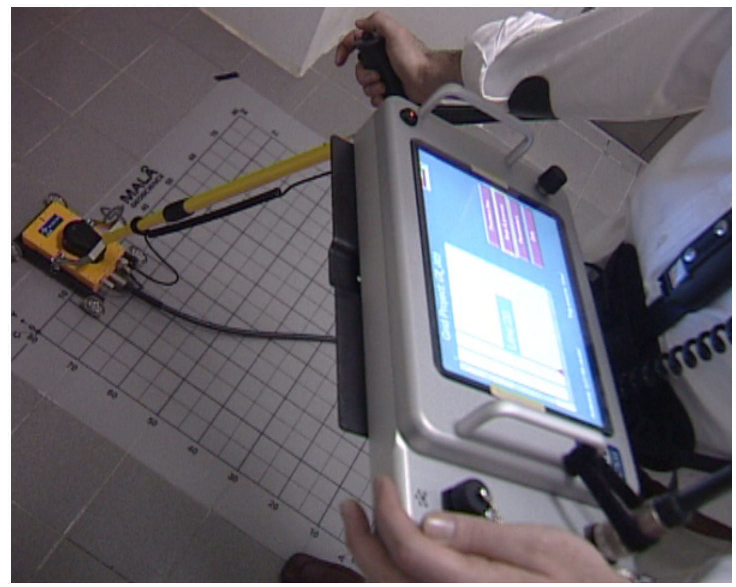
Microwave/Radar methods

- Examples of commercial radar systems:
  - Geophysical Survey Systems, Inc. (GSSI) (Salem, New Hampshire) (http://geophysical.com/)
  - Subsurface Interface Radar (SIR) systems (10 and 3000)
  - Antennas can be used in any system controller
    - 16-80, 100, 200, 400, 900, 1500 MHz (ground based)
    - 1.0, 2.2 GHZ (horn antennas – air launched)

(source: GSSI)

Microwave/Radar Methods *(cont'd)*

- Examples of commercial radar systems:
  - Mala Geoscience, Inc., (Sweden and Charleston, South Carolina) (http://www.malags.com/)
  - MALÅ Imaging Radar Array (MIRA), CX System, Easy Locator System, ProEx, X3M, etc.
  - Antennas can be used in any system controller
    - 100, 250, 500, 800, 1000 MHz (shielded)
    - 25, 50, 100, 200 (unshielded)



(source: Mala Geoscience, Inc.)

Microwave/Radar Methods *(cont'd)*

- Applications and their interpretation:
  - Inspection scheme:
    - Handheld
    - Portable
    - Mobile
  - Data registration is an issue.

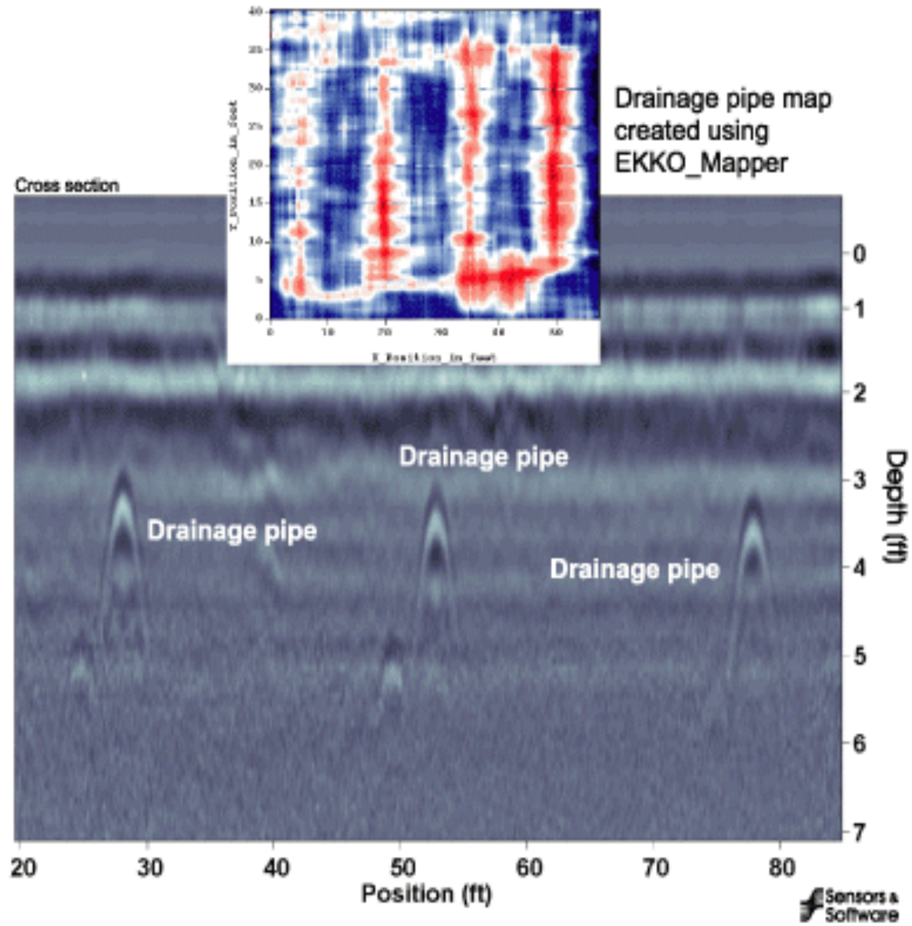
(source: Mala Geoscience, Inc.)

