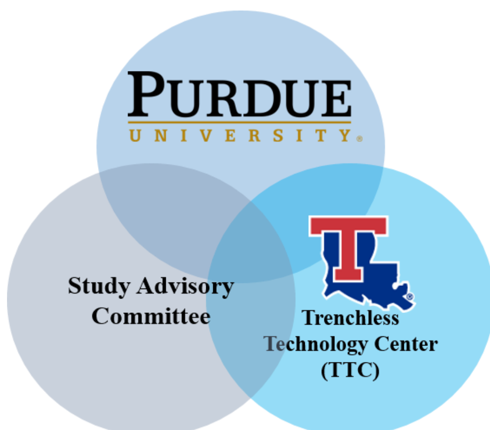
WaterRF 4661: Practical Condition Assessment and Failure Probability Analysis of Small Diameter Ductile Iron Pipe

<u>Survey of Water Utilities</u>

Purdue University and Louisiana Tech University are partnering on a research project (WaterRF #4661) to develop a manual of practice (MOP), for the condition assessment of small diameter (12” and smaller) ductile iron pipes. This project aims to collect input from industry, utility and condition assessment practitioners, about identifying failures in small diameter ductile iron pipes, the technology capabilities and barriers to implementation of condition assessment technologies, and developing guidelines for condition assessment programs.

This survey is geared towards **Water Utilities** and will take approximately **35 minutes** for completion. The information collected is confidential and will be used only for research purposes. Findings of the study will be aggregated and shared with the Water Research Foundation.



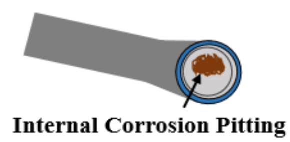
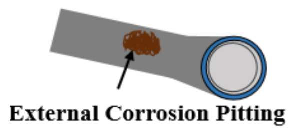
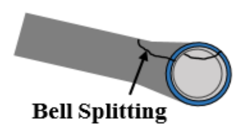
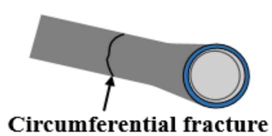
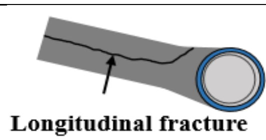
Abbreviations:

CA Condition Assessment
DIP Ductile Iron Pipe
ID Internal Diameter
WDS Water Distribution System

Terms:

Small DIP - Ductile iron pipe with an ID of 12 inch (30 cm) or less

Table 1. Small DIP failure modes

Failure Mode	Figure	Definition
Corrosion Pitting (Internal)		A localized form of corrosion, which manifests itself as pits on the pipe's internal surface.
Corrosion Pitting (External)		A localized form of corrosion, which manifests itself as pits on the pipe's external surface.
Blowout		Blowouts occur when corrosion or graphitisation has reduced the strength of the pipe wall in a local area, to a point where a pressure surge causes the wall to rupture.
Bell Splitting (Split pipe)		The crack terminates just below the bell of the pipe.
Circumferential Failure		Cracks propagate around the circumference of the pipe.
Longitudinal Failure		The pipe wall fractures parallel to the axis of the pipe.
Graphitization	**N/A**	A process which removes some of the iron in the pipe, but leaves behind a matrix of graphite flakes that is held together in part by iron oxide.
Joint Failure	**N/A**	As distinct from bell splitting or bell shearing which indicate fracture of the bell/socket, joint failure means that the joint is no longer watertight, resulting in leakage. This can undermine the pipe bedding and may produce heave forces in expansive clay soils.

Section 1 – Information about your agency

In this section, we seek information about the size of your agency, the number of customers that your agency serves, and the extent of your infrastructure network.

1. What is the size of the population, which your agency serves in: a) urban areas (population greater 50,000 people), and b) rural areas (population less than 50,000 people)?

