Introduction of the New Culvert and Storm Drain Inspection Manual

NCHRP Project 14-26
NCHRP is a State-Driven Program

- Sponsored by individual state DOTs who
  - Suggest research of national interest
  - Serve on oversight panels that guide the research.

- Administered by TRB in cooperation with the Federal Highway Administration.
Practical, ready-to-use results

- Applied research aimed at state DOT practitioners
- Often become AASHTO standards, specifications, guides, syntheses
- Can be applied in planning, design, construction, operations, maintenance, safety, environment
Additional NCHRP Publications Available on this Topic

- NCHRP Synthesis 474: Service Life of Culverts

You can learn more about these publications by visiting www.trb.org
Today’s Speakers

• Jesse Beaver, Simpson, Gumpertz & Heger, Inc.
• Matthew Richie, Simpson, Gumpertz & Heger, Inc.
• Moderator: Ray Trujillo, New Mexico DOT
Introduction of the Culvert and Storm Drain System Inspection Manual

NC HRP Project 14-26

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30 January 2017
Background

• **Culverts**
  – Buried structures.
  – Pass water under roadways, railways, or embankments.
  – Structurally similar to bridges, but with span less than 20 ft.

• **Storm Drains**
  – Low-head or gravity flow.
  – Closed-end conduits, inlet/outlet structures, in-line junction boxes.
  – Convey stormwater to collection and discharge points.

• **Highway bridges**
  – Includes culverts with spans greater than 20 ft.
  – Federally mandated (and funded) inspection every 2 yrs.

• **Culverts & storm drains outnumber bridges approximately 10 to 1**
  – No federally mandated (or funded) inspection cycle.
  – Many are not tracked and go **uninspected for years until failure**.
Agency Inspection Programs

• Some jurisdictions have developed specifications and hired consultants for culvert inspections.
  – Colorado

• Many jurisdictions have developed their own manuals (or used bridge inspection manuals to inspect culverts).
  – Minnesota, Federal Lands Highways, New York State, Connecticut, New Jersey, Ohio

• Some states have developed training and/or certification courses for their culvert inspection programs.
  – Ohio, California
How do States Manage Culvert Inventories?

• Inventory Management Systems
  – Catalog and track infrastructure assets.
  – Identify the infrastructure asset value.
  – Effective systems include: inventory, inspection, management/documentation, planning, budgeting, decision-making.

*Based on January 2007 questionnaire sent to state bridge engineers.*
NCHRP Project 14-26

- Completed: May 2016.
- Objective: Develop an inspection manual for assessing the condition of in-service culvert and storm drain systems to ensure system safety and performance and the economical use of owner resources.
- Final Deliverable: *Culvert and Storm Drain System Inspection Manual*.
CULVERT AND STORM DRAIN SYSTEM INSPECTION MANUAL

FINAL REPORT

Prepared for
NCHRP 14-26 Culvert and Storm Drain System Inspection Manual

Transportation Research Board
of
The National Academies

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES
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Waltham, MA
May 2016
Overview of the New Culvert and Storm Drain System Inspection Manual

- Quantitative and consistent condition rating criteria based on engineering principles and existing best practices.

- Enable culvert and storm drain inspectors to:
  - Identify structural distress for culvert or storm drain system components,
  - Rate the condition of the system components,
  - Document findings of an inspection, and
  - Recommend corrective actions or further in-depth inspection, as appropriate.

- Provide methods and data for owners to justify repair funding requests and to prioritize rehabilitation programs.
Culvert and Storm Drain System Inspection Manual: Goals

- Evaluate structural integrity, hydraulic performance, and roadside compatibility.
- Identify minor issues that can be addressed through maintenance before they become safety hazards.
- Mitigate repair costs.
- Reduce risk of failure.
- Provide input to prioritize rehabilitation and maintenance.
- Allow for short- and long-term planning and budgeting for repairs and rehabilitation.
- Provide a method to meet state and federal requirements to quantify the value of highway infrastructure assets.
Culvert and Storm Drain System Inspection Manual: Organization of the Manual

• Section 1 – Introduction
• Section 2 – Design and Performance Characteristics
  – Appendix A – Structural Shapes, Materials, and System Components
• Section 3 – Inspection Procedure
• Section 4 – Condition Rating System
  – Appendix B – Catalog of Distressed Conditions
• Section 5 – Asset Management

Figure 1.2-1 – Roadway Collapse Due to Piping along Culvert and Loss of Backfill
Culvert and Storm Drain System Inspection Manual:

Section 1 – Introduction
Culvert and Storm Drain System Inspection Manual: Section 1 – Introduction

• Introduces culvert and storm drain system inspection.
• Outlines need for standardized inspection program.
• Provides the manual objectives.
• Identifies the intended audience.
• Instructs users on the manual organization and use for inspections.

