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PII - Objectives

- What is "PII"?
- Why is it necessary?
- Pipe Failure Modes
- Inspection Methods
- Inspection Technology
- Inspection Evaluation
- Examples

What is PII?

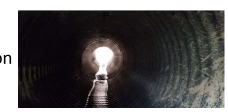
- Post Installation Inspection
  - Testing & Verification after construction is complete

Stages of Inspection

Before Installation

During Installation

After Installation



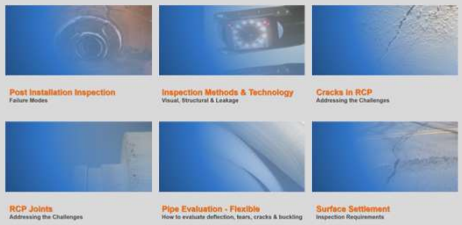
Why is it necessary?

- To Verify Project was Constructed as Designed
  - Out of sight, out of mind

Why is it necessary?

Meridian, MS 2015

Post Installation Inspection



Post Installation Inspection

Failure Modes

Rigid Pipe Failure Mechanisms

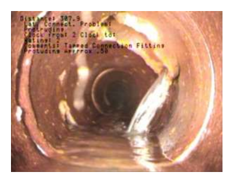
Pipe Specific Mechanisms

RCP Pipe
- Handling Issues
- Spalling
- Acidic Corrosion
- Reinforcement Corrosion

Clay Pipe
- Breakage

Universal Mechanisms
- Improper design
- Cracks due to Loading
- Construction Factors
- Soil Settlement Factors
- Abrasion
- Open Joints

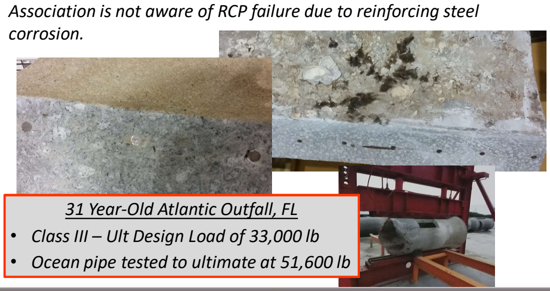
Rigid Pipe Failure Mechanisms



Rigid Pipe Failure Mechanisms

*__RCP Reinforcement Corrosion__

Despite concerns to the contrary, the American Concrete Pipe Association is not aware of RCP failure due to reinforcing steel corrosion.



31 Year-Old Atlantic Outfall, FL
- *Class III – Ult Design Load of 33,000 lb*
- *Ocean pipe tested to ultimate at 51,600 lb*

Flexible Pipe Failure Mechanisms

Pipe Specific Mechanisms

Plastic Pipe
- Cracks/Tears/Delamination
- Oxidation
- Groundwater Fluctuation
- Fire
- Flotation

Metal Pipe
- Pipe Wall Corrosion
- Lining/Coating Issues

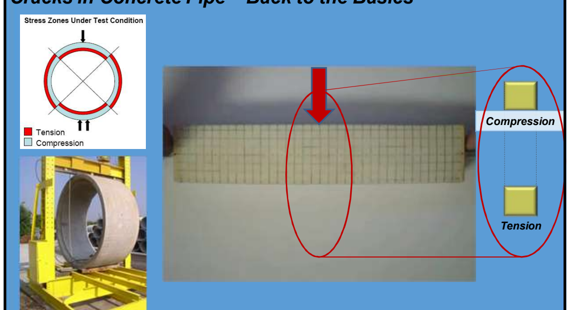
Universal Mechanisms
- Deflection
- Buckling
- Racking
- Improper design
- Construction Factors
- Soil Settlement Factors
- Abrasion
- Age
- Open Joints

Flexible Pipe Failure Mechanisms

Flexible Pipe Failure Mechanisms

Rigid Pipe Failure Mechanisms

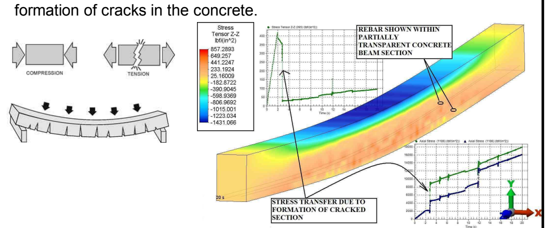
Cracks in Concrete Pipe – Back to the Basics



Rigid Pipe Failure Mechanisms

Cracks in Reinforced Concrete

- ACI 318-08, R10.6.1 states "When high-strength reinforcing steels are used at high service load stresses…visible cracks should be expected."
- Stress is transferred from concrete in tension to tension steel at the formation of cracks in the concrete.



