**JOINT TRANSPORTATION RESEARCH PROGRAM**

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY


# Large Culvert Inspection Procedures: Guidelines for INDOT


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**16. Abstract**

Within the state of Indiana, there are approximately 9,000 structures with unsupported span lengths that range from 4 ft to 20 ft that the Indiana Department of Transportation (INDOT) is responsible for maintaining. These structures are referred to as large culverts by INDOT. The agency recognized the need to improve culvert inspection procedures so that inspection data that is collected can provide essential information to asset engineers who make decisions regarding culvert management. The purpose of the project described in this report was to identify best practices for the inspection and management of these structures to develop guidelines that optimize the resources allocated for the maintenance and inspection of large culvert structures. This study found that standardizing the inspection process and evaluation criteria for inspection will positively impact the overall performance of the inventory of these structures. A proposed large culvert inspection manual accompanies this report and provides a detailed guide for large culvert inspection.

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# EXECUTIVE SUMMARY

## Introduction

The Indiana Department of Transportation (INDOT) defines a large culvert as a structure that has an unsupported span length between 4 ft and 20 ft. Nearly 9,000 structures within the state fit this definition and are included in the Bridge Inspection Application System (BIAS) database. Because of the broad definition of a large culvert, several materials, shapes, and sizes are included within this category. The FHWA's National Bridge Inspection Standards (NBIS) do not govern the inspection of culverts. Thus, development of policy surrounding the frequency of inspections, inspection procedures, and qualifications of inspectors are established and enforced by INDOT.

Many of the large culverts in the state are at low risk of failure as the structures are in good condition and the likelihood of significant changes to their condition over a several-year period is low. By identifying these low-risk structures, DOT resources can be saved by performing less frequent and/or less intensive inspections of these large culverts. Conversely, other large culverts within the state system are at a higher risk of failure and may require more attention. Through development of clear inspection procedures and optimization of inspection frequencies for these structures, necessary data can be collected for asset management to improve the overall condition of the large culvert inventory. The goal of this research project was to improve the inspection process for these structures by creating an inspection manual dedicated to large culvert inspection.

## Findings

The research team identified best practices from DOTs across the United States and assessed existing culvert inspection resources from across the country. A comprehensive evaluation of the existing large culvert inventory in the state was also conducted to identify important trends in culvert conditions over time. Best practices that would best accommodate the framework of INDOT's large culvert structure inspection program were identified. Recommended modifications include new condition rating scales and descriptors for evaluation of the culvert barrel, evaluation of additional components of the large culvert structure, standardized equipment lists, and modifications to the current inspection frequency scales.

## Implementation

Implementation will be application of the proposed guidelines for inspection of large culvert structures. Applying the proposed guidelines is expected to result in (1) more uniform assessment of culverts statewide, thus reducing subjectivity when rating culvert conditions, and (2) the collection of field data that will better assist asset engineers in their decisions regarding culvert maintenance/replacement. Furthermore, the resources provided to INDOT will be useful for training inspectors in uniform culvert inspection practices.

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# 1. INTRODUCTION

## 1.1 Background and Terminology

The Federal Highway Association mandates that structures with unsupported lengths greater than 20 ft, typically referred to as bridges (Figure 1.1), must be inspected every two years to ensure the structure is safe for public use (FHWA, 1995). For structures with unsupported lengths of 20 ft or less, these federal mandates do not apply. This allows individual state transportation agencies to determine the level of resources they allocate to these structures. The Indiana Department of Transportation (INDOT) refers to these structures as culverts and separates this group into two sub-groups: large culverts and small culverts. A large culvert is defined as a structure with an opening span between 4 ft and 20 ft (INDOT, 2020). These are the structures that received focus during the study described in this report. There are nearly 9,000 large culvert structures inventoried in the state's internal database.

Most large culvert structures in the state of Indiana perform the function of transporting water underneath a roadway without interrupting the flow of traffic above. When evaluating a large culvert on its performance of this function, consideration should be provided for the structural performance as well the hydraulic performance of the large culvert. Proper evaluation of structural performance of a large culvert structure is dependent on its overall behavior. The two main categories of culvert behavior are rigid and flexible. Behavior is generally determined by the material of the culvert structure. Materials such as reinforced concrete and stone/masonry exhibit rigid behavior, while corrugated metals and plastic materials typically exhibit flexible behavior. The behavior type of a culvert structure determines the importance of the soil surrounding the structure and the types of deterioration mechanisms inspectors are tasked with identifying within the structure.

## 1.2 Current INDOT Procedures

Written guidelines for INDOT's current large culvert inspection procedures resemble the procedures outlined in the *Bridge Inspector's Reference Manual* (FHWA, 2012). The inspection process begins with an initial inspection for collection of inventory data about the structure. These data include the structure's location, geometry, physical characteristics, and information related to the surrounding environment. This information is typically collected during or immediately after construction and does not change unless the structure is later modified. Additional information such as the current condition of the structure and surrounding features is collected during routine inspections and recorded in an inspection form. These data are stored in the Bridge Inspection Application System (BIAS) database where the information can be accessed by INDOT inspectors and asset management personnel. The amount of time between routine inspections is determined by the evaluation of the condition rating of the large culvert during the previous inspection.

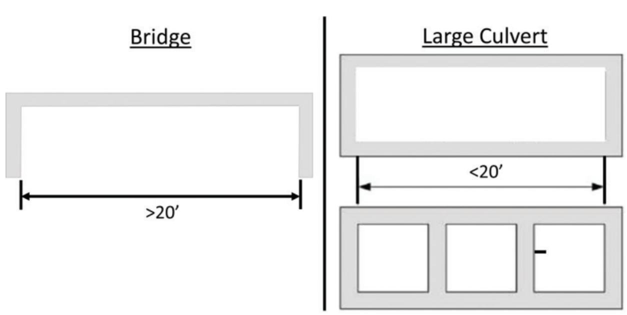



**Figure 1.1** Differentiation between bridge and large culvert structures.

The condition rating scales that are used for bridge inspection, defined in Items 058, 059, and 060 in the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995), are also applied to large culvert structures in Indiana. These rating scales, also known as the National Bridge Inventory (NBI) scales, consist of values from zero to nine with nine representing excellent condition and zero indicating a closed or failed structure. In accordance with the *INDOT Bridge Inspection Manual* (INDOT, 2020), structures that receive a barrel rating of seven or greater are allowed 72 months between inspections except for corrugated metal structures with a constant water flow. In this case, the inspection interval is limited to 48 months. Ratings of five or six are allowed 48 months between inspections, and ratings of four or below are limited to 12 months between inspections. The state of Indiana has 26 positions for inspectors who are qualified to inspect large culvert structures. These inspectors are divided among six districts that each operate as the local authority of a different geographical region of the state. These six districts are identified in Figure 1.2.

## 1.3 Project Objective and Scope

The primary objective of this project is to create a set of comprehensive inspection guidelines that can be used for the population of large culverts in Indiana. This inspection manual addresses (1) data that should be collected for inventory purposes, (2) the equipment necessary to perform a proper inspection, (3) suggestions for documenting findings during large culvert inspections (e.g., level of detail that is necessary), and (4) suggestions for modification of the current condition rating system and the scales used for evaluation. To accomplish this, the project was divided into the components listed below. Each component corresponds with a chapter in this report.

- Literature Review (Chapter 2): Understand the practices being implemented by other transportation entities by reviewing available literature.

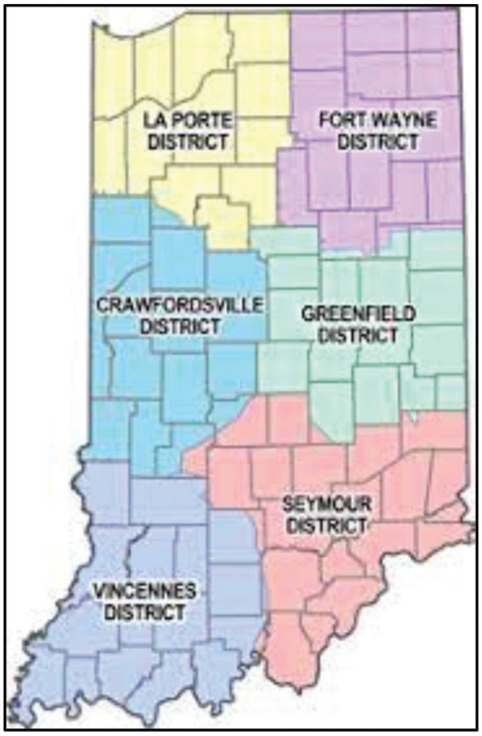



**Figure 1.2** Regional districts of INDOT (INDOT, n.d.).

- National Survey (Chapter 3): Conduct a national survey to supplement the literature review to understand the practices being implemented by other transportation entities; identify practices that can be adopted or modified for use by INDOT inspectors based on collected responses.
- Data Collection and Categorization (Chapter 4): Categorize large culverts within INDOT's inventory based on shared characteristics to better understand the overall inventory composition.
- Data Analysis (Chapter 5): Analyze the data categorized in the previous chapter to identify any trends present across inspection reports and collected data fields; determine the level of risk associated with current inspection frequencies and practices.
- Recommended Guidelines (Chapter 6): Develop guidelines and inspection standards based on successful practices identified throughout the project; evaluate the practices followed by other transportation agencies and their potential impact on INDOT's large culvert inventory; organize the inspection guidelines and compile a concise and comprehensive large culvert inspection manual.