Figure 1.2-3 – Roadway Collapse Due to Structural Failure of Culvert
(Photo courtesy of Iowa Department of Transportation)
Culvert and Storm Drain System Inspection Manual: 
Section 1 – Introduction

• **Target audience**
  - Highway departments
    - State highway agencies (Departments of Transportation).
    - County Highway Divisions.
    - Other local agencies.
  - Personnel
    - Agency culvert and storm drain system inspectors.
    - Agency bridge inspectors.
    - Consultants to highway agencies responsible for culvert and storm drain system inspection.
    - Personnel responsible for performing scheduled maintenance on culvert and storm drain systems.
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

• Subsections Include:
  – Design Characteristics
    • Hydraulic Requirements
    • Structural Behavior – Flexible vs. Rigid Materials
    • Loads on Culverts and Storm Drains
    • Construction and Installation Requirements
  – Performance Characteristics
    • Durability
  – Culvert and Storm Drain Shapes and System Components
    • Refer to Appendix A for additional details
Hydraulic Requirements

Figure 2.2-1 – Example Drainage Area (Estimate Runoff)

Figure 2.2-2 – Factors Affecting Hydraulic Capacity (Hydraulic Design)
Culvert and Storm Drain System Inspection Manual:
Section 2 – Design and Performance Characteristics

• Structural Behavior and Materials – Flexible Pipe vs. Rigid

Figure 2.2-3 – Deflection of Flexible Culverts

Figure 2.2-4 – Load in Flexible Culverts

Figure 2.2-6 – Zones of Tension and Compression in Rigid Pipes Develop to Resist Vertical Load in the Three Edge Bearing Test

Figure 2.2-7 – Trench Installation (friction on trench sides reduces the width of the column of fill carried by the pipe)
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

• Loads on Culverts and Storm Drains

Figure 2.2-8 – AASHTO HL-93 Live Load

Figure 2.2-9 – Live Load Distribution Through Fill (Note: Pipe orientation may vary for storm drains)
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Loads on Culverts and Storm Drains – AREMA Cooper E-80

Figure 2.2-10 – AREMA Cooper E80 Railway Loading

TTCI FAST Test Installation of HDPE below RR
(https://www.dot.state.oh.us/engineering/OTEC/2015_OTEC_Presentations/ Wednesday_Oct.28/72/Babcanec_72.pdf)

Corrugated Metal below RR
• Construction and Installation Terminology - Trench

Figure 2.2-11 – Trench Installation for Buried Culvert or Storm Drain
• Construction and Installation Terminology - Embankments

Figure 2.2-12 – Embankment Installation for Buried Culvert or Storm Drain
• Construction and Installation Considerations
  – Compaction and Side Support
  – Trench Width
  – Foundations and Bedding
  – Minimum Depth of Fill
  – Camber
  – High Groundwater (flotation)
• Performance Characteristics – Durability
  – Corrosion of Metals
  – Degradation of Concrete
  – Degradation of Plastic
  – Abrasion of barrel materials
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Culvert and Storm Drain Shapes and System Components – Appendix A
  - Shapes
  - Materials
  - Culvert Systems and Components
  - Storm Drain Systems and Components
  - Pipe Coatings and Linings
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

• Culvert and Storm Drain Shapes and System Components – Appendix A
  – Shapes

- Circular
- Pipe Arch
- Box
- Arch
- Three-Sided
- Multi-Cell / Multi-Barrel
Culvert and Storm Drain Shapes and System Components – Appendix A

- Materials – Descriptions and Shapes
  - Corrugated Steel and Aluminum
    - Factory-Made Pipe
    - Structural Plate Steel
    - Corrugated Box Culvert
    - Long-Span Corrugated Structures
  - Plastic
    - Thermoplastic vs. Thermoset Resins
    - HDPE, PVC, PP
    - FRP
    - SRPE
  - Concrete
    - Precast Shapes
    - Cast-In-Place
    - Fiber Reinforced Concrete Pipe

(Corrugated Metal Shapes)
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

• Culvert and Storm Drain Shapes and System Components – Appendix A
  – Other materials
    • Solid Wall Steel Casing
    • Cast and Ductile Iron
    • Masonry
    • Timber
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Culvert and Storm Drain Shapes and System Components – Appendix A
  - Culvert Systems and Components

Figure A.3-1 – Culvert System Components

Figure A.3-6 – Headwall (Arrow 1) and Wingwall (Arrow 2) on Concrete Box
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Culvert and Storm Drain Shapes and System Components – Appendix A
  - Culvert Systems and Components
    - Inlet and Outlet End Treatments

Figure A.3-5 – Apron (also called Flared End Section) on Corrugated Metal Pipe

Energy Dissipator
Culvert and Storm Drain Shapes and System Components – Appendix A

- Foundations

Figure A.3-10 – Typical Pile Foundation

Figure A.3-8 – Typical Reinforced Concrete Spread Footing Foundations (Left: Spread Footing, Right: Pedestal Footing)
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Culvert and Storm Drain Shapes and System Components – Appendix A
  - Storm Drain Systems and Components

Figure A.4-1 – Storm Drain System Components
Culvert and Storm Drain System Inspection Manual: Section 2 – Design and Performance Characteristics

- Culvert and Storm Drain Shapes and System Components
  - Storm Drain Systems and Components
    - Stormwater Collection
    - Stormwater Conveyance
    - Stormwater Best Management Practices (BMPs)