*Gestech.net

RCP Proof of Design

48" ASTM C-76 Class III:

$D_{Service}$ = 1350 lb/ft/ft

D_{ULT} = 2000 lb/ft/ft

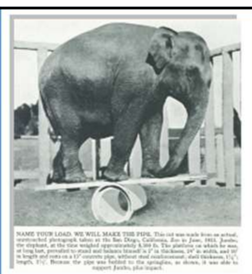
Total Load Required:

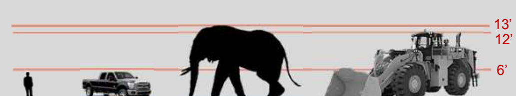
$D_{Service}$ = (48"/12)(8')(1350)

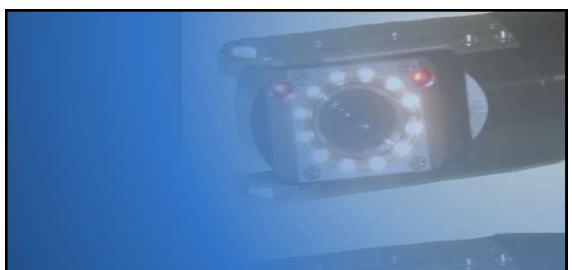
= 43,200 lbs.

D_{ULT} = (48"/12)(8')(2000)

= 64,000 lbs.





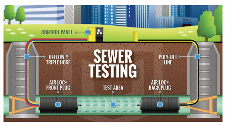


Inspection Methods & Technology

Visual, Structural & Leakage

Inspection Methods

- Inspection Methods After Construction Based On:
  - Pipeline Access
  - Pipe Diameter
  - Pipe Material Type
  - Anticipated Degradation
  - Level of Detail Required

Inspection Timing

- AASHTO Sections 26, 27 & 30
  - PII 30 days after installation
  - Inspect 10% of all pipe installed
- USACE
  - PII 30 days & 365 days after installation
  - Inspect 100% under travel lanes, random 10% otherwise
- AASHTO SOC Guide
  - PII 30 days after installation
  - Inspect 100% of all pipe

Inspection Technology

• Manual • Video	Visual
• Manual • Mandrel • Laser Profiler / Micrometer • 3D Scan	Structural
• Infiltration • Exfiltration • Individual Joint	Leakage



Visual Inspection

- AASHTO SOC – Manual Inspection
  - Manual Inspection Dia Greater than 36”
  - Measurements Taken Every 10’
  - Measure Deflection with 1/16” Metal Tape at 45° locations



Visual Inspection

- Video Inspection

Structural Inspection

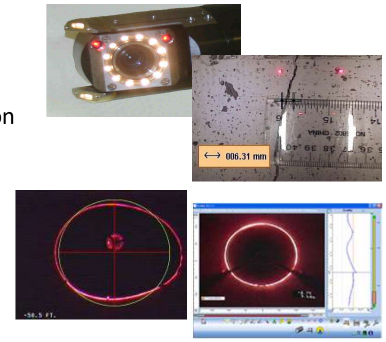
- Manual
- Mandrel
- Laser Profiler / Micrometer
- 3D Scan



Structural Inspection

Checks for:

- Cracks
- Tears
- Delamination
- Deflection
- Racking
- Buckling
- Corrosion
- Abrasion



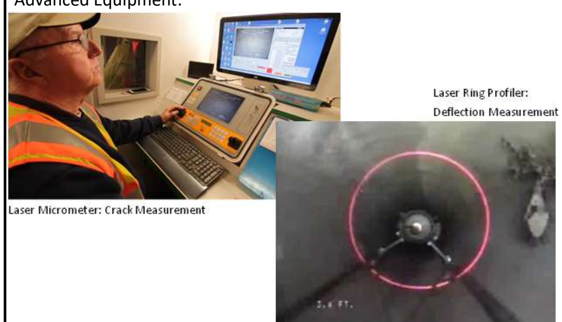
Structural Inspection Tools

Common Equipment:

- Tape Measure
- Laser Micrometer
- Mandrel
- Laser Profiler

Structural Inspection Tools

Advanced Equipment:



Laser Micrometer: Crack Measurement

Laser Ring Profiler: Deflection Measurement

Leakage Inspection

Checks for:

- Joint & Pipe Wall Issues

National Specifications:

- ASTM C969 – Infiltration/Exfiltration
  - Infiltration Allowance: 200 gal / in dia / mile / day with 6’ of avg head
  - Exfiltration Allowance: 200 gal / in / mile / day with 3’ of avg head
- ASTM C1103 – Joint Acceptance Testing
  - Air Test: If pressure holds or drops < 1psi in 5s
  - Water Test: Pressure holds or drops < 1psi in 5s

Pipe Inspection - Evaluation

Pipe Inspection Evaluation:

- Different Pipe Materials:
  - Are Designed Differently
  - Are Installed Differently
  - Are Inspected Differently
  - Should be Evaluated Differently

Cracks in RCP

Addressing the Challenges

Evaluation – Rigid Pipe

Crack Evaluation:
Location
Size
Pattern

Severity: Location, Size

Forensics: Location, Pattern

Crack Evaluation - Size

AASHTO Section 27

- **Cracks < 0.01**
  ok
- **Cracks > 0.01**
  evaluate to determine if detrimental
- **Cracks >0.10**
  In non-corrosive environments (ph>5.5) cracks up to 0.10" are considered acceptable

SCALE:

Crack Evaluation - Size

"Cracks up to approximately 1/16" (.0625) will not permit corrosion except under the most adverse conditions."

Repairing Reinforced Concrete Pipe, M.G. Spangler, Structural Engineering Handbook by Edwin H Gaylord Jr. and Charles N Gaylord, 1968.

Crack Evaluation - Size

Concrete pipe is designed to handle controlled size cracks.

- Cracks ≤ dime: **No Concern**
- Cracks > dime: **Consider Pattern & pH**

Crack Evaluation - Pattern

- Random crack
- Longitudinal crack
  – Radial Tension Sheer
- Circumferential crack
- Multidirectional crack

CONCRETEPIPE.ORG

Crack Evaluation – Location/Pattern

Random Crack:
– shrinkage/curing cracking
– surface cracks w/ no depth.

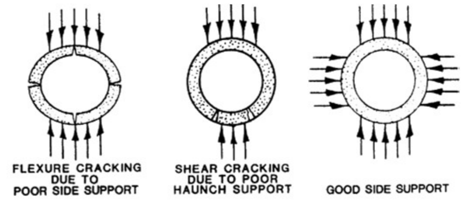
Significance:
NOT A STRUCTURAL or DURABILITY CONCERN

Crack Evaluation – Location/Pattern


Longitudinal Cracks:
- Result of loading
  - 12 o-clock
  - 6 o-clock

Significance: NOT Structural or durability Issue if only found at invert and crown < 0.05"

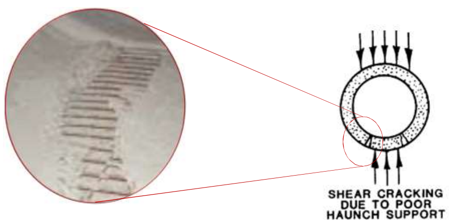
Crack Evaluation – Location/Pattern



Longitudinal Cracks:
- 12, 3, 6, & 9 o-clock

Significance: The pipe has likely been loaded beyond the stress anticipated in design. Springline cracks more than likely extend through the pipe wall. New pipes with longitudinal cracking usually require remediation or replacement.

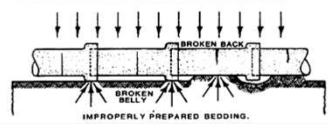
Crack Evaluation – Location/Pattern



Radial Tension Sheer Cracks
- Cracks 30 deg off invert
- Slabs of concrete can become dislodged
- Slabbing is repairable

Significance: Exposed steel must & CAN be repaired. After equilibrium the pipe is no longer experiencing deformation.

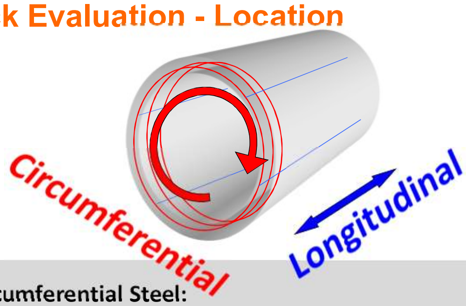
Crack Evaluation – Location/Pattern

Circumferential Cracks:
- Located across invert: Broken Belly
- Located across crown: Broken Back

Significance: Not of structural concern in most environments; however, if backfill is infiltrating into the pipe it requires remediation.