Microwave/Radar Methods *(cont'd)*

- Underground object detection:

(source: Sensors and Software, Inc.)

Locating drainage pipes is necessary when assessing or repairing drainage systems. GPR reflection surveys enable mapping and 3D imaging of non-metallic concrete, clay tile and plastic pipes. The depth and locations of drainage pipes are clearly visible in the GPR cross section. The plan map view provides an overhead view of the pipe locations.



Radiographic Methods

- Neutron radiography facilities at UML:

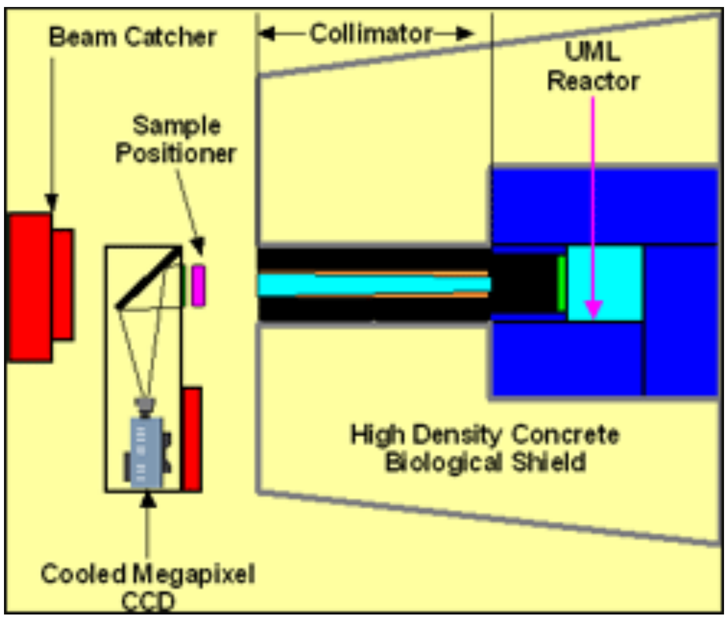


Figure 1. Laptop Hard Drive

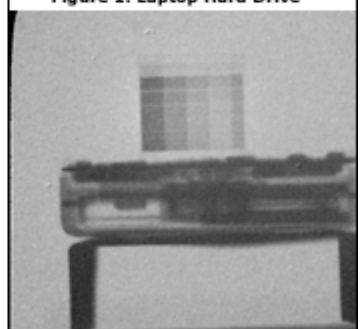