Curb and Gutter
Grate Inlet
Catch Basin Inlet Structure
• Culvert and Storm Drain Shapes and System Components
  – Pipe Coatings and Linings
    • Nonstructural Pipe Coatings and Linings
      – Cement Mortar, Bituminous, Epoxy, Galvanized, Polymer, Invert Paving, Internal Joint Bands
    • Structural Pipe Linings
      – Sliplining, Multi-Plate or Structural Plate, Fold-and-Form PVC, Cured-in-Place Pipe (CIPP), Spray-Applied, Spiral Wound, Swagelining and Rolldown, Pipe Bursting and Splitting
Culvert and Storm Drain System Inspection Manual:

Section 3 – Inspection Procedure
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Subsections Include:
  – General
  – Purpose and Scope of Inspections
  – Inspection Frequency
  – Preparation and Planning
  – Types of Inspections
  – Types of Entry
  – Inspection Team Role and Qualifications
  – Inspection Equipment
  – Recording the Inspection
  – Safety
  – Inspection Quality Control and Quality Assurance
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Purpose
  – Assess the condition of the entire culvert or storm drain system
    • Structural issues
    • Materials issues
    • Service performance
  – Make accurate ratings that are repeatable by other inspectors
  – Collect data to be included in an agency’s asset management system
    • Used for maintenance, repair, and rehabilitation decisions/budgets
  – Collect data that assess roadway safety for the traveling public
Culvert and Storm Drain System Inspection Manual:
Section 3 – Inspection Procedure

• Scope of Inspections
  – All culverts and storm drains in an agency’s inventory
  – All systems should be inventoried upon installation or when creating an asset management system
  – Many culverts may not require routine inspection
    • Small diameter pipes, low traffic areas
  – Each agency should define its inspection program in terms of:
    • Inspection frequency
    • Characteristics of culverts to be inventoried and inspected (importance)
    • The information to be collected
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Inspection Frequency
  – Culverts with spans > 20 ft are bridges (NBIS inspection every 2 years)
  – This manual recommends similar frequency for spans > 10 ft
    • Similar to bridges, but less data collected
  – Recommended minimum frequency by barrel span and condition rating

<table>
<thead>
<tr>
<th>Barrel Size (S)</th>
<th>Inspection Frequency (Ratings ≤ 2)</th>
<th>Inspection Frequency (Ratings ≥ 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Installation (S &gt; 1 ft)</td>
<td>Inspect annually for the first 2 years after construction.</td>
<td>N/A</td>
</tr>
<tr>
<td>S ≤ 1 ft</td>
<td>No routine inspection required. Inspect during roadway maintenance activities.</td>
<td>No routine inspection required. Inspect during roadway maintenance activities.</td>
</tr>
<tr>
<td>1 ft &lt; S ≤ 4 ft</td>
<td>Every 10 years or prior to routine roadway maintenance activities, whichever is less.</td>
<td>At least every 5 years and with routine roadway maintenance activities.</td>
</tr>
<tr>
<td>4 ft &lt; S ≤ 10 ft</td>
<td>Every 5 years or prior to routine roadway maintenance activities, whichever is less.</td>
<td>At least every 2 years and with routine roadway maintenance activities.</td>
</tr>
<tr>
<td>S &gt; 10 ft</td>
<td>Every 2 years</td>
<td>At least every 2 years and with routine roadway maintenance activities.</td>
</tr>
</tbody>
</table>
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Types of Inspections
  – Initial (Inventory) Inspection
    • Detailed first inspection establishes agency inventory record
    • Baseline for future comparison
    • Provide data required for agency asset management decisions
  – Routine Inspection
    • On defined frequency, visual and non-destructive measurements to assess condition and assign ratings
    • Note changes to inventory baseline
    • Track how components are functioning and aging
  – Special Inspection
    • Triggered by critical or failed rating in a routine inspection
    • Research to monitor new materials, special detailing, etc
  – Damage Inspection
    • Not scheduled
    • Event-driven emergency inspection - flooding, fires, roadway sinkholes, traffic accidents
    • Determine if emergency restrictions/closures/critical repairs are required
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

- Types of Entry
  - Person-Entry Internal Inspection
    - Preferred
    - Component ratings require close-up inspection
    - Must follow OSHA and local confined space entry procedures
  - Non-Entry Internal Inspection
    - Visually examine structure from both ends
    - Not as thorough as person-entry
    - Useful for high flows, deep sedimentation, smaller diameters
    - Identifies significant problems (not detailed problems) in barrel, etc
    - Outlet observations may be representative of worst-case abrasion, etc
  - Remote-Entry Internal Inspection
    - When internal inspection is necessary but person-entry is not practical
      - Small diameter, deep sedimentation, deep water, closed-end conduits
    - Preferred to have video plus other specialized measurement equipment
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Inspection Team Roles & Qualifications
  – Roles and qualifications for culvert and storm drain inspection are based on National Bridge Inspection Standards
    • *Program Manager* supervises multiple inspection teams
    • *Inspector* is responsible signatory for each inspection
    • *Assistant Inspector* performs day-to-day routine inspections
  – Training by the manual and on-the-job experience
    • Understanding of design, soil-structure-interaction, failure modes, system function, and hydraulic performance
    • Working knowledge of the manual condition rating system
    • Ability to read plans and construction documents
    • Basic hand-drafting (sketching) abilities
    • Working knowledge of inspection tools, application, limitations
    • Competency for highway and site safety including confined spaced
  – Physical Ability
    • Be prepared to work in demanding conditions including cramped spaces, rugged terrain, steep embankments, in and around water
    • Able to carry tools and equipment
• Recording the Inspection
  – Inventory Record
    • Location, type, span, etc
    • Road and stream/feature crossed by the structure
  – Assigned structure identification number
  – Design and installation records
  – If no inventory data is available on existing culverts, establish guidelines to prioritize collection methods for maintenance and construction staff
Recording the Inspection