2. What is the total length of pipeline in your Water Distribution System (WDS)?

ft	or	mi

3. Please indicate the total length of the following classes of DIP in your WDS (ft/mi)?

Size (inches)	Thickness Class						
	50	51	52	53	54	55	56
≤ 8							
10							
12							
≥12							

4. What is the total length of small diameter DIP that serves rural areas?

ft	or	mi

5. What is the total length of small diameter DIP that serves urban areas?

ft	or	mi

Section 2 – Modes of failure, causes of failure, and experience with condition assessment (CA) techniques

In this section, we seek information about the failure modes that your agency has observed, the causes of failure, and your experience with different condition assessment techniques. We also hope to find out how the location of the pipe (whether in Urban or Rural areas), affects your choice of condition assessment technique. Questions 6 – 15, are related to small DIP in Urban areas, and Questions 16 – 25, are related to small DIP in Rural Areas.

Questions related to failure modes, and causes of failure in small DIP located in Urban areas (population greater than 50,000 people)

6. Which of the following **failure modes** have you observed in your small DIPs (in **urban** areas)? Among the failure modes that you have observed, please rank them numerically according to how frequently they occur (in **urban areas**)? (Enter 1 for the most frequent failure mode, 2 for the second most frequent, and so on. **Enter N/A if your utility has not experienced this failure mode in small DIP**)

Failure Mode	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Corrosion Pitting (Internal)		
Corrosion Pitting (External)		
Blowout Holes		
Bell Splitting (Split pipe)		
Circumferential Failure		
Longitudinal Failure		
Graphitization		
Joint Failure		
Others (please specify)		

7. Please indicate the most common failure modes for your small diameter DIP based on their age (in urban areas)?
    a. Less than 10 years – Modes of failure: ______________________
    b. Between 10 - 30 years – Modes of failure: ______________________
    c. Between 30 - 50 years – Modes of failure: ______________________
    d. Greater than 50 years – Modes of failure: ______________________

8. Please rank the following external causes of failure for your small diameter DIP, based on their frequency of occurrence (in urban areas)? (Enter 1 for the most frequent cause of failure, 2 for the second most frequent cause of failure, and so on. **Enter N/A if your utility has not experienced this cause of failure in small DIP**)

Cause of failure (External)	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments (Please indicate if this is the initial cause or the final trigger leading to failure)**
Additional loading to the system (truck loads, frost loads, changes in temperature, or changes in water pressure)		
Third-party damage		
Joint damage		
Manufacturing defects		
Corrosion Pitting (external)		
Installation damages		
Others (please specify)		

9. Please rank the following internal causes of failure for your small diameter DIP based on their frequency of occurrence (in Urban areas)? (Enter 1 for the most frequent cause of failure, 2 for the second most frequent cause of failure, and so on. **Enter N/A if your utility has not experienced this cause of failure in small DIP**)

Cause of failure (Internal)	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments (Please indicate if this is the initial cause or the final trigger leading to failure)**
Leakage (That results in pipe bedding being washed away)		
Transient loading		
Structural damage (During installation)		
Internal corrosion		
Manufacturing defects		
Others (please specify)		

Questions related to condition assessment (CA) of small DIP located in urban areas

10. Which of the following Condition Assessment techniques (CA) do you use for small diameter DIP (in urban areas)? Among the CA techniques that you use, please rank them according to their frequency of use. (Enter 1 for the most frequent failure mode, 2 for the second most frequent, and so on. **Enter N/A if your utility has not used a particular technique in the CA of small DIP**)

Condition Assessment (CA) Technique	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Acoustic propagation velocity measurement (APVM)		
Broadband Electro-Magnetics (BEM)		
CCTV inspection technology (CCTV)		
Magnetic Flux Leakage (MFL)		
Manual Pit Depth Measurement (MPDM)		
Remote Field Technology (RFT) (otherwise known as Remote Field Eddy Current)		
Soil Linear Polarization Resistance (SLPR)		
Ultrasonic—Automated, Handheld, Phased Array (UA, UH, UPA)		
Ultrasound C-scan (UCs)		
Acoustic leak detection (ALD)		
Others (Please specify)		

11. Please rate on a scale of 1-5 (1 representing the most satisfied and 5 representing the least satisfied), your satisfaction with each of the CA technique that you selected in Question 10, in the following areas: Ease of use, Confidence in data, Ease of data interpretation, Speed of use, Interruption in service, and Overall cost.