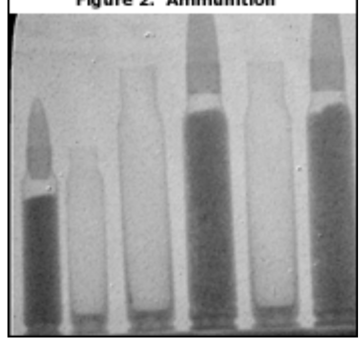
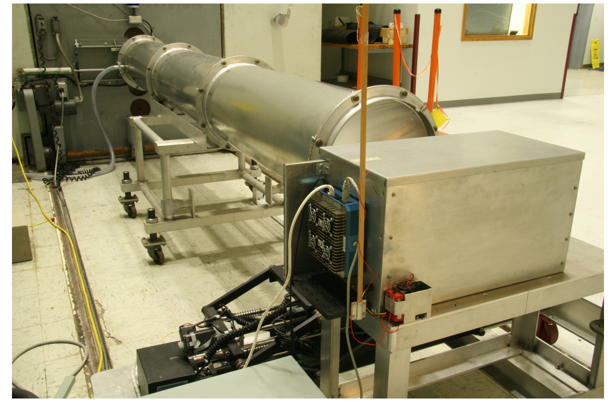
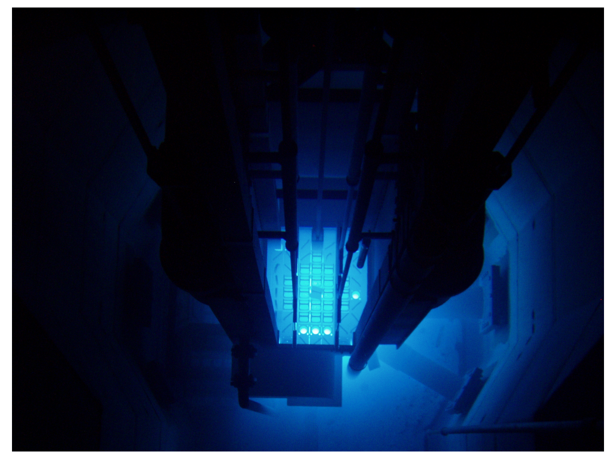


Figure 2. Ammunition







(Source: T. Regan, UML Radiation Laboratory)

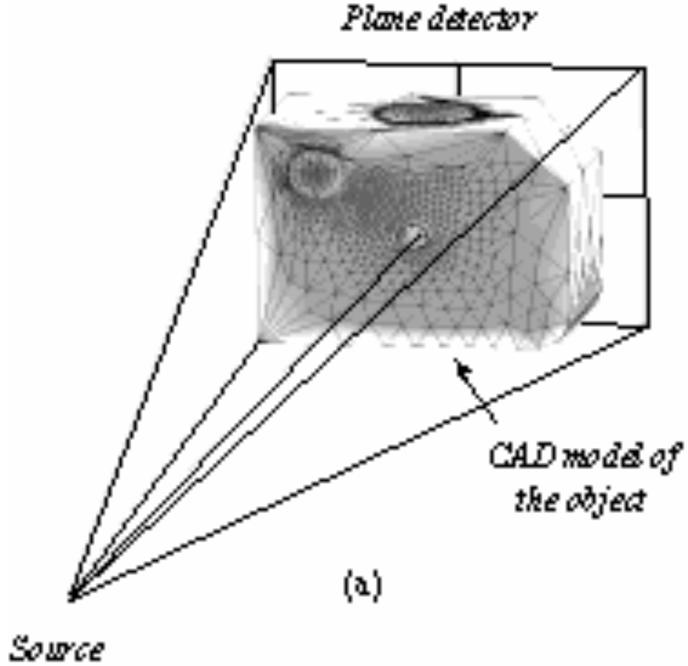
Radiographic Methods *(cont'd)*

- X-ray diffraction:

(Source: N. Scott)

Radiographic Methods *(cont'd)*

- Principle of X-ray radiography:
  - Linear attenuation coefficient



(Source: Freud *et al.* (2000))

Radiographic Methods *(cont'd)*

- X-ray radiography systems:

X-ray chamber inspection system

X-ray pipeline inspection system

(Source: YXLON Intl., Germany)