- Inspection Record
  - Standardization is important
  - Agencies should have standard forms to suit their asset management needs
- Forms should include space for:
  - Relevant data from previous inspections (identify components that may need particular attention)
  - Fields for different features
  - Sketches and narrative description
  - Photos/photo references
  - Condition ratings/comments
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Preparation and Planning
  – Organize and schedule inspections while considering:
  – Review Data from Previous Inspections
  – Develop an Inspection Sequence
  – Use a Checklist or Developed Procedure
Culvert and Storm Drain System Inspection Manual: Section 3 – Inspection Procedure

• Safety
  – Requires a thorough safety plan and training
    • OSHA and state- or jurisdiction-specific
    • 22 states currently have their own OSHA-approved plans
  – Topics include:
    • Confined space entry (permit, non-permit)
    • Traffic hazards
    • Drowning hazards
    • Rugged terrain
    • Animals and insects
    • Poisonous plants
    • Equipment safety
    • Miscellaneous hazards (fire, floods, chemical spills, quicksand, etc)
Culvert and Storm Drain System Inspection Manual: 
Section 3 – Inspection Procedure

• Inspection Quality Control/Quality Assurance
  - Program purpose:
    • Maintain a minimum level of consistent quality
    • Accurate and repeatable across teams and across the agency inventory is critical for asset management
  - Framework for a QA/QC Program

  – PLAN, DO, CHECK, ACT
    • Basis of ISO 9001 quality management system
    • PLAN: annual meeting prior to inspections, review QA/QC program and update accordingly
    • DO: perform inspections in accordance with QA/QC program
    • CHECK/STUDY: study the results, plan for improved performance, reevaluate PLAN phase
    • ACT: follow up on all changes and issues, make corrective actions to address deficiencies
Culvert and Storm Drain System Inspection Manual:

Section 4 – Condition Rating System
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Subsections Include:
  – Use of the Condition Rating System
  – Approach Roadway
  – Embankment
  – Channel
  – End Treatments and Appurtenant Structures
  – Concrete Footing and Invert Slab
  – Barrel Alignment
  – Plastic, Concrete, Corrugated Metal, Masonry, and Timber Barrels
  – Joints and Seams
  – Storm Drain System Components
  – Manholes, Catch Basins, Buried Junctions
  – Aquatic Organism Passage
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

- Use of the Condition Rating System
  - Scale of 1 to 5
    - 1 (Good) is like new, little or no deterioration, structurally sound, functionally adequate
    - 5 (Failed) indicates component failure
  - Ratings based on comparison of the existing condition with the as-designed condition and are assigned before leaving the site
  - Each component gets a rating
    - The poorest characteristic rating (highest number) determines the component rating
    - Where quantified criteria are provided, measurements may be required
    - If the provided table criteria are not adequate, judgement and experience may be used to assign a rating
  - Appendix B Catalog of Distressed Conditions shows photographs of varying levels of distress severity to allow assignment of consistent ratings
### Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

- **Use of the Condition Rating System**
  - Ratings are tied to specific actions

#### Rating Scale and Associated Action

<table>
<thead>
<tr>
<th>RATING SCALE AND ASSOCIATED ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>GOOD</td>
</tr>
<tr>
<td><strong>CONDITION</strong></td>
</tr>
<tr>
<td><strong>ACTION INDICATED</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rating No.</th>
<th>Condition</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good</td>
<td>No Action</td>
</tr>
<tr>
<td>2</td>
<td>Fair</td>
<td>No Immediate Action, More Frequent Inspection, Inform Maintenance</td>
</tr>
<tr>
<td>3</td>
<td>Poor</td>
<td>Evaluate the Need for Corrective Action</td>
</tr>
<tr>
<td>4</td>
<td>Critical</td>
<td>Corrective Action is Required, Engineering Evaluation Recommended</td>
</tr>
<tr>
<td>5</td>
<td>Failed</td>
<td>Emergency Action is Required</td>
</tr>
</tbody>
</table>
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Use of the Condition Rating System
  – Documentation Convention
    • Distress Severity
      – Document severity, extent, and location of significant and typical distress
      – Include photos and sketches as necessary
      – Adequate for follow-up inspections
    • Distress Location
      – Use offsets (stationing) from outlet end
      – Use clock positions looking upstream from outlet or offsets from corners of box culvert, etc
  • Joint Distress
    – Identify offset/stationing rather than counting joint numbers to allow for location identification after lining, barrel extensions, etc
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Component Condition Rating Tables provided for:
  – Approach Roadway
  – Embankment
  – Channel Alignment and Protection
  – End Treatments and Appurtenant Structures
  – Concrete Footings and Invert Slab
  – Barrel Alignment
  – Barrel Material
    • Plastic Barrel
    • Concrete Barrel
    • Corrugated Metal Barrel
    • Masonry Barrel
    • Timber Barrel
  – Joints
  – Seams
  – Manholes, Catch Basins, Buried Junctions
Culvert and Storm Drain System Inspection Manual:
Section 4 – Condition Rating System