CA technique	**Ease of use**	**Confidence in data collected**	**Ease of data interpretation**	**Speed of use**	**Interruption in service**	**Overall cost**	**Comments**
APVM							
BEM							
CCTV							
MFL							
MPDM							
RFT							
SLPR							
UA, UH, UPA							
UCs							
ALD							
Others							

12. Which of the CA techniques mentioned in Question 10 require taking the pipeline out of service? Could you provide us an estimate of how long the pipeline is typically out of service for?

CA technique	**Length (ft/miles) of the pipeline that is out of service**	**Internal diameter of the pipe (inches)**	**Number of access ports**	**Number of inline valves**	**Time pipeline is out of service**	**Comments**
APVM						
BEM						
CCTV						
MFL						
MPDM						
RFT						
SLPR						
UA, UH, UPA						
UCs						
ALD						
Others						

13. Do any of the CA techniques that you use require the pipe to be excavated? If yes, could you please list them?

____

____

____

14. Which of the following condition monitoring technique do you use for small diameter DIP in urban areas? Among the condition monitoring techniques that you use, please rank them according to their frequency of use. (Enter 1 for the most frequently used condition monitoring technique, 2 for the second most frequent, and so on. **Enter N/A if your utility has not used a particular technique in the condition monitoring of small DIP**)

Condition Monitoring Technique	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Corrosion rate sensor		
Acoustic emission sensor		
Magnetostrictive sensor		
Conformable and flexible eddy current array		
Flexible ultrasonic sensor		
Guided wave sensor		
Damage sensor		
Microwave back-scattering sensor		
Fiber optic sensor		
Others (Please specify)		

15. Please rate on a scale of 1-5 (1 representing the most satisfied and 5 representing the least satisfied), your satisfaction with each of the condition monitoring technique that you selected in Question 14, in the following areas: Confidence in data, Ease of data interpretation, and Overall cost.

Condition monitoring technique	**Confidence in data collected**	**Ease of data interpretation**	**Overall cost**	**Comments**

<u>Questions related to failure modes, and causes of failure in small DIP located in rural areas (population less than 50,000 people)</u>

16. Which of the following **failure modes** have you observed in your small DIPs (in **<u>rural</u>** areas)? Among the failure modes that you have observed, please rank them numerically according to how frequently they occur (in **<u>rural</u> areas**)? (Enter 1 for the most frequent failure mode, 2 for the second most frequent, and so on. **Enter N/A if your utility has not experienced this failure mode in small DIP**)

Failure Mode	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Corrosion Pitting (Internal)		
Corrosion Pitting (External)		
Blowout Holes		
Bell Splitting (Split pipe)		
Circumferential Failure		
Longitudinal Failure		
Graphitization		
Joint Failure		
Others (please specify)		

17. Please indicate the most common failure modes for your small diameter DIP based on their age (in rural areas)?
    a. Less than 10 years – Modes of failure: ______________________
    b. Between 10 - 30 years – Modes of failure: ______________________
    c. Between 30 - 50 years – Modes of failure: ______________________
    d. Greater than 50 years – Modes of failure: ______________________

18. Please rank the following external causes of failure for your small diameter DIP, based on their frequency of occurrence (in rural areas)? (Enter 1 for the most frequent cause of failure, 2 for the second most frequent cause of failure, and so on **Enter N/A if your utility has not experienced this cause of failure in small DIP**)