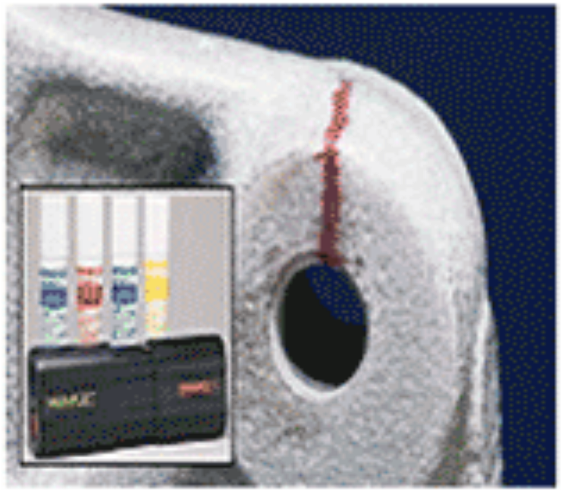
Liquid Penetrant Tests

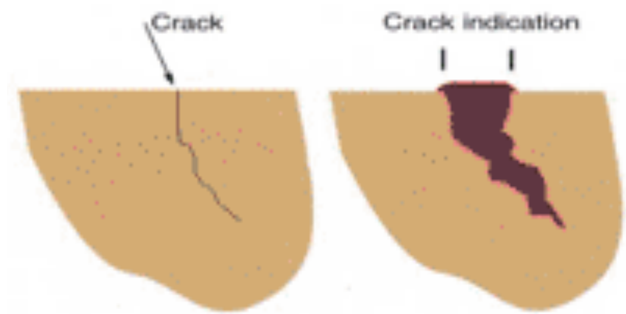
- Examples of the application of liquid penetrants:
  – Spraying

(Source: Saturn Machine, Inc.)

(Source: Hi-tech Cluster, Inc.)

Liquid Penetrant Tests *(cont'd)*

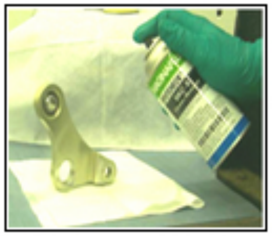


- Surface opening is crucial to reveal the presence of cracks.

  → Porous media are not applicable.

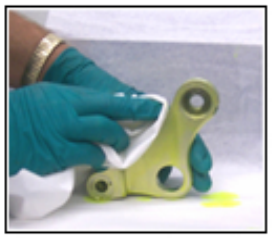
(Source: Odera Group)

Liquid Penetrant Tests *(cont'd)*


Pre-Clean Part


Apply Penetrant

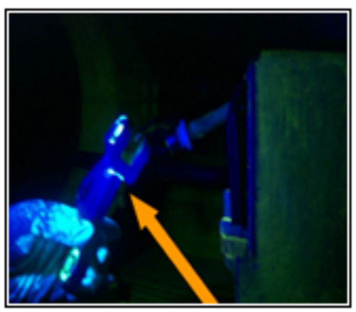

Dwell Penetrant


Remove Excess Penetrant


Apply Developer

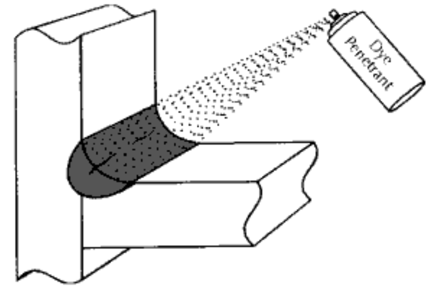

Dwell Developer


View with Black Light


Crack View under Black Light


Post Clean Part

(Source: AC NDT, Inc.)




(Source: Great Lakes Testing, Inc.)

Liquid Penetrant Tests *(cont'd)*

- Effects of the penetrant color:

(Source: Anke, Inc.)