• Approach Roadway
  – Purpose
    • Identify distress indicators in roadway for the structure below
    • Alerts inspector to possible issues with culvert or storm drain below
  – Distress indicators:
    • cracking, humps or sags, patches, settlement

Figure 4.3-2 – Pavement Failure Due to Inadequate Embedment Soil Compaction or Low-Quality Embedment Soil Adjacent to Flexible Pipe

Figure 4.3-3 – Pavement Failure Due to Inadequate Compaction or Low-Quality Fill Soil Adjacent to Rigid Pipe
Figure 4.3-4 – (A) Backfill Loss Beneath Pavement Causing Sag in the Approach Roadway (A.1). (B) Large Void Beneath Pavement Due to Backfill Loss, Discovered by Probing Small Hole (B.1). These distress indicators should alert the inspector to check for evidence of backfill infiltration inside barrel (A.2 and B.2)
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Approach Roadway

Figure 4.3-5 - Bridging in Flexible Pavements

Figure 4.3-6 – Failure Due to Piping (Water flowing along outside of pipe and washing away backfill)
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Approach Roadway

Figure 4.3-7 - Left: High Severity Transverse Pavement Cracks, Right: High Severity Longitudinal Pavement Cracks

Figure 4.3-8 – Alligator Cracking in Pavement

Figure 4.3-9 - Misalignment of Guardrail at Culvert Outlet (Note also patching of pavement, cracking and sagging at same location)
## Approach Roadway

### Pavement

- **Good**
  - All areas of potential distress to paving, guardrail, and shoulders are in good condition for a minimum length of 20 ft either side of crossing culvert or full length of storm drains.
  - Sags or humps less than 1/8 in. over 10 ft.
  - Guardrail generally aligned and plumb. No displacement of posts due to settlement or sliding of shoulder.

- **Fair**
  - Low severity transverse pavement cracks (less than ¼ in. wide).
  - Low severity sags or humps less than 2 in. over 10 ft over culvert barrel.

- **Poor**
  - Rutting in wheel paths localized over culvert/storm drain.
  - Evidence of repeated patching.
  - Medium severity transverse pavement cracks greater than ½ in. wide.
  - Medium severity sags or humps (up to 4 in. over 10 ft) over culvert barrel.

- **Critical**
  - High severity transverse or longitudinal cracks greater than ½ in. wide. with raveling of pavement over the culvert or storm drain.
  - High severity sags or ruts with voids beneath pavement.

- **Failed**
  - Collapsed pavement over culvert or storm drain (complete or partial).

### Guardrail

- **Good**
  - Slight misalignment of posts due to settlement or sliding of shoulder.

- **Fair**
  - Misalignment and medium severity settlement/sag or rotation of posts due to ground movement (not due to impact damage).

- **Poor**
  - High severity settlement/sags or rotation of posts due to ground movement (not due to impact damage).
  - Guardrail may be ineffective.

- **Critical**
  - Collapsed guardrail (complete or partial).

### Shoulders

- **Good**
  - Low severity sag over culvert/storm drain. Low severity cracking local to shoulder.

- **Fair**
  - Settlement around catch basins. Evidence of repeated patching.
  - Moderate severity cracking (transverse or longitudinal)

- **Poor**
  - High severity transverse or longitudinal cracking and/or sags over culvert/storm drain. Voids in roadway in vicinity of culvert (piping or infiltration). Soil cracking or slope movement in shoulder area.

- **Critical**
  - Loss of shoulder pavement; shoulder soil movement presents immediate safety hazard to traffic.

### Evaluation

<table>
<thead>
<tr>
<th>Condition</th>
<th>Evaluate Need for Action</th>
<th>Corrective Action Required</th>
<th>Emergency Action Required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Good</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fair</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Embankment
  – Purpose
    • Identify distress indicators in roadway for the structure below
    • Alerts inspector to possible issues with culvert or storm drain below
  – Look for sloughing, erosion, rill, gullying, etc

Figure 4.4-1 - Embankment Sloughing

Figure 4.4-2 – Moderate Sheet Erosion on Steep Embankment
Figure 4.4-3 – Minor Rill from Roadway Runoff
Figure 4.4-4 – Severe Gullying with Severe Sheet Erosion
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Channel
  – Purpose
    • Identify channel-related problems that may affect performance or structural stability of the culvert
    • Identify issues that may affect ability to handle design flow
  – Look for alignment changes, bank erosion/scour, issues with channel protection, issues with water adequacy (non-AOP)
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• End Treatments and Appurtenances
  – Purpose
    • Identify conditions that may relate to their structural stability, hydraulic performance, and traffic safety characteristics
  – Look for projecting ends, changes to prefabricated end treatments, issues with headwalls/spandrel walls/wingwalls, issues with aprons and flumes, debris accumulations, and issues with weep holes, etc

Figure 4.6-2 – Erosion Around Mitered End Section (Photo shows erosion on sides and below mitered end section)
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• End Treatments and Appurtenances

Figure 4.6-3 – End section drop-off due to erosion under projecting end

Figure 4.6-4 – Deformation of Prefabricated End Sections

Figure 4.6-5 – Separation of Headwall and Culvert Pipe
Concrete Footing and Invert Slab

- **Purpose**
  - Identify distress and distress indicators that result in foundation problems for three-sided and other structures.
  - Look for differential settlement, scour, concrete deterioration, etc.