Cause of failure (External)	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments (Please indicate if this is the initial cause or the final trigger leading to failure)**
Additional loading to the system (truck loads, frost loads, changes in temperature, or changes in water pressure)		
Third-party damage		
Joint damage		
Manufacturing defects		
Corrosion pitting (external)		
Installation damages		
Others (please specify)		

19. Please rank the following internal causes of failure for your small diameter DIP based on their frequency of occurrence (in rural areas)? (Enter 1 for the most frequent cause of failure, 2 for the second most frequent cause of failure, and so on **Enter N/A if your utility has not experienced this cause of failure in small DIP**)

Cause of failure (Internal)	**Frequency** (1 – most frequent, 2 – second most frequent, and so on)	**Comments (Please indicate if this is the initial cause or the final trigger leading to failure)**
Leakage (That results in pipe bedding being washed away)		
Transient loading		
Structural damage (During installation)		
Internal corrosion		
Manufacturing defects		
Others (please specify)		

<u>Questions related to condition assessment (CA) of small DIP located in rural areas</u>

20. Which of the following Condition Assessment techniques (CA) do you use for small diameter DIP (in <u>rural</u> areas)? Among the CA techniques that you use, please rank them according to their frequency of use. (Enter 1 for the most frequently used CA technique, 2 for the second most frequently used CA technique, and so on. **Enter N/A if your utility has not used a particular technique in the CA of small DIP**)

Condition Assessment (CA) Technique	**Frequency** (1 – most frequent, 2 – second most frequent, and so on)	**Comments**
Acoustic propagation velocity measurement (APVM)		
Broadband Electro-Magnetics (BEM)		
CCTV inspection technology (CCTV)		
Magnetic Flux Leakage (MFL)		
Manual Pit Depth Measurement (MPDM)		
Remote Field Technology (RFT) (otherwise known as Remote Field Eddy Current)		
Soil Linear Polarization Resistance (SLPR)		
Ultrasonic—Automated, Handheld, Phased Array (UA, UH, UPA)		
Ultrasound C-scan (UCs)		
Acoustic leak detection (ALD)		
Others (Please specify)		

21. Please rate on a scale of 1-5 (1 representing the most satisfied and 5 representing the least satisfied), your satisfaction with each of the CA technique that you selected in Question 12, in the following areas: Ease of use, Confidence in data, Ease of data interpretation, Speed of use, Interruption in service, and Overall cost.

CA technique	**Ease of use**	**Confidence in data collected**	**Ease of data interpretation**	**Speed of use**	**Interruption in service**	**Overall cost**	**Comments**
APVM							
BEM							
CCTV							
MFL							
MPDM							
RFT							
SLPR							
UA, UH, UPA							
UCs							
ALD							
Others							

22. Which of the CA techniques mentioned in Question 20 require taking the pipeline out of service? Could you provide us an estimate of how long the pipeline is typically out of service for?

CA technique	**Length (ft/miles) of the pipeline that is out of service**	**Internal diameter of the pipe (inches)**	**Number of access ports**	**Number of inline valves**	**Time pipeline is out of service**	**Comments**
APVM						
BEM						
CCTV						
MFL						
MPDM						
RFT						
SLPR						
UA, UH, UPA						
UCs						
ALD						
Others						

23. Do any of the CA techniques that you use require the pipe to be excavated? If yes, could you please list them?

____
____
____

24. Which of the following condition monitoring techniques do you use for small diameter DIP in urban areas? Among the condition monitoring techniques that you use, please rank them according to their frequency of use. (Enter 1 for the most frequently used condition monitoring technique, 2 for the second most frequent, and so on. **Enter N/A if your utility has not used a particular technique in the condition monitoring of small DIP**)

Condition Monitoring Technique	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Corrosion rate sensor		
Acoustic emission sensor		
Magnetostrictive sensor		
Conformable and flexible eddy current array		
Flexible ultrasonic sensor		
Guided wave sensor		
Damage sensor		
Microwave back-scattering sensor		
Fiber optic sensor		
Others (Please specify)		

25. Please indicate on a scale of 1-5 (1 representing the most satisfied and 5 representing the least satisfied), your satisfaction with each of the condition monitoring technique that you selected in Question 24, in the following areas: Confidence in data, Ease of data interpretation, and Overall cost.