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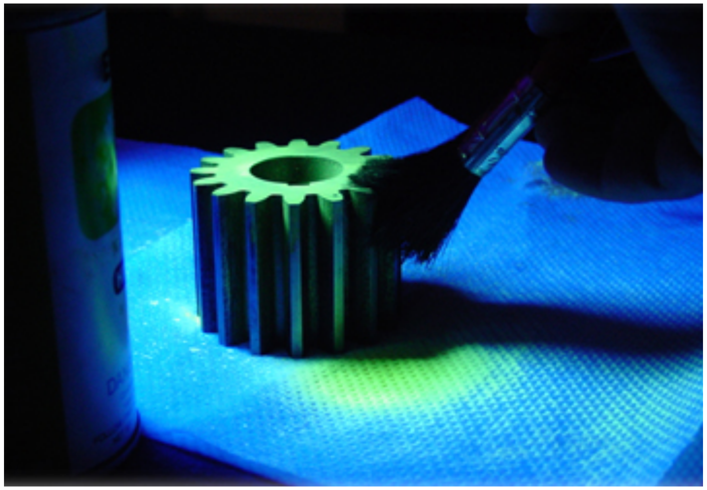
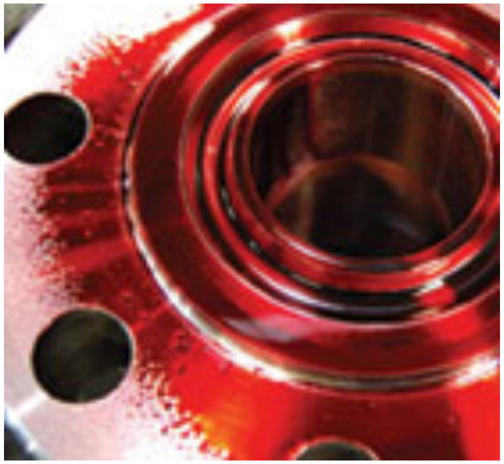
Liquid Penetrant Tests *(cont'd)*

- Defect detectability:



(Source: Techmaster Electronics, Inc.)

(Source: M.A.C.E., Inc.)

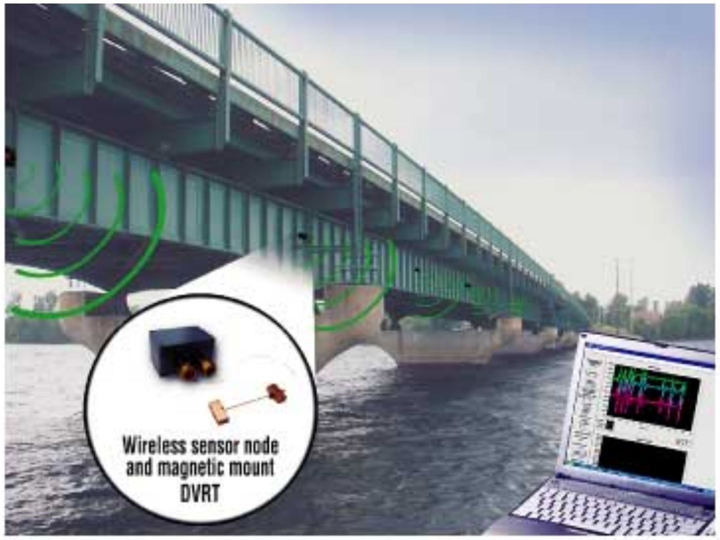


(Source: Machine Specialty, Inc.)

Structural Health Monitoring

- Wired SHM systems
  - Cabling required for each sensor for power supply and/or data transmission
  - More reliable and robust
  - High maintenance

- Wireless SHM systems
  - No cabling required for sensors
  - Power supply is crucial.
  - Background interference becomes an issue.



3. Wireless sensors are used to measure long-term stress and strain in civil engineering structures like buildings and bridges. (Courtesy: Microstrain Inc.)

Summary

- Inspection of engineering structures is a challenging task for engineers (engineers are the doctor of engineering structures).
- There are a number of various inspection techniques to be used for different inspection problems. The question is, which technique is best for particular inspection problem?
- Need to study

  i) the math and physics in each technique (so we know how to use it) and

  ii) the features of each inspection problem (so we know what defects/damages we are looking for).

Questions?