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**Figure 4.7-1** – Differential Footing Settlement

**Figure 4.7-2** – Differential Settlement of Footing Supporting Corrugated Metal Arch
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

- Concrete Footing and Invert Slab

Figure 4.7-3 – Footing Rotation

Figure 4.7-2 – Differential Settlement of Footing Supporting Corrugated Metal Arch

Figure 4.7-5 – Severe scour undermining wing wall foundation

Figure 4.7-6 – Invert slab in critical condition due to severe degradation of concrete
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Barrel Alignment
  – Purpose
    • Identify misalignment of pipe segments and may reduce hydraulic performance or lead to structural problems.
  – Look for vertical misalignments (sag, pooled water), sheared joints, etc.

Figure 4.8-1 – Severe visible sag in vertical alignment causing ponding

Figure 4.8-2 – Severe vertical misalignment has dislodged pipe segment resulting in joint offset and loss of support to embedment soil
## Barrel Alignment

<table>
<thead>
<tr>
<th>BARREL ALIGNMENT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAIR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRITICAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAILED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Horizontal alignment** shows no signs of movement from installed condition (straight or smooth bends). Vertical alignment shows no sagging or heaving.
- **Horizontal alignment** shows small visible deviations from installed condition that does not affect joints or barrel. Vertical alignment has minor sagging or heaving.
- **Horizontal alignment** with deviations from installed condition that may affect joints or barrel (refer to joint inspection). Vertical misalignment causing ponding / sediment accumulation at sags between 10% and 30% of diameter.
- Distress at joints or in barrel due to vertical or horizontal misalignment with pipe section offsets. Vertical misalignment has caused ponding/sediment accumulation of more than 30% of diameter. Indication of significant flow restriction.
- Cannot cause failed rating.

**Evaluate Need for Action**

**Corrective Action Required**

**N/A**

- **Barrel structure ratings evaluated separately**
Concrete Barrel

- What to look for:
  - Cracking
    - Longitudinal
    - Circumferential
    - Radial Offsets
  - Spalling
  - Delamination
  - Slabbing
  - Deterioration
  - Clogged Weep Holes

Figure 4.10-1 – Results of Poor and Good Side Support in Rigid Pipe

Figure 4.10-2 – Pipe with Critical Longitudinal Cracks with Rust Staining and Efflorescence

Figure 4.10-3 – Cracks with Radial Offset
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System: Barrels

• Concrete Barrel

Figure 4.10-4 – Transverse or Circumferential Cracking due to Poor Bedding Conditions

Figure 4.10-4 – Left: Small Spall along Crack, Right: Large Spall with Exposed/Corroded Rebar
Culvert and Storm Drain System Inspection Manual: 
Section 4 – Condition Rating System: Barrels

• Concrete Barrel

Figure 4.10-5 – Delaminated Area Marked on Pipe Wall, Located by Sounding with Hammer

Figure 4.10-6 – Slabbing in concrete pipe
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System: Barrels

- Concrete Barrel

Figure 4.10-7 – Severe Freeze-Thaw Deterioration with Stand-Out Aggregate and Pop Outs

Figure 4.10-8 – Moderate Deterioration (Probable Chemical Attack) with Exposed Aggregate and Loss of Surface Mortar

Figure 4.10-9 – Severe Deterioration (Probable Chemical Attack) with Complete Loss of Invert
## Concrete Barrel Rating Table – Overview

<table>
<thead>
<tr>
<th>CRACKING</th>
<th>GOOD</th>
<th>FAIR</th>
<th>POOR</th>
<th>CRITICAL</th>
<th>FAILED</th>
</tr>
</thead>
<tbody>
<tr>
<td>No measurable crack width greater than hairline (maximum 0.01 in.).</td>
<td>Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating from cracks.</td>
<td>Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0 – 3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.</td>
<td>Longitudinal cracks greater than 0.1 in. wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset. Large areas of rust staining emanating from cracks.</td>
<td>Collaps (complete or partial) or imminent collapse of culvert barrel.</td>
<td></td>
</tr>
<tr>
<td>SLABBING, SPALLING, DELAMINATION, PATCHES</td>
<td>No spalling or slabbing, as indicated by wall visual appearance. No delamination. Patched areas that are sound.</td>
<td>Localized spalls less than ½ in. in depth and less than 6 in. in diameter. No exposed rebar. No slabling. Small delaminations indicated by hollow sounds at patches but patch remains stable. delaminations larger than ¾ in. in depth and larger than 6 in. in diameter. No exposed rebar. Some rust staining from spalled areas, structure stable. No slabling. Patched areas that are delaminated or deteriorating.</td>
<td>Widespread spalling greater than ¾ in. in depth or delamination with exposed rebar, structure unstable. Slabbing of concrete.</td>
<td>Cannot cause failed rating.</td>
<td></td>
</tr>
<tr>
<td>DETERIORATION</td>
<td>No scaling, abrasion, or other surface damage.</td>
<td>Light or moderate scaling (less than 0.25 in. exposed aggregate). Abrasion less than 0.25 in. deep over less than 20% of pipe surface. Localized superficial (less than 0.25 in.) impact damage No rebar exposed. Multiple plugged weep holes.</td>
<td>Moderate to severe scaling (aggregate clearly exposed). Abrasion between 0.25 in. and 0.5 in. deep over more than 30% of pipe surface. Impact damage with exposed rebar. Extensive surface damage and aggregate pop-out. Includes exposed and/or corroded rebar. Complete invert deterioration and loss of pipe wall section.</td>
<td>Collapse (complete or partial) or imminent collapse of culvert barrel.</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix B – Catalog of Distressed Conditions