Throughout the project, a Study Advisory Committee (SAC) consisting of personnel from INDOT and the industry provided feedback and guidance that aided in identifying culvert inspection practices that best fit within the current framework of INDOT's inspection program.

# 2. LITERATURE REVIEW

This chapter provides a summary of the core literature that was referenced throughout the research project and that aided with identifying best practices for large culvert inspection. The documents described in the following sections provided the research team with a technical understanding of terminology and trends in culvert inspection practices that have been observed over the past few decades. The contents of the documents also served as inspection program models that were referenced when determining what procedures and practices best suit the needs for a culvert inspection program in Indiana.

## 2.1 *FHWA Culvert Inspection Manual* (1986) and *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (1995)

In 1986, the FHWA published the *Culvert Inspection Manual* (FHWA, 1986) that was intended to be used as supplemental material to the FHWA *Bridge Inspector's Training Manual 70* (FHWA, 1970) for bridge inspectors. The FHWA *Culvert Inspection Manual* provides recommendations for evaluation of a culvert structure and its components. The manual served as the first comprehensive set of recommendations published by the federal government specifically related to culvert inspection. In addition to discussing the collection of data and classification of culverts, this manual provides objective condition rating descriptors for metal, concrete, and masonry structures and outlines recommended procedures for inspection practices (FHWA, 1986). The document serves as a building block for practices and procedures developed in the AASHTO *Culvert and Storm Drain System Inspection Guide (CSDIM-1)* (AASHTO, 2020) (see Section 2.2) related to culvert components as well as condition rating scale descriptors.

The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) is the current set of guidelines for bridge inspection regarding the recording of bridge data. The guide contains the condition rating scale that INDOT currently uses for large culvert evaluation (INDOT, 2020). Along with the FHWA *Culvert Inspection Manual* (FHWA, 1986), this document was referenced during the current research project for information regarding objective descriptors and acceptable tolerances for condition rating scale modification.

## 2.2 AASHTO Culvert and Storm Drain System Inspection Guide (2020)

The objective of the research published in the AASHTO *Culvert and Storm Drain System Inspection Guide (CSDIM-1)* (AASHTO, 2020) was to develop a successor to the inspection guidelines introduced in the FHWA *Culvert Inspection Manual* in 1986 (FHWA, 1986). The AASHTO CSDIM-1 introduces guidelines for assessing the condition of in-service culvert and storm drain systems. To develop these guidelines, trends in inspection program development across transportation entities in the United States were evaluated. The manual includes comprehensive condition rating scales for each identified component of a culvert system. In addition to overhauling the condition rating system and updating criteria for existing materials, the AASHTO CSDIM-1 addresses aspects of culvert inspection that were not present or have changed significantly since the publication of the FHWA *Culvert Inspection Manual* (FHWA, 1986), including the following (AASHTO, 2020):

- safety, qualifications, and equipment of the inspector;
- structural characteristics including loads and structural design;
- culvert materials and replacement methods;
- impact on aquatic life;
- inspection procedures and quality measures; and
- rating systems and inventory management.

A key observation of the research was that a significant obstacle to an effective inspection system is reduction of ambiguity in inspection practices and condition rating scales. Through analysis of case studies, it was discovered that ensuring system public safety, functional performance, and economical use of resources rely on accurate and consistent inspection findings. Therefore, ratings need to be consistent across different culvert system types as well as between inspectors (AASHTO, 2020). During the current research project, the manual served as both a comprehensive introduction to culvert terminology and a benchmark for the development of recommendations and guidelines for large culvert inspection in Indiana.

### 2.3 Culvert Asset Management System: Best Practices/Pilot Project (Villwock-Witte et al., 2016)

The report titled *Culvert Asset Management System: Best Practices/Pilot Project* (Villwock-Witte et al., 2016) contains relatively recent information regarding the management of small culverts across the United States. The study described in the report was conducted to identify best practices for culvert asset management systems in state departments of transportation (DOTs) on behalf of the New Mexico DOT. The report provides the details of a survey that was conducted for small culvert structures and management practices at a national level. Results of the national survey conducted for small culvert inspection practices provided insight into which states had developed programs and noted similarities that were discovered between different state programs. While the survey was aimed at smaller structures, understanding what states were investing in their small culvert structures provided a reasonable expectation that the state had some form of an inspection program in place for larger structures as well (Villwock-Witte et al., 2016). Gaining an initial understanding of the culvert management programs in place across the United States helped determine what questions were necessary to ask in the national survey that was developed and distributed during the beginning months of the current research project.

### 2.4 Risk Assessment and Update of Inspection Procedures for Culverts (Mitchell et al., 2005)

The report titled *Risk Assessment and Update of Inspection Procedures for Culverts* (Mitchell et al., 2005) describes a project focused on the improvement of the Ohio Department of Transportation's (ODOT's) culvert inspection procedures at the time of its publication. The study considered a selection of 60 culverts across the state of Ohio to evaluate condition rating scales, estimated service life of structures, and the impact that factors such as abrasiveness of debris, pH of water, and flow velocity have on the life span of a structure. New descriptors for condition rating scales are proposed in the document to increase the level of objectively for culvert assessment. Increasing the number of components evaluated during culvert inspections is also recommended. The authors recommend the application of a 10-point scale to 33 components and systems, an increase from the 16 components ODOT was considering at the time (Mitchell et al., 2005). The objective descriptors developed by Mitchell et al. (2005) impacted the condition rating descriptors recommended to INDOT as a result of the current research project.

### 2.5 *NCHRP Report 782: Proposed Guideline for Reliability-Based Bridge Inspection Practices* (Washer et al., 2014)

*NCHRP Report 782: Proposed Guideline for Reliability-Based Bridge Inspection Practices* (Washer et al., 2014) introduces a risk-based approach for defining the inspection frequency of bridge structures. Condition rating data from more than 7,000 bridge structures collected over 20 years was used to observe the length of time over which condition rating values remain constant for different bridge types. Statistical analyses were performed on this data to create proposed inspection frequencies based on the risk of failure of a structure. Risk is defined using two factors: an occurrence factor and an importance factor. The occurrence factor is based on the likelihood of failure between the current inspection date and the next suggested inspection date. The importance factor considers the impact a failure of the structure would have on public safety. The researchers found that bridge inspection intervals for structures in good condition could reasonably be extended beyond the current 24-month period between inspections (Washer et al., 2014).

The concept of basing inspection on the risk of failure was identified as one of the objectives of the current research project described in this report. Through evaluation of the risk-based framework used by Washer et al. (2014), the concept was adapted for use on the available data provided by INDOT for large culvert structures.

## 3. NATIONAL SURVEY

After gathering information about the procedures and practices developed by various entities through the literature review, the research team developed a survey to be distributed to DOTs throughout the United States. The questions on the survey were focused on identifying differences in current practices for large culvert inspection between various transportation agencies and better understanding the impact of these practices. The following sections provide an overview of the survey, describe the survey distribution and responses, and discuss the identification of best practices from other transportation entities.

## 3.1 Overview of Survey

The questions included in the survey can be divided into two general categories: policy-related questions or procedure-related questions. Policy-related questions were aimed at understanding the reasoning behind culvert inspection practices and asset management decisions. The focus of the questions included culvert inspection frequency, database development and asset management, the existence of written guidelines, and other general items. Procedure-related questions were focused on identifying the current practices and procedures of each transportation agency. Included in this category were inspector qualifications, condition rating scales, and the use of non-destructive testing equipment during culvert inspection and evaluation. In addition to the policy- and procedure-related inquiries, the survey included three preliminary questions used to filter the other questions on the survey based on a few basic items related to the agency's culvert inspection program. More specifically, the preliminary questions determined if each transportation agency (1) has a database or inventory of its culvert structures, (2) inspects its culverts, and (3) uses structural liners to rehabilitate deteriorated large culvert structures.