Condition monitoring technique	Confidence in data collected	Ease of data interpretation	Overall cost	Comments

<u>Questions related to performing CA “in-house” versus “contracting out” to a third party</u>

26. Does your agency perform condition assessment ‘in house’ or does it ‘contract out’ to a ‘third party’?
    a. In house ☐
    b. Third party ☐
    c. Both ☐

If you answered ‘in house’ to Question 26, please answer Questions 27 and 28.

If you answered ‘both’ to Question 26, please answer Questions 27 to 32.

If you answered ‘third party’ to Question 26, please skip to Question 29.

27. Which of the following CA techniques does your agency perform **in-house**? (you may select more than one technique)

Condition Assessment (CA) Technique	**Comments**
☐ Acoustic propagation velocity measurement (APVM)	
☐ Broadband Electro-Magnetics (BEM)	
☐ CCTV inspection technology (CCTV)	
☐ Magnetic Flux Leakage (MFL)	
☐ Manual Pit Depth Measurement (MPDM)	
☐ Remote Field Technology (RFT) (otherwise known as Remote Field Eddy Current)	
☐ Soil Linear Polarization Resistance (SLPR)	
☐ Ultrasonic—Automated, Handheld, Phased Array (UA, UH, UPA)	
☐ Ultrasound C-scan (UCs)	
☐ Acoustic leak detection	
☐ Others (Please specify)	

28. Among the CA techniques performed by **in-house** personnel, please indicate on a scale of 1 to 5, the
    a. Ease of use in the field (1 – being very easy to use, 5 – being very difficult to use),
    b. Ease of data interpretation (1 – being very easy to interpret, 5 – being very difficult to interpret), and
    c. Level of operator training required (1 – being minimal operator training, 5 – being extensive operator training).
    d. Reliability of the collected data (1 – being very reliable, 5 – being very unreliable)
    e. Relative cost (1 – being economical, 5 – being very expensive)
    f. Speed of obtaining results (1 – being very quick, 5 – being very slow)

Condition Assessment (CA) Technique	**Ease of use in the field**	**Ease of data interpretation**	**Level of operator training required**	**Reliability of collected data**	**Relative cost**	**Speed of results**	**Comments**

29. Which CA techniques do you **contract out** to third parties? (You may select more than one CA technique)

Condition Assessment (CA) Technique	**Comments**
☐ Acoustic propagation velocity measurement (APVM)	
☐ Broadband Electro-Magnetics (BEM)	
☐ CCTV inspection technology (CCTV)	
☐ Magnetic Flux Leakage (MFL)	
☐ Manual Pit Depth Measurement (MPDM)	
☐ Remote Field Technology (RFT) (otherwise known as Remote Field Eddy Current)	
☐ Soil Linear Polarization Resistance (SLPR)	
☐ Ultrasonic—Automated, Handheld, Phased Array (UA, UH, UPA)	
☐ Ultrasound C-scan (UCs)	
☐ Acoustic leak detection	
☐ Others (Please specify)	

30. Among CA techniques that are **contracted out**, please indicate on a scale of 1 to 5, the
    a. Reliability of the collected data (1 – being the very reliable, 5 – being very unreliable)
    b. Relative cost (1 – being economical, 5 – being very expensive)
    c. Speed of obtaining results (1 – being very quick, 5 – being very slow)

Condition Assessment (CA) Technique	**Reliability of collected data**	**Relative cost**	**Speed of results**	**Comments**

31. What factors govern your decision to '**contract out'** condition assessment of small diameter DIP? (You may select multiple factors)