#### CONCRETE BARREL

<table>
<thead>
<tr>
<th>Grade</th>
<th>Condition Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2</strong></td>
<td><strong>FAIR</strong></td>
</tr>
<tr>
<td></td>
<td>Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating from cracks.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>POOR</strong></td>
</tr>
<tr>
<td></td>
<td>Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0 – 3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.</td>
</tr>
</tbody>
</table>

### Fair: Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating from cracks.

![Image](image1.png)

### Poor: Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0 – 3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.

![Image](image2.png)
**Critical**

Longitudinal cracks greater than 0.1 in. wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset. Large areas of rust staining emanating from cracks.

**Failed**

Collapse (complete or partial) or imminent collapse of culvert barrel.
• Joints and Seams
  – Joint Types
    • **Plastic Pipe:**
      – Bell and spigot, split couplers
    • **Concrete Pipe:**
      – Tongue and groove, bell and spigot
    • **Corrugated Metal:**
      – Connecting bands, bell and spigot

---

**Figure 4.14-1** – Tongue-and-groove Joint

**Figure 4.14-2** – Bell-and-Spigot Joint
• Joints and Seams
  – Joint Types
    • Plastic Pipe:
      – Bell and spigot, split couplers
    • Concrete Pipe:
      – Tongue and groove, bell and spigot
    • Corrugated Metal:
      – Connecting bands, bell and spigot, bolted

Figure 4.14-3 – Connecting Bands for CMP
Figure 4.14-4 – Standard Connecting Bands for CMP (without gasket)
Figure 4.14-5 – Gasketed Connecting Bands for CMP
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System: Joints & Seams

• Joints and Seams
  – Look for joint separation, offset, rotation, cracking, spalling, infiltration/exfiltration, etc

Figure 4.14-6 – Joint Separation in Corrugated Metal Pipe with Visible Backfill
Figure 4.14-7 – Joint Offset Causing Completely Dislodged Pipe Section
Figure 4.14-9 – Water Infiltration through Joints
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System: Joints

- **Joint Rating Table**

<table>
<thead>
<tr>
<th>JOINTS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GOOD</strong></td>
<td>Joints are tightly installed with proper alignment and functioning well.</td>
<td>Joint separation, offset, or rotation with no indication of distress. Gasket not exposed.</td>
<td>Joint separation, offset, or rotation in one or more joints, with exposed or missing gasket materials.</td>
<td>Joint separation, offset, or rotation with exposed backfill material. Multiple locations of exposed or missing gaskets.</td>
<td>Cannot cause failed rating.</td>
</tr>
<tr>
<td><strong>FAIR</strong></td>
<td>No joint cracking.</td>
<td>Longitudinal cracks of 0.01 in. to 0.05 in. wide (thickness of dime) emanating from joint. No spalling.</td>
<td>Between 0.05 in. and 0.1 in. wide longitudinal cracks emanating from joint. Small spalls along edge of spigot end.</td>
<td>Greater than 0.1 in. longitudinal cracks emanating from joint. Large spalls along edge of spigot end.</td>
<td></td>
</tr>
<tr>
<td><strong>POOR</strong></td>
<td>Joints are performing as intended with respect to infiltration and exfiltration.</td>
<td>Joint distress identified by coarse grained soil infiltration through soil-tight joints. Fines infiltration through silt-tight joints. Any water infiltration/exfiltration through leak resistant or watertight joint.</td>
<td>Joint distress directly causes distress to barrel/end section, roadway/shoulder, or embankment.</td>
<td>Evaluate Need for Action</td>
<td>Corrective Action Required</td>
</tr>
</tbody>
</table>

- Joints cannot cause failed ratings.
- Evaluation of the need for corrective action is required for:
  - Joint separations, offsets, or rotations with exposed or missing gaskets, 0.05 to 0.1 in. wide longitudinal cracks at joint, small spalls, soil or water infiltration if not meeting specified performance criteria.
- Corrective action is required for:
  - Exposed backfill, multiple locations of exposed or missing gaskets, longitudinal cracks greater than 0.1 in. width, large spalls, joint distress causing distress to the barrel or other component.
Seams

Figure 4.15-1 – Cocked Seam with Cusp Effect

Figure 4.15-2 – Severe Bolt Tipping in Corrugated Metal Plate

Figure 15-3 - Cracking at bolt holes
# Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System: Seams