Crack Evaluation - Location



Circumferential Steel:
- Structural reinforcing within the pipe
- Circumferential cracks likely don't impact circumferential/structural steel

Crack Evaluation - Pattern

Multi-directional Cracks:
- Severity depends on size of area, size of cracks
- Star cracks with vertical offset greater than "dime" in acidic areas are candidates for remediation

Crack Evaluation - Pattern

RCP Patterns tell a Story:
- Longitudinal
- Multi-directional
- Circumferential
- Radial Tension Shear

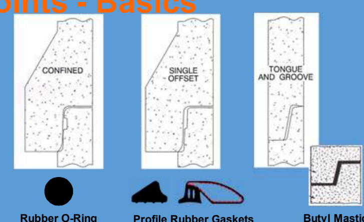
Crack Evaluation - Pattern

Construction Loading:
- Culverts are designed for the loads they must carry after installation. Construction loads often exceed design loads. These heavy loads can cause considerable damage in flexible pipes and can cause cracking in rigid pipes.
- Additional temporary fill is needed to protect the pipe from construction loads.

RCP Joints

Addressing the Challenges

RCP Joints - Basics

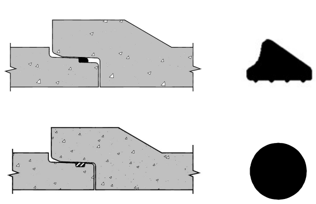


Confined O-ring: Spigot end of the pipe contains a confined groove for the gasket to seat. This style of flared bell joint is the hardest to manufacture.

Single Offset: Spigot is much easier to manufacture as the form can easily slip off the end. Less stringent lubrication requirements for the gasket.

Tongue & Groove: Joint consists of a tongue (male end) and groove (female end) with no defining areas for gasket material placement.

RCP Joints - Performance



AASHTO PP 63 - hierarchy:
- Special Design (Water-Tight)
- Leak Resistant
- Silt-Tight
- Soil-Tight

RCP Joints - Evaluation

- **Performance Requirement**
  Soil Tight, Silt Tight, Leak-Resistant
- **Gap Vs Performance Requirement**
  Joint Material + Joint shape = Performance
  Each Manufacturer has different Gap dimensions
- **Construction "bruising"**
- **Determine severity**
  (repair Vs no repair)

CONCRETEPIPE.ORG

Joints - Installation

Minimize ALL Pipe Joint Issues:

- Handle with Reasonable Care
- Provide Solid Foundation
- Proper Bedding and Grade
- DO NOT Force on Grade
- Proper Installation of Joint Materials
- Cover Before LOAD – Careful with construction Loading!

Pipe Evaluation - Flexible

How to evaluate deflection, tears, cracks & buckling

Evaluation – Plastic Pipe

Failure Modes

- Cracks/fractures/holes
- Excessive Deformation
- Inverse Curvature
- Joint Displacement
- Corrugation Growth
- Buckling
- Flotation
- Fire
- Chemical Attack







Evaluation – Plastic Pipe

FHWA: Degradation of Plastics

- Oxidation
  - Atmospheric Oxygen reacts with plastic to result in polymer chain scission. UV & elevated temperatures accelerate reaction. Antioxidants are added and react with oxygen to deplete sacrificially. One antioxidants are gone, Oxygen attacks the polymers.
- Environmental Stress Cracking
  - Leading factor in polymer cracking and brittle failure. Caused by resin degradation due to chemical exposure while under physical stress.
- Ultraviolet Degradation
  - UV Radiation results in photo-induced embrittlement and cracking in sunlight. UV Stabilizers are added to absorb radiation and dissipate energy as low level heat.

Evaluation – Plastic Pipe

FHWA: Degradation of Plastics

- Thermal Degradation
  - Decomposition of polymer chains due to exposure to high temperatures. Can reduce strength, stiffness and toughness.
- Chlorine Induced Degradation
  - Under common environmental conditions, polyethylene can be susceptible to degradation due to exposure to chlorine, a common disinfectant. Trace Chlorine can cause oxidative embrittlement and crack initiation.
- Abrasion
  - Severity of abrasion is directly related to the particle size, shape and hardness. Bedload is primarily responsible for abrasive action (more than velocity).