The finalized survey included 19 questions consisting of three preliminary questions, nine policy-based questions, and seven procedure-based questions. The participants were also offered the opportunity at the end of the survey to upload additional documents to supplement the survey responses. A copy of the full survey is provided in Appendix A.

## 3.2 Distribution and Responses

The survey was distributed to transportation agency contacts and was administered using an online web form. Survey responses were collected from February through April 2021. In total, 40 unique responses representing 35 DOTs and transportation agencies were collected. A list of the states/agencies represented through the survey responses is provided in Table 3.1.

Based on the survey responses, 26 of the 35 DOTs were identified to define culverts in a manner that is at least partially compatible with the culvert and large culvert definitions used by INDOT. More specifically, these 26 DOTs define a culvert as a structure with an unsupported length equal to or less than 20 ft. Out of these 26 DOTs, 12 agencies define their culvert inventory with measurements that were within 2 ft of INDOT's large culvert opening span range used for classifying structures as a large culvert (Figure 1.1). Furthermore, the responses indicate that a total of nine states recognize a difference between structures with opening lengths of 10 ft to 20 ft and structures with shorter opening lengths. A detailed breakdown of how the 26 DOTs define culvert structures is provided in Figure 3.1. The responses from states listed with red text indicate that inspections of their culvert inventory are not performed by agency personnel but are instead conducted by outside consultants.

Of the 26 DOTs that use definitions for culverts that are at least partially compatible with INDOT's definitions for the terms culvert and large culvert, 10 DOTs indicated that they had written guidelines and inspection manuals for their culvert inspection programs. The contents of the inspection manuals and written guidelines vary significantly amount these agencies. The contents of these documents range from simplified versions of bridge inspection requirements to custom inspection manuals that include multiple aspects of the inspection and evaluation processes and outline inspector expectations. The research team gathered multiple ideas from manuals and written guidelines shared by other DOTs (ODOT, 2021; WSDOT, 2010; Youngblood, 2017) that may be beneficial to INDOT if implemented. Key ideas that were identified are listed in Table 3.2 along with the DOTs that provided the idea.

Policy for inspection intervals was also found to vary between DOTs. Some DOTs perform inspections based on calendar cycles regardless of condition, while other agencies incorporate the risk of failure into their inspection frequencies. A summary of inspection intervals followed by state DOTs as indicated by the

TABLE 3.1
**List of Responding DOTs**

| Responding DOTs in Alphabetical Order | | | | |
|---|---|---|---|---|
| Arizona | Kansas | Montana | Ohio | Texas |
| Arkansas | Kentucky | Nebraska | Oregon | Vermont |
| Colorado | Maryland | Nevada | Pennsylvania | Virginia |
| Delaware | Massachusetts | New Jersey | Rhode Island | Washington |
| Florida | Michigan | New Mexico | South Carolina | West Virginia |
| Idaho | Minnesota | North Carolina | South Dakota | Wyoming |
| Illinois | Mississippi | North Dakota | Tennessee | USDOT |

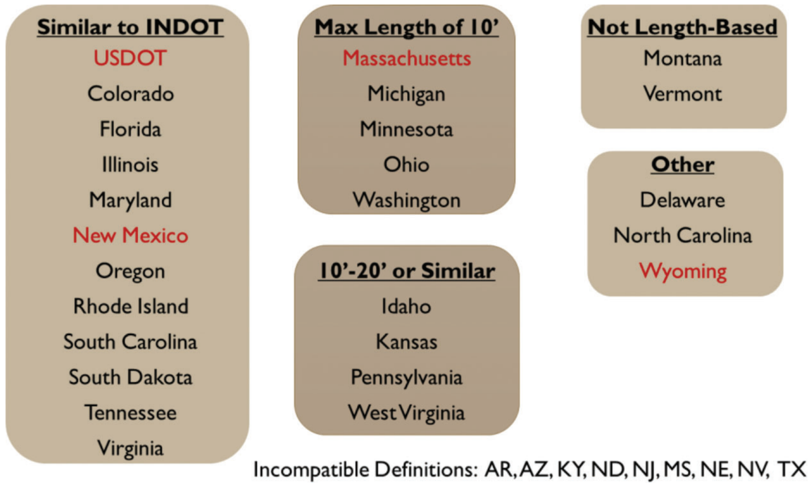



**Figure 3.1** Culvert definitions according to survey responses.

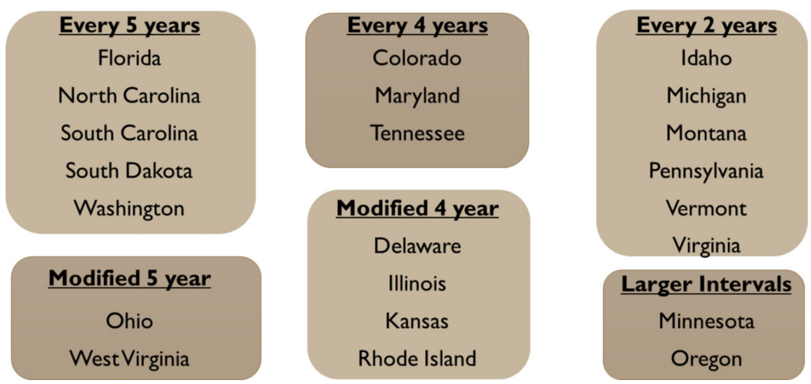



**Figure 3.2** Inspection frequencies followed by DOTs.

TABLE 3.2
**Ideas Gathered from DOT Inspection Manuals and Written Guidelines**

| Identified Practice | State |
|---|---|
| Collection of pH value of waterway directly upstream of the inlet | TN[1], MN |
| Consideration of the level of submergence experienced by a structure | MN |
| Use of multiple inspection levels with different degrees of detail | WS |
| Scheduled inspection after backfill material and other components have settled | OH |
| Separating slab culvert structures from remaining large culvert population | OH |

[1]Researchers were informed of draft manual contents through personal interview with C. Starr on June 30, 2021.

survey responses are provided in Figure 3.2. The states listed in the figure include those with compatible or partially compatible culvert and large culvert definitions that perform their own inspection of the structures. The categories "modified 4 year" and "modified 5 year" indicate that the typical inspection frequency followed by the DOT (4 years or 5 years) is adjusted to incorporate the previous condition ratings of the structures to consider risk. The survey responses indicated that four DOTs incorporate consideration of the roadway supported by the large culvert structure to determine the inspection frequency assigned to the structure. For these DOTs, the roadways supported by culverts that receive more frequent inspections are interstate highways and U.S. routes. In a similar manner, bridge structures along designated National Highway System (NHS) routes as defined by the United States Department of Transportation (USDOT) undergo more detailed inspections, referred to as an element level inspection, where specific components of a bridge structure are assigned an element state value ranging from one to four that indicates the condition of the component (FHWA, 2014). The research team considered the distinction of culvert importance based on the supported roadway as a possible method to incorporate the consideration of risk into proposed culvert inspection guidelines for INDOT (see Section 6.3.2).

TABLE 3.3
**Overview of Condition Rating Assignments Used by DOTs**

| Single Overall Rating | Multiple/Elemental Rating | Hybrid Rating Approach |
|---|---|---|
| Colorado | Delaware | Michigan |
| Florida | Idaho | Montana |
| Maryland | Illinois | Oregon |
| Minnesota | Kansas | South Dakota |
| Ohio | North Carolina | Tennesse |
| Pennsylvania | Rhode Island | |
| Vermont | South Carolina | |
| Virginia | Washington | |
| West Virginia | | |

Information from questions in the survey that pertained to the elements of culvert structures receiving condition rating values and the rating scales that are applied to culverts were also gathered. Responses were again filtered using the subset of DOTs that indicated that their culvert and large culvert definitions are compatible or partially compatible with INDOT's current definitions and perform their own inspection of their culvert structures. Large variations were found among the DOTs. When asked about the current approach to evaluating the condition of a culvert structure, the responses collected from survey participants indicate that there is a nearly even distribution of DOTs that apply one overall rating to encompass the condition of a culvert structure and DOTs that rate multiple components within the culvert structure. The DOTs are categorized accordingly in Table 3.3, along with a list of those that use a hybrid approach where both an overall value and elemental values are used to assess the condition of the structure or specific components of the structure. Through follow-up questions, it was discovered that DOTs that assign one overall rating to culverts do consider multiple components of the culvert structure when assigning the condition rating value. Based on this finding and further discussion with the Study Advisory Committee, the research team determined that separating evaluation of the structure into a select number of components would be beneficial for asset management purposes.