- **Seam Rating Table**

<table>
<thead>
<tr>
<th>SEAMS OF CORRUGATED METAL PLATE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INFILTRATION/EXFILTRATION</strong></td>
<td>GOOD</td>
<td>FAIR</td>
<td>POOR</td>
<td>CRITICAL</td>
<td>FAILED</td>
</tr>
<tr>
<td>No signs of infiltration or exfiltration.</td>
<td>Minor water infiltration through leak resistant seams but no soil infiltration.</td>
<td>Significant water infiltration and evidence of fine soils infiltrating through seams.</td>
<td>Coarse soil infiltration through seam openings. Possible hollow sounds behind structure wall near seams indicating loss of backfill support. Evidence of piping due to exfiltration.</td>
<td>Collapse (complete or partial) or imminent collapse of Structure.</td>
<td></td>
</tr>
<tr>
<td><strong>SEAM ALIGNMENT</strong></td>
<td>No visible misalignment.</td>
<td>Slight cocked seams without cusp effect, but does not affect cross section shape.</td>
<td>Cocked seams such that it affects cross-section shape. Cusped effect with local wall bending.</td>
<td>Cocked seams severely affecting cross-section shape. Cusp effect with seam cracking. Seam capacity loss imminent.</td>
<td>Complete separation of pipe segments such that backfill is visible.</td>
</tr>
<tr>
<td><strong>SEAM BOLTS/FASTENERS</strong></td>
<td>No loose or missing bolts/fasteners</td>
<td>Less than 5% loose or missing bolts in any seam.</td>
<td>5% to 15% of loose or missing bolts in any seam.</td>
<td>Greater than 15% loose or missing bolts in any seam.</td>
<td>Collapse (complete or partial) or imminent collapse of Structure.</td>
</tr>
<tr>
<td><strong>SEAM BOLT HOLES</strong></td>
<td>No yielding or deformation of bolt holes. No wall prying due to bolt tipping.</td>
<td>Minor yielding of steel and/or cracking/splitting less than 1 in. long local to bolt holes. Minor corrosion developing around bolt holes or on bolts.</td>
<td>Yielding of steel and/or cracking/splitting 1 in. to 3 in. long local to bolt holes. Corrosion with section loss around bolt holes or on bolts.</td>
<td>Significant yielding of steel at bolt holes. Cracking/splitting 3 in. or more local to bolt holes. Corrosion with section loss around bolt holes or on bolts.</td>
<td>Seam has completely failed, possible structural collapse.</td>
</tr>
</tbody>
</table>

- Failed seams can cause failed ratings.
- Evaluation of the need for corrective action is required for:
  - Significant water infiltration with fines, cocked or cusped seams, 5% to 15% loose or missing bolts in a seam, moderate yielding/cracking/splitting at bolt holes.
- Corrective action is required for:
  - Coarse soil infiltration, possible voids behind steel, evidence of piping from exfiltration, severely cocked or cusped seams with potential loss of capacity, greater than 15% loose or missing bolts in a seam, significant yielding/cracking/splitting at bolt holes, corrosion and section loss at bolts/bolt holes.
Culvert and Storm Drain System Inspection Manual: Section 4 – Condition Rating System

• Aquatic Organism Passage (AOP)
  – Not historically considered in design
  – Culverts can result in barriers and stream fragmentation
  – Common barriers include:
    • Excessive velocity
    • Outlet configuration (drops)
    • Turbulence
    • Insufficient depth
    • Excessive lengths (darkness)
    • Debris and sediment
    • Culvert damage (can prevent fish from passing)
Culvert and Storm Drain System Inspection Manual:

Section 5 – Asset Management
Culvert and Storm Drain System Inspection Manual:
Section 5 – Asset Management

• Transportation Asset Management
  – Makes an account of inventory and maintenance to prolong the service life of highway assets.
  – Weigh costs and benefits of maintenance with importance of structure and performance goals to prioritize and optimize actions
  – Goals can be over an extended time horizon and draw from both economics and engineering principles
  – Allows for accountability and transparency in public funding
Culvert and Storm Drain System Inspection Manual: Section 5 – Asset Management

• Best Practices for Developing an Asset Management Plan
  – AASHTO Transportation Asset Management Guide
    • Published in response to growing emphasis and requirements for transportation asset management
    • Recommended resource for development of a culvert and storm drain system asset management plan
• Best Practices for Developing an Asset Management Plan
  – FHWA Case Studies
    • FHWA Report No. IF-07-032: Culvert Management Systems
      – Case studies from Alabama, Maryland, and Shelby County Alabama
    • FHWA Report No. FHWA-HIF-14-008: Culvert Management Case Studies
      – Case studies and best practices from Vermont, Oregon, Ohio, Los Angeles County
  – Minnesota DOT Culvert Management System
    • Transportation Asset Management Plan (TAMP)
    • HYDINFRA (HYDraulic INFRAstructure) for spans < 10 ft
  – New Jersey DOT Culvert Information Management System (CIMS)
Concluding Remarks

• NCHRP 14-26 Final Report available at:

• Email mcrichie@sgh.com for announcements on:
  – Expected publication date of manual
  – Upcoming presentations
  – Upcoming training and implementation seminars
Questions and Discussion

Thank you!