Failure Mode
☐ Price (It is cheaper to contract out CA)
☐ Time (Contracting out CA, yields quicker results)
☐ Accuracy (Contracting out CA, yields more accurate results)
☐ Lack of trained in-house personnel
☐ Other (Please specify)

32. Please list the names of the CA contractors most commonly used by your agency.

    ____

    ____

33. What is the annual maintenance budget for DIP in your agency?

    ____

Questions related to handling and installation of small DIP

34. Do you have a standard specification and installation procedure for small DIP? If yes, please specify what it is?

    ____
    ____

35. Do you use any special techniques to improve the life of your small DIP? If yes, please specify what they are?

    ____
    ____

36. Does your agency adopt the following methods for small DIP? Please answer yes/no.
    a. Installation of corrosion test stations (CTS): ____________
    b. Collect/test pipe-to-soil potentials: ____________
    c. Performing soil analysis: ____________
    d. Stray current interference testing: ____________
    e. Using cathodic protection: ____________
    f. Installation of pipe joint bonds: ____________
    g. Installation of polyethylene encasement: ____________
    h. Relying on the asphaltic coatings: ____________
    i. Operating until failure: ____________

Questions related to cost of failure of small DIP

37. Please provide an estimate on the average annual number of failures (over the last 10 years), for small diameter DIP in urban areas, for failures with the following consequences:
    a. Minor damage (e.g. few households affected): __________
    b. Moderate damage (e.g. critical infrastructure, commercial areas affected): _____________
    c. Severe damage (e.g. road closure): __________
    d. Others (Please specify): ____________

38. Please provide an estimate of the average direct costs (cost of labor, cost of materials, cost of equipment, other direct costs.) per occurrence of failure, for small diameter DIP in urban areas.

____

39. Please provide an estimate of the average indirect costs (e.g., damage to property, compensation for loss of business, road closure, etc.) per occurrence of failure, for small diameter DIP in urban areas.

____

40. Please provide an estimate on the average annual number of failures (over the last 10 years), for small diameter DIP in rural areas, for failures with the following consequences:
    a. Minor damage (e.g. few households affected): ___________
    b. Moderate damage (e.g. critical infrastructure, commercial areas affected): ______________
    c. Severe damage (e.g. road closure): ___________
    d. Others (Please specify): _____________

41. Please provide an estimate of the average direct costs (cost of labor, cost of materials, cost of equipment, other direct costs.) per occurrence of failure, for small diameter DIP in rural areas.

____

42. Please provide an estimate of the average indirect costs (e.g., damage to property, compensation for loss of business, road closure, etc.) per occurrence of failure, for small diameter DIP in rural areas.

43. Is the maintenance work related to small DIP failures performed by in-house personnel or is contracted out?

    In house ☐
    Third party ☐

Questions related to manufacturing defects in small DIP

44. Which of the following manufacturing defects have you observed in your small DIP? Among the manufacturing defects that you have observed in your small DIP, please rank them according to their frequency of occurrence (1 being the most frequent manufacturing defect, 2 being the next most frequent manufacturing defect, and so on. **Enter N/A if your utility has not experienced a particular manufacturing defect**)

Manufacturing defect	**Frequency** (1 – most frequent, 2 – second most frequent, and so on. N/A for no experience)	**Comments**
Porosity		
Inclusions (unintentional objects created in metals during manufacturing, that are not part of the continuous fabric of the material)		
Longitudinal flaws/irregularities		
Lumps of metal		
Wall thickness variations		
Other (Please specify)		

If you are interested in engaging further with the research team on this project and for receiving a copy of the final results, please fill in the following information:

Name: ____

Organization/Agency/Company: ____

Role in organization/agency/company: _____________________________________

Postal Address: ____

Email Address: ____

Phone number: ____

Please return the completed survey to Dulcy M. Abraham via email (dulcy@purdue.edu) or via postal mail to: Professor Dulcy M. Abraham. Lyles School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907