Additionally, when asked about the condition rating scale used for evaluating large culvert structures, seven DOTs indicated use of a scale that is different from the NBI 0–9 scale that is applied to the evaluation of bridge structures. These seven DOTs use condition rating scales with a smaller range of values, typically consisting of three to five points. While this idea was considered for implementation in Indiana, the Study Advisory Committee expressed a desire to keep consistency between the 0–9 rating scales used for bridges and the scales used for large culvert structures because inspectors in the state evaluate both structure types.

### 3.3 Identification of Best Practices

Upon reviewing the responses collected from the national survey, certain practices and procedures were identified as either being compatible or partially compatible with INDOT's current inspection program. These ideas were then collected and organized as potential recommendations and ideas that could be expanded upon during later tasks of the research program. Several of the responses collected from the survey also merited follow-up conversations, either by email or virtual meetings, to better understand how certain policies or practices are being implemented by the agencies. The research team followed up with the following states after reviewing the survey responses: Delaware, Kansas, Massachusetts, Michigan, Minnesota, Nebraska, North Carolina, Ohio, Tennessee, Texas, and Washington. Ideas and recommendations collected from these interviews and follow-up questions were added to the list of recommendations and ideas collected from the survey for consideration during the development of proposed guidelines for Indiana.

The following is a list of potential recommendations that were collected from the survey and the follow-up discussions. Some, but not all, of the items listed are included in the final recommendations to INDOT.

1. Divide culvert condition rating into more than one value.
2. Create varying levels of inspection requiring different degrees of detail.
3. Consider higher frequency for culverts located on NHS routes.
4. Schedule the first routine inspection 12 months after the construction of a new culvert.
5. Add a field to the inspection form for indicating if the culvert is submerged, partially submerged, or not submerged at the time of inspection.
6. Add a pH field to the inspection form to record pH values when water is present.
7. Separate the evaluation procedures for slab-bridge culverts with spans greater than 10 ft from the evaluation procedures for large culvert structures.

## 4. DATA COLLECTION AND CATEGORIZATION

To gain a comprehensive understanding of the characteristics of the large culverts in Indiana, details of the complete inventory of the large culverts managed by INDOT were collected in the form of a culvert database. Information not included in the existing inspection database that was deemed to be important to develop a complete picture of the range of culvert characteristics in the state was added by the research team through further investigation. Culverts in the inventory were categorized to aid with an analysis of the culvert database, the results of which were used for the development of inspection guidelines. In the following sections, the culvert collection and categorization processes are described along with important insights into the composition of the culvert inventory that were identified.

## 4.1 Data Collection

INDOT is responsible for nearly 9,000 large culverts across the state. To better understand the makeup of the large culvert inventory, categorizing the structures based on shared characteristics such as material type, shape, structure type, and other properties was needed. Much of this information is collected during the initial inspection of a large culvert when it is first added to the inventory. However, due to changes in the manner in which culvert inspection data have been stored by INDOT over the past two decades, not all this information was present for structures in the electronic Bridge Inspection Application System (BIAS) database used by the DOT. Before 2016, data from inspections of large culverts were stored in local digital storage drives in each of the agency's six districts. This decentralized storage of data was replaced in the final months of 2015 by the BIAS database. When the local files for large culverts were transferred to the database, much of the stored information was not carried over, resulting in empty data fields. To obtain the missing information, the research team used photos collected during inspections conducted from 2016 to 2021 to repopulate the data fields for 8,830 large culverts. The data that were repopulated consisted of characteristics that could be reasonably identified through visual inspection. These included properties such as the material type, shape, structure type, presence of a structural liner, and the number of cells present in the structure. Other data fields such as structure geometry (horizontal and vertical opening lengths, depth of fill cover, skew, length, etc.) and year-built information were not identifiable through visual techniques alone. Without this information, the ability to categorize the culverts based on these characteristics was limited. The challenge of acquiring year-built information is further discussed in Section 4.3.

## 4.2 Data Categorization

Following the repopulation of missing data fields, the culverts were categorized into groups based on shared properties. This section provides an overview of three of the key categorizations of the culvert inventory—material type, barrel shape, and structure type. Knowledge of the distribution of culverts with each property aided the research team with developing culvert inspection guidelines specific to the needs of INDOT. For example, the distribution of culverts based on material type informed the research team regarding the material-specific condition rating scales that should be included in the guidelines that were developed (see Section 6.1.1). Furthermore, the distribution of culverts based on structure type aided with ensuring that recommended condition rating descriptors considered common deterioration patterns experienced by the prominent structure types in the culvert inventory.

### *4.2.1 Culvert Material Type*

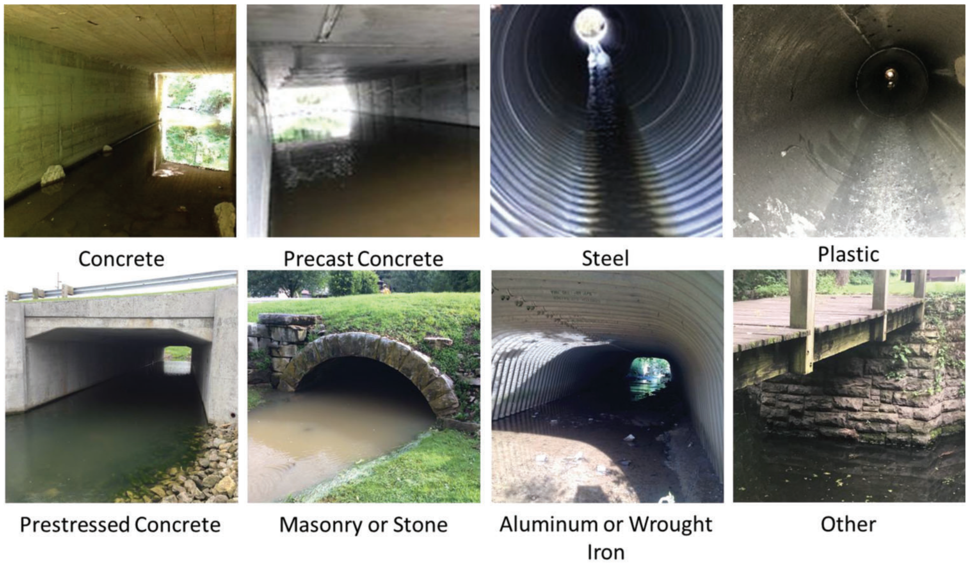
INDOT has eight different large culvert material classifications present within the large culvert inventory. INDOT's material type categorizations for large culverts are based on the material types listed in Item 43 of the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) with modifications made to include material types common for large culvert structures (i.e., precast concrete, plastic vinyl, and masonry or stone). Knowing the distribution of material types within the inventory is important as different materials experience unique types of deterioration and undergo deterioration at different rates. The eight material classifications are represented in Figure 4.1.

For the development of inspection guidelines, especially those related to the frequency of inspections, identifying the relationship between material type and deterioration rate of the structure was critical. A summary of the makeup of the large culvert inventory based on material type is provided in Table 4.1. Concrete, precast concrete, and steel comprise 90.1% of the inventory with plastic being the only other material type that corresponds to more than 100 structures. Culverts constructed with the four most common materials comprise 98.3% of the inventory. It should be noted that culverts classified as plastic structures include both stand-alone plastic structures as well as structures that have had a majority of the barrel lined with a plastic material for rehabilitation purposes. For structures consisting of multiple materials, the culvert was categorized based on the material that comprises the majority of the culvert length.

### *4.2.2 Culvert Barrel Shape*

Six distinct large culvert barrel shapes are present within INDOT's large culvert inventory. These six shapes are each represented in Figure 4.2.

The categorization of the large culvert inventory based on shape is presented in Table 4.2. Understanding the shape of the barrel is especially important for flexible culverts because the shape will influence how the structure deflects when it experiences uneven soil pressure. Box and round culverts together comprise nearly 80% of the large culvert inventory. Pipe arch is




Note: Photos provided by the Indiana Department of Transportation.

**Figure 4.1** Material type categorizations within large culvert inventory (A. Rearick, personal communication, June 10, 2022).

TABLE 4.1
**Large Culvert Inventory Categorized by Material Type**

| Code | Material | Count |
|---|---|---|
| 1 | Concrete | 3,136 |
| 2 | Precast Concrete | 1,878 |
| 3 | Steel | 2,945 |
| 4 | Plastic Vinyl | 726 |
| 5 | Prestressed Concrete | 1 |
| 8 | Masonry or Stone | 26 |
| 9 | Aluminum or Wrought Iron | 30 |
| 0 | Other | 6 |
| ? | Uncategorized | 82 |
| *Total* | | *8,830* |

the next most common shape, comprising 12.5% of the inventory.

### *4.2.3 Culvert Structure Type*

INDOT's structure type categorizations for large culverts are based on structure types listed in Item 43 of the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) with modifications made to include structure types common for large culvert structures (e.g., pipe, three-sided box, and four-sided box). The primary structure types used to categories large culverts in INDOT's inventory are shown in Figure 4.3.

The categorization of large culverts by structure type is provided in Table 4.3. Like material type and shape, the culverts are not uniformly distributed across the structure type classifications. Four-sided box and pipe structures together comprise 85.1% of the overall inventory. As expected, four-sided boxes were found to be almost exclusively concrete and precast concrete structures. Pipes were primarily steel and plastic-lined structures, but 649 of the structures categorized as pipes were precast concrete. The research team used the categorization to determine if any structure type presented a unique trend in deterioration rates based on condition rating values over time. Box-shaped structures (Table 4.2) were also differentiated based on the whether they are four-sided or three-sided structures to determine if any differences in performance over time were evident.

## 4.3 Estimation of Year-Built Data

When categorizing the large culvert inventory, culvert structures that were built before transferring the inventory data from local hard drives to the BIAS database in 2016 were largely missing year-built information. Reliably categorizing most culverts in the state inventory based on the age of the structure was not possible due to the lack of year-built information for a majority of the culverts. For the purposes of both asset management and identifying correlations between age and condition rating, estimated year-built information was needed. More specifically, knowing the estimated ages of culverts allows trends in culvert condition with age to be compared for different culvert properties, such as material type.

Through the efforts of asset engineers at INDOT, year-built data were estimated for culverts by considering the construction dates for the roadways carried by the culverts and for neighboring structures. Contract dates for road paving and construction permits were also considered. Using this technique and including structures where year-built information was already populated, estimated ages for approximately 60% of the large culvert inventory were determined. The estimated year-built dates allowed the distribution of age across


Note: Photos provided by the Indiana Department of Transportation.

**Figure 4.2** Shape categorizations within large culvert inventory (A. Rearick, personal communication, June 10, 2022).

TABLE 4.2
**Large Culvert Inventory Categorized by Shape**

| Shape | Count |
|---|---|
| Arch | 210 |
| Box | 3,564 |
| Elliptical | 607 |
| Round | 2,605 |
| Pipe Arch | 1,102 |
| Slab | 660 |
| Uncategorized | 82 |
| *Total* | *8,830* |

much of the culvert inventory to be identified, providing useful data for analysis (see Section 5.2). Estimated year-built information for large culverts, grouped by decade built, is provided in Figure 4.4. Considering the distribution of the data, periods of heavy investment in infrastructure by the federal government during the 1960s and 1970s are evidenced. Construction of large culvert structures increased again during the 2000s and 2010s, corresponding with the increase in resource allocation toward large culvert structures in the state.

For a small population of large culvert structures, year-built information for the original culvert at a specific site was available along with the date when the original culvert was replaced with the structure currently existing at the site. For these cases, the available dates indicate the lifespan of the original culvert structure. Using these data, the lifespans of 213 large culverts were collected. The results are presented in Figure 4.5. Lifespan information from these historical data was beneficial for the development of inspection frequency recommendations based on culvert material type as it provides a means to estimate expected lifespans of culverts constructed with specific materials (see Section 5.2).


Note: Photos provided by the Indiana Department of Transportation.

**Figure 4.3** Structure type categorizations within large culvert inventory (A. Rearick, personal communication, June 10, 2022).

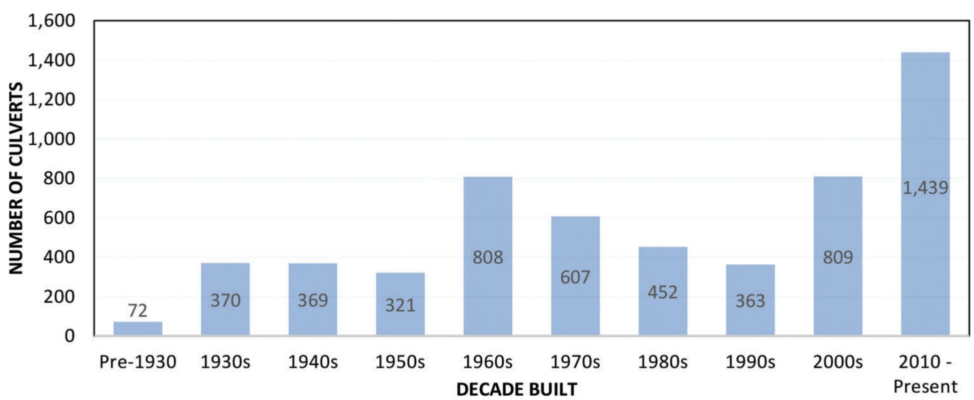



**Figure 4.4** Year-built data for large culvert structures.

TABLE 4.3
**Large Culvert Inventory Categorized by Structure Type**

| Code | Structure Type | Count |
|---|---|---|
| 01 | Slab | 637 |
| 02 | Stringer/Multi-Beam or Girder | 16 |
| 03 | Pipe | 4,314 |
| 05 | Box Beam Adjacent | 4 |
| 07 | Three-Sided Box | 361 |
| 11 | Arch | 210 |
| 19 | Four-Sided Box | 3,198 |
| 22 | Channel Beam | 7 |
| 00 | Other | 1 |
| – | Uncategorized | 82 |
| *Total* | | *8,830* |

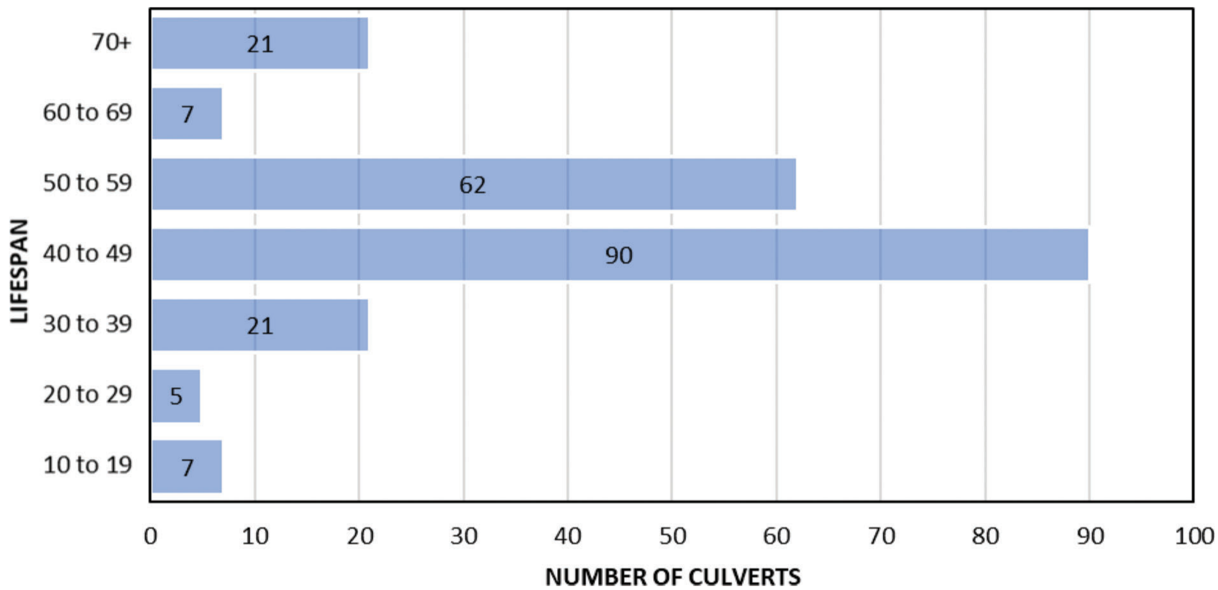



**Figure 4.5** Lifespan of large culverts based on year-built data.

## 5. DATA ANALYSIS

After the categorization of the large culvert inventory, the data were analyzed to identify trends or correlations in culvert characteristics that may aid with the development of inspection guidelines. More specifically, the categorized inventory was analyzed to find any trends in culvert condition ratings when compared against specific culvert properties such as age and material type. Furthermore, the inventory was evaluated to identity the reasons for significant reductions in condition rating values. Key findings of the inventory analysis are summarized in the following sections.

### 5.1 Condition Rating History

The large culvert database consists of more than 25,000 condition rating values across the large culvert structures in the inventory. A historical condition rating timeline for each large culvert was constructed by assigning the previous condition rating values to a year based on the inspection interval used by INDOT at the time of the corresponding inspections. The collection of condition rating histories allowed for a general picture of the rate of deterioration to be established for the inventory. Specific observations based on the condition histories are described in the following subsections.

#### *5.1.1 Culvert Structure Rehabilitation and Replacement*

After organizing the historical condition rating data for the culvert inventory, the number of culvert rehabilitations and replacements that had been performed from January 2016 to April 2021 were identified. A sudden increase of two or greater in the condition rating value for a culvert was evaluated through use of previous inspection reports to identify if rehabilitation or replacement work had been performed on the large culvert. During the January 2016 to April 2021 time frame, 313 large culvert structures had been rehabilitated, and 323 large culverts had been replaced. Considering the total of 636 culverts that had been rehabilitated or replaced, 66.4% of the structures were steel pipes. This observation is reflected within the risk-based inspection approach adopted in the culvert inspection recommendations (see Section 6.3). A breakdown of the material of the culverts that were rehabilitated or replaced from January 2016 to April 2021 is provided in Table 5.1.

#### *5.1.2 Importance of Culvert Structure Components*

Special attention was given to culverts with condition ratings that decreased by a value of two or greater between subsequent inspections. The goal of further investigating these structures was to identify the cause of these relatively significant condition changes between inspections. Between 2016 and 2021, 539 cases of condition rating decreases of two or greater were found in the database. Comments and pictures in individual inspection reports were reviewed to determine the cause

TABLE 5.1
**Culvert Material and Shape Before Rehabilitation/Replacement**

| Culvert Type | Number of Structures | Percentage of Total |
|---|---|---|
| Steel Pipe | 422 | 66.4 |
| Concrete Box | 93 | 14.6 |
| Concrete Slab | 44 | 6.9 |
| Other | 15 | 2.4 |
| Unclear | 62 | 9.7 |
| *Total* | *636* | *100* |

of these decreases. The majority of the cases corresponded to metal pipes and were primarily caused by deterioration of the invert due to the presence of flowing water. The observation that most of the changes were related to the barrel condition was not a surprise as the current condition rating scales and descriptors are primarily focused on the culvert barrel. Through comments in inspection reports, it was noted that the deterioration of other components of the culvert was not typically noted until the deterioration affected the barrel of the structure. This observation led to the recommendation that these additional components be evaluated separately from the barrel and receive their own rating (see Section 6.2). The components cited as the cause for a reduction in the condition rating of two or greater for culverts in the inventory are summarized in Table 5.2. Although 539 cases are represented in Table 5.2, multiple components were cited during some inspections as the cause of the decrease in rating. This should be kept in mind when considering the sum of the values in the columns of the table.

## 5.2 Impact of Material Type

The culvert inventory data were analysed to identify important trends related to material type. The following subsections address key observations between material type and culvert age, lifespan, and early deterioration.

TABLE 5.2
**Component Responsible for Condition Value Decreases of Two or Greater**

| Component Cited | Number of Structures | Percentage Affected |
|---|---|---|
| Anchoring/Footing | 8 | 1.5 |
| Barrel | 493 | 91.5 |
| Inlet/Outlet | 42 | 7.8 |
| Headwall | 25 | 4.6 |
| Wingwall | 17 | 3.2 |
| Channel | 10 | 1.9 |

### *5.2.1 Culvert Age*

Using the estimated age data described in Section 4.3, the culvert inventory is presented in Figure 5.1 based on the decade in which each culvert was built, with the data further broken down based on material type. Distinct periods during which a certain material was dominant for the construction of large culverts are evident in the figure. Of the large culverts for which the estimated year-built is available, concrete was the dominate material for culverts built from the 1930s through the 1950s. From the 1960s through the 1980s, steel was the dominant material, mainly in the form of metal pipes. From 2000 to the present day, the use of precast concrete has become the most popular material. The information for culverts built in the 1990s suggests that steel was the dominant material, but due to the low volume of data available for this decade, historical year-built data for culverts constructed during this time may be missing from the large culvert inventory. Overall, the trends presented in Figure 5.1 provide one potential reason why metal pipes comprised 66.4% of the population of culverts for which repair work was performed during the period from January 2016 to April 2021 (see Section 5.1.1). Overall, the historical data in Figure 5.1 are expected to be useful to asset engineers in understanding the relative age of the culvert inventory based on material type.

The distribution of the condition ratings assigned to culverts during the most recent inspections of the structures are provided in Figure 5.2 for the three most common material types (see Table 4.1). Considering the condition ratings indicated by the data in Figure 5.2 along with the ages of culverts, the seemingly superior

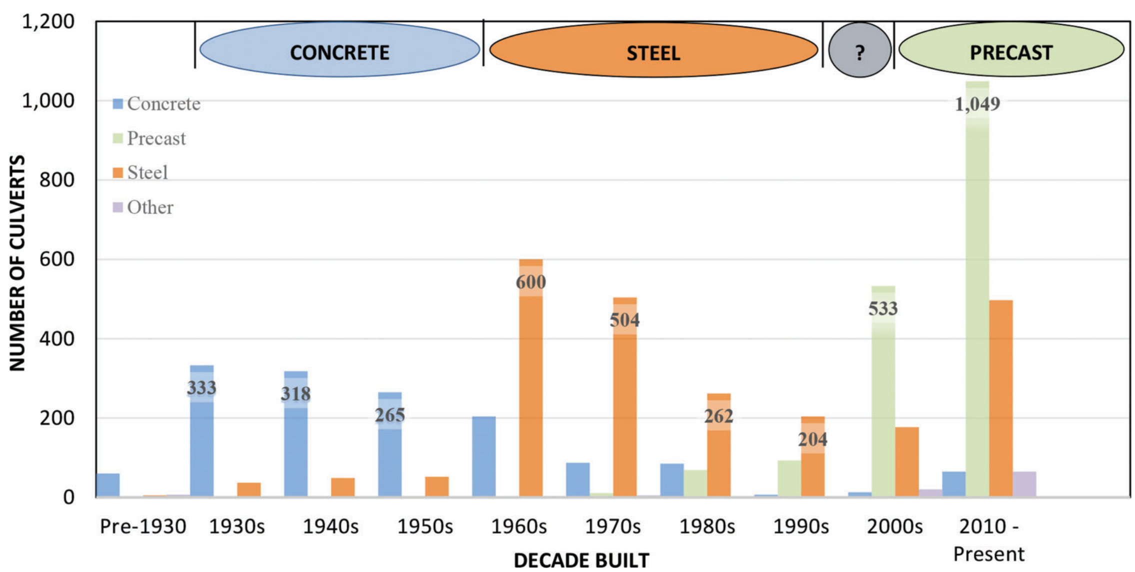



**Figure 5.1** Dominant large culvert material by decade.

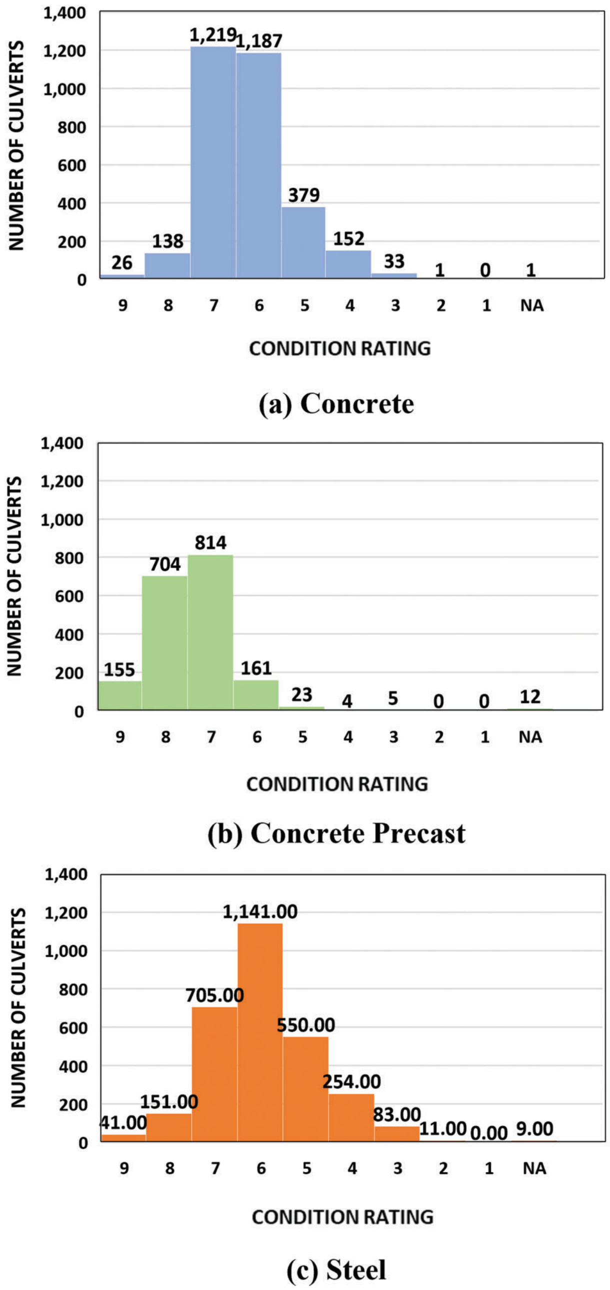



**Figure 5.2** Condition rating values of large culverts by material.

durability of concrete relative to steel for the construction of large culverts is suggested by the data and impacted the decision to incorporate material type into recommended inspection frequencies (see Section 6.3). Nevertheless, the somewhat subjective nature of applying the current condition rating scales to culverts in the field must be recognized, and condition rating history should not therefore be seen as a dependable tool for assessing material durability. Efforts to improve the objectively of inspection procedures are expected to enhance the usefulness of condition rating data for asset engineers (see Section 6.1).

TABLE 5.3
**Average Lifespan of Large Culverts Based on Material Type**

| Material | Average Lifespan (years) | Count |
|---|---|---|
| Concrete/Precast Concrete | 59.95 | 40 |
| Steel | 47.77 | 171 |
| Unclear | 46.5 | 2 |

### *5.2.2 Culvert Lifespan*

For further consideration, the 213 culverts presented in Figure 4.5 for which estimated lifespans are available were grouped based on material type (concrete/precast concrete vs. steel). The resulting average lifespans of the culverts are presented in Table 5.3. Based on this relatively small subset of culverts, the data suggest that concrete and precast concrete culverts outlast steel structures by approximately 12 years on average.

### *5.2.3 Early Deterioration*

Condition rating histories were evaluated to identify large culvert structures that had already reached a condition rating value of 5 despite the structure being relatively early in its expected lifespan. The condition rating value of 5 was selected as the benchmark for evaluation as INDOT internally reviews large culvert structures once they reach this value and consider whether they should be scheduled for repair or replacement. Evaluation of available data indicated that 51 of the 2,722 large culverts reached a condition rating value of 5 before achieving an age of 30 years old. Of these 51 culverts, the material type of 49 of the culverts was steel, and the material type of the remaining two culverts was precast concrete. This observed disparity based on material provides an additional reason to incorporate material type into recommended inspection frequencies (see Section 6.3).

## 6. RECOMMENDED GUIDELINES

The formation of guidelines and recommendations for INDOT based on results from the analysis of the culvert inventory (see Chapter 5), best practices identified in the literature (see Chapter 2), and the national survey responses (see Chapter 3) is described in this chapter. Recommendations are made with the consideration of the needs of asset engineers and the collection of data that will be most useful for management of the culvert inventory. Other proposed ideas such as the need for standardized inspection equipment are also discussed in this chapter. The recommended guidelines described here were compiled into a comprehensive manual for large culvert inspection that is provided in Appendix B.

In this chapter, the recommendation of replacing the existing condition rating scale descriptors used by INDOT for the barrel of culvert structures with descriptors that are based on the most common deterioration mechanisms experienced for each material is discussed in Section 6.1. This recommendation is derived from findings in Section 5.2 regarding the impact of material type on the condition rating performance over time. The development of condition rating scales for components other than the barrel of the structure is described in Section 6.2. These components were selected through the consideration of portions of the structure that may impact the overall health of the culvert (see Section 5.1.2), existing literature (see Chapter 2), and survey responses (see Section 3.2). Suggested modifications to inspection frequency intervals using a risk-based approach inspired by Washer et al. (2014) (see Section 2.5) is introduced in Section 6.3. The proposed frequencies accommodate the additional components to be considered during large culvert inspections as described in Section 6.2. Section 6.4 introduces a standardized equipment list that is suggested in order to accommodate proposed inspection procedures and the need to collect detailed measurements during inspections. Section 6.5 revisits the list of recommendations that were gathered following the collection of responses from the national survey (see Section 3.3) and lists the main ideas that guided the development of the recommended culvert inspection guidelines. Finally, Section 6.6 discusses the creation of a proposed inspection manual developed for INDOT that includes the recommended culvert inspection guidelines in addition to supplementary material.

Descriptors and condition rating scales described in this chapter have been influenced and/or adopted from various key sources. They are based in part on information from the *Culvert and Storm Drain System Inspection Guide*, by the American Association of State Highway and Transportation Officials (AASHTO, 2020), used with permission. Additionally, content from the ODOT *Conduit Management Manual* (ODOT, 2021), the FHWA *Culvert Inspection Manual* (FHWA, 1986), the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995), and the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022) was used to develop the rating scales.

## 6.1 Barrel Condition Rating Scale Descriptors

Based on the trends identified from the condition rating history and performance of large culverts, it was determined that the condition rating scale descriptors currently used by inspectors are vague and rely on subjective language that does not specifically describe the extent of deterioration allowable for a structure assigned a certain condition rating. As a result, descriptors for each condition rating value with less ambiguity and enhanced objectivity were developed for application to culvert barrels. Furthermore, because of the significant differences in deterioration experienced by culverts of different material types, separate condition rating scales and accompanying descriptors were created for each primary culvert barrel material. During the development of the updated scales for culvert barrels, materials that are not explicitly considered in the current rating scale (e.g., plastic and masonry) were included. The primary goals of the updated rating scales were to reduce subjectivity inherent in the inspection process and increase the confidence and understanding of what a condition rating value indicates from the perspective of asset management.

### *6.1.1 Descriptors Based on Material*

To create more objective descriptors that provide a benchmark for condition rating values during culvert inspections, the most common deterioration mechanisms for concrete, metal, plastic, and masonry structures were identified. The selection of deterioration mechanisms was based on a combination of existing literature, inspector experience, and visual observations. Once these mechanisms were established, descriptors were developed for each condition rating value and for each material type. The resulting condition rating scales for each material are included in Appendix B.

In many instances, the descriptor for a specific rating value includes multiple deterioration mechanisms (e.g., cracking, spalling, and scaling). It is recognized that a structure or component may not exhibit deterioration that meets the limits for each of these mechanisms associated with a particular rating. However, if one of the limits associated with a descriptor is met, the condition rating value corresponding to that descriptor should be assigned to the structure or component. The reasoning behind this approach is that each deterioration mechanism by itself can indicate potential issues with the condition/integrity of the structure.

Tolerances and deterioration mechanisms described in the material scales below are based in part on information from the *Culvert and Storm Drain System Inspection Guide*, by the American Association of State Highway and Transportation Officials (AASHTO, 2020), used with permission.

**6.1.1.1 Concrete**. For concrete structures, the main deterioration mechanisms considered in the descriptors include cracking, scaling and abrasion, delamination, spalling, and the exposure of reinforcing steel. Tolerances for crack widths range from hairline (0.01 in.) to 0.25 in. and consider the presence of efflorescence, leakage, and rust staining emanating from the cracks. Values for these tolerances were based on limits in the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022), the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), and the ODOT *Conduit Management Manual* (ODOT, 2021). Consideration is also given to the spacing of cracks transverse to the flow of traffic (AASHTO, 2020). For scaling and abrasion, descriptors are based on both the depth of the deterioration and the percentage of the structure's surface area where scaling or abrasion is present.

The descriptors for delamination and spalling are similar in that both the measurement of the spall or delaminated area and the percentage of the structure's surface area affected by the spall or delamination are considered. Depths for scaling and abrasion as well as for spalls was adapted based on tolerances found in the FHWA *Culvert Inspection Manual* (FHWA, 1986) as well as the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020). Percentages of surface area for both scaling and delamination are adopted from the ODOT *Conduit Management Manual* (ODOT, 2021). Furthermore, for low condition rating values, the presence and condition of exposed reinforcing steel are considered.

**6.1.1.2 Metal**. For metal structures, the main deterioration mechanisms considered in the descriptors include corrosion, section loss and perforations, shape deformation, and isolated instances of impact damage. For corrosion, the severity of the descriptors ranges from discoloration of the surface with partial removal of the protective coating to extensive corrosion with scaling occurring throughout the barrel of the large culvert structure. For section loss and perforations, descriptors are based on the surface area of the structure that has been affected and are adopted from the ODOT *Conduit Management Manual* (ODOT, 2021). Limiting values are based on the affected area per square foot for localized instances and on the percentage of the surface area of the entire structure for more widespread occurrences (ODOT, 2021). When using the descriptors, both the localized and widespread limits must be satisfied to receive the associated rating value. For example, in a steel structure for which the widespread section loss meets the limit described for a condition rating value of 6 but a localized area exceeds the limit stated for a 6, this rating should not be applied as it does not satisfy both limits. Tolerances for shape deformation were established using existing guidelines from reference material. Descriptions of the overall shape appearance were adopted from the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) and the FHWA *Culvert Inspection Manual* (FHWA, 1986). The values for allowable deflection in the vertical direction are consistent with the recommendations in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020). Additional descriptions to consider the effects of impact damage were also developed to account for localized damage that occurs to the structure due to blunt forces from external objects (AASHTO, 2020). While the overall structure may be in good condition based on the typical deterioration markers, depending on the severity of the impact damage, failure of functionality either structurally or hydraulically is possible.

**6.1.1.3 Plastic**. For plastic structures, the main deterioration mechanisms considered in the descriptors include mechanical splits and tears, UV radiation and material softening, abrasion and wearing, and shape deformation. According to the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the term "plastic" encompasses high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), and fiberglass-reinforced plastic (FRP) materials. Most plastic materials are susceptible to UV radiation damage from the sun. Signs of UV radiation damage in a plastic structure can be visually identified by a distinct discoloration or mottled appearance of the material. FRP structures are susceptible to material softening through a process referred to as blistering (AASHTO, 2020). As plastic materials age, splits or tears can occur within the material, typically along manufactured welds and seams (ODOT, 2021). These openings can allow for exfiltration of water during high flow periods or the infiltration of backfill. Plastic materials such as HDPE, PVC, and PP exhibit abrasion resistance, but abrasion can still occur and should be noted (AASHTO, 2020). Initial abrasion and wearing that does not disrupt water flow are not a significant concern, but repair work should be considered as deterioration continues. Like metal pipe structures, the descriptors related to barrel shape of plastic culverts were derived from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995), and the FHWA *Culvert Inspection Manual* (FHWA, 1986).

**6.1.1.4 Masonry**. For masonry structures, the main deterioration mechanisms considered in the descriptors include the condition of masonry units, the condition of mortar, infiltration and exfiltration, and the alignment of the structure. The scale and descriptors for this material are taken from the FHWA *Culvert Inspection Manual* (FHWA, 1986). Little modification was applied to the scale presented in the proposed culvert inspection manual provided in Appendix B as it was determined to be suitable for application to the limited number of existing masonry culverts in Indiana. Masonry structures are comprised of masonry units and mortar. The masonry units provide structural strength while the mortar holds the individual units together. Forces applied to masonry structures are distributed across the individual units through the mortar. Similarly, as the mortar deteriorates over time, its ability to transfer forces and hold masonry units in place diminishes. Deterioration of the mortar can lead to dislodged masonry units and infiltration or exfiltration of soil and water (FHWA, 1986). As water infiltrates the cracks or openings surrounding a masonry unit, it can begin to erode the material and accelerate the deterioration of the structure. As the soil around the structure is disturbed, the alignment of the masonry units within the structure may change. Shifting caused by localized scouring can also result in differential settlement or undermining of the soil beneath the structural footings (AASHTO, 2020; FHWA, 1986).

### *6.1.2 Accompanying Visual Scales*

With the increased level of detail provided in the condition rating descriptors, it was recognized that the inspection process may become more time-consuming for culvert inspectors. To offset the potential increase in inspection time, visual condition rating scales were developed to aid inspectors with the evaluation of metal and concrete barrels of large culvert structures. These visual scales are presented in Appendix B and provide images of large culvert structures that exhibit the conditions described for condition rating values of 2 to 9 so that inspectors can compare the culvert being inspected to actual examples. The visual aid serves as a point of reference for all culvert inspectors in the state to help align ratings between inspectors. The visual scales can be used when evaluating the condition state of a culvert barrel that may be considered a borderline case based on descriptor definitions alone.

Development of the visual scales was accomplished by collecting photographs of large culverts in various states of deterioration from previous inspection reports and selecting images that represent the deterioration mechanisms included in the updated condition rating descriptors.

### *6.1.3 Inspector Feedback*

Following development of the proposed condition rating scales for the barrel based on material, feedback from INDOT's large culvert inspectors was sought. To solicit feedback, a collection of inspection reports stored in BIAS that were developed during previous culvert inspections was compiled to serve as a sample set of the overall large culvert inventory. The sample set consisted of 22 reports: 11 for concrete or precast concrete structures and 11 for steel structures without plastic liners. The most common deterioration markers that were observed while categorizing and analyzing data in the large culvert inventory (see Chapters 4 and 5) were represented within the sample set. Information that could be used to identify the location of the structure in the inspection reports was redacted, and comments identifying aspects of the culvert structure shown in the report photos but not explicitly stated in text within the existing report were added to accompany the photos. Upon distributing the sample set of reports to INDOT inspectors, a period of one month was given for the inspectors to rate each of the structures and provide any feedback they felt would improve the condition rating descriptors.

The form distributed to the inspectors that was used to receive feedback allowed the inspectors to rate the structure using the proposed scale descriptors based on visual and written documentation from the report and explain the reasons for assigning the chosen rating value. They were also provided the opportunity to list any concerns or comments they had about the draft state of the condition rating descriptors and overall scales. In total, feedback was received from 24 inspectors. The research team assessed each of the feedback comments that was received. Several comments referred to the descriptors for the metal and concrete condition rating scales. Revisions were implemented to address the concerns posed related to wording of the descriptors. Furthermore, the need to document the condition of footings in concrete structures and anchors in steel structures was emphasized. Due to the importance of these two components, an additional condition rating scale was developed and included in the recommendations to INDOT (see Appendix B).

## 6.2 Development of Major and Minor Component Condition Rating Scales

As described in Section 5.1.2, the need for rating the condition of multiple culvert components was identified. Instead of assigning one overall rating to the structure based on a combination of the performance of the multiple components of the large culvert, evaluation criteria to allow inspectors to assess components separately were created. By implementing unique scales for specific culvert components, the collected data from an inspection will provide more detailed information about what aspects of a structure are deteriorating. The inspection reports will provide a better summary of the health of the culvert structure and will allow asset engineers to consider culvert condition on a more granular level. The data will also provide a better understanding of how the performance of these individual components impacts the overall condition of large culvert structures.

The culvert inspection recommendations for INDOT include the implementation of condition rating scales for both major and minor culvert components. Major components are identified as the parts of a culvert that most directly impact the capability of the culvert to perform its structural and hydraulic functions. The minor components encompass parts of a culvert that may be considered less critical but that still affect the function of the culvert over time. The condition of minor components serves as a precursor that indicates the rate at which the structure is deteriorating and can provide insight into the performance of hidden or unobservable aspects of the culvert structure, such as the condition of the soil envelope surrounding the culvert cell.

During the investigation into culverts that experienced a reduction in the condition rating of two or greater between subsequent inspections (see Section 5.1.2), three overarching categories began to emerge when considering components of the structure: components that are located above the culvert barrel, components that are part of or attached to the culvert barrel, and components that exist below the midline of the culvert barrel. In total, 11 components that should

TABLE 6.1
**Culvert Components**

| Above Culvert | Culvert Structure | Below Culvert |
|---|---|---|
| Roadway and Shoulder | Barrel Condition | Channel Condition |
| Embankment | Inlet/Outlet<br>End Treatments<br>Alignment and Joints/Seams<br>