Evaluation – Metal Pipe

Failure Modes

- ***Corrosion***
- Lining delamination
- Abrasion
- Excessive Deformation
- Cracks/fractures/holes
- Inverse Curvature
- Joint Displacement
- Buckling
- Flotation

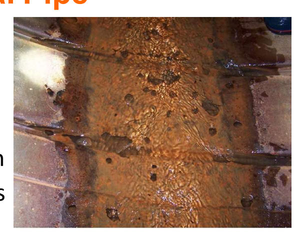


Figure 2.3-2 – Steel Pipe with Invert Perforations


Evaluation – Plastic Pipe

NCHRP:

SECTION 4: CONDITION RATING SYSTEM 4-36

4.9 Plastic Barrel (HDPE, PVC, PP, FRP)

Plastic pipe are often used in both culvert and storm drain applications. Plastic pipe are classified as flexible structures because their design and performance rely on soil-structure interaction; plastic pipes depend upon the soil embedment around the full pipe circumference and backfill to provide structural stability and support. Plastic pipe and the surrounding soil are designed together. Round-shaped solid or profile wall high density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), or fiberglass reinforced plastic (FRP) are commonly used for culverts and storm drains. Refer to Section 2 for additional information on behavior of flexible pipe.

- Shape
  - Typical allowable maximum dead load service deflection is 5% of the vertical diameter. Greater deflection may be acceptable, but should receive an engineering evaluation.
  - Fair: deflection 5% to 7.5% of vertical diameter
  - Poor: deflection 7.5% to 10% of vertical diameter
  - Critical: deflection greater than 10% of vertical diameter

Evaluation – Plastic Pipe

NCHRP:

- Surface Damage
  - Damage such as impacts, creases, cracks and tears can be serious if the distress are extensive and can impair either the integrity of the barrel in ring compression or permit infiltration of groundwater or backfill.
  - Small, localized instances are not ordinarily critical but should be noted along with any indications of the cause.
  - Inspection should document the type, extent and location of all wall distress and photograph significant instances.

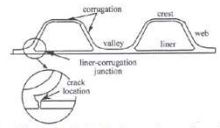


Figure 3: Location of liner-corrugation junction where cracks were observed in NCHRP Report 429 (McGrath and Hsuan 1999).

Evaluation – Plastic Pipe

NCHRP:

- Splitting
  - Splitting can occur along plastic welded seams and/or abrupt changes in geometry in the pipe wall or corrugation, or at the bond between the walls and liners in corrugated wall pipe.
  - Older HDPE pipes can experience cracking in the corrugated wall liner due to stresses that are residual from the manufacturing process and that may also b in locations that are not structurally significant.
- Photodegradation
  - Plastic pipe is susceptible to UV degradation if not adequately designed or treated to be resistant. Photodegradation is the weakening of the plastic material due to oxidation from absorption of UV radiation. If photodegradation is suspected, pipe wall should be struck with a hammer and any fracturing or crumbling reported.

Evaluation – Plastic Pipe

NCHRP:

- Local Buckling
  - Bulges in the pipe wall follow an undulating inward-outward pattern along or around the pipe circumference (rippling) should be identified as local buckling. Pipe cross section geometry maintains a circular shape though the wall is significantly weakened and has a reduced vertical load carrying capacity. Changes to the circular shape such as wall-flattening, increasing to reverse curvature, would be evaluated in the shape characteristic as global buckling.

Figure 4.9-2 – Local Buckling in Plastic Barrel
(Photo courtesy of Ohio Department of Transportation)

Evaluation – Plastic Pipe

NCHRP:

PLASTIC BARREL

	1 GOOD	2 FAIR	3 POOR	4 CRITICAL	5 FAILED
SHAPE	Barrel maintains round shape with no local wall flattening. Vertical deformation less than 5% of original inside diameter.	Minor wall flattening. Vertical deformation 5%-7.5% of original inside diameter.	Significant wall flattening or increased wall curvature. Vertical deformation 7.5%-10% of original inside diameter. Visual out-of-roundness.	Extreme wall flattening with reversal of curvature (global buckling), and/or kinks. Vertical deformation greater than 10% of original inside diameter. Significant visual out-of-roundness.	Reverse curvature, collapse (complete or partial) or imminent collapse of culvert barrel.
SURFACE DAMAGE	No indication of wear, abrasion, impact damage or UV degradation.	Minor wear, abrasion, less than 10% of wall thickness. Minor staining or UV degradation. Blistering over less than 25% of pipe inner surface (FRP).	Wear, abrasion that exceeds 10% of wall thickness. UV degradation (pipe ends) causing discoloration. Blistering over greater than 25% of pipe inner surface (FRP).	Wear, abrasion that exceeds 25% of wall thickness. UV degradation (pipe ends) resulting in cracked or broken pipe wall.	Cannot cause failed rating.
LOCAL BUCKLING, SPLITS, AND CRACKING	Smooth interior wall. No splits in welded seams or cracking in wall.	Initiation of local buckling indicated by rippling in wall. Wall cracking or splits, less than a quarter of circumference. No infiltration. No longitudinal cracking.	Advanced and widespread local wall buckling indicated by extensive interior surface rippling. Wall cracking or splits up to half of circumference. Minor water infiltration but no soil infiltration. Longitudinal cracking less than 12 in. in length.	Kinks though the full wall thickness. Pipe wall buckles inward locally. Wall cracking or splits greater than half of pipe circumference. Longitudinal cracking more than 12 in. in length. Cracks with indication of soil infiltration.	Extensive cracking of pipe wall allowing soil infiltration.

Evaluation – Plastic Pipe

AASHTO Section 30:

AASHTO

Section 30.5.6:

- Thermoplastic - Final inspections no sooner than 30 days after completion of installation and final fill.
- Deflections less than 5% - Acceptable
- Deflections more than 5% - Evaluate by Engineer
- Deflections greater than 7.5% - Evaluate by Engineer & Remove or Remediate Plan

Evaluation – Metal Pipe
AASHTO Section 26:

AASHTO

Section 26.5.7:

- CMP - Final inspections shall be conducted no sooner than 30 days after completion of installation and final fill.
- CMP Deflection less than 7.5% - Acceptable
- Deflection greater than 7.5% - Remove & Replace

Surface Settlement
Inspection Requirements

Post Installation Inspection
Surface Settlement

Approach roadway rated according to components:

- Pavement
- Shoulders
- Guardrail

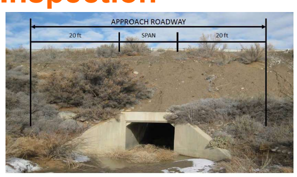


Figure 4.3-1 – Approach Roadway Inspection Length

Inspect with visual evaluation and hand measurements.

Pavement Distress:

- Cracks
- Humps
- Sags
- Patches
- Indications of settlement

Road surface may indicate condition of pipe

MN 95 near MP 89, near Marine on the St. Croix

Post Installation Inspection
Surface Settlement

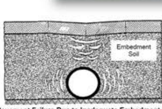
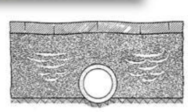
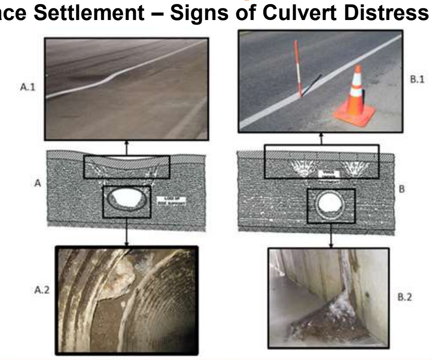


Figure 4.3-2 – Pavement Failure Due to Inadequate Embedment Soil Compaction or Low-Quality Embedment Soil Adjacent to Flexible Pipe (Photo courtesy of Colorado Department of Transportation)



4.3-3 – Pavement Failure Due to Inadequate Compaction or Low-Quality Fill Soil Adjacent to Rigid Pipe

Post Installation Inspection
Surface Settlement – Signs of Culvert Distress



Post Installation Inspection

Pavement Bridging

Figure 4.3-6 – Failure Due to Piping (Water flowing along outside of pipe and washing away backfill)
(Photos courtesy of FEMA)

How can PII Improve Quality?

- Better installations will result because of remediation costs for inspection problems.
- Proper installation will increase life span of the system.
- Problems will be corrected before they can impact other infrastructure items.

PII Evaluation Tools:
Use the tools wisely…

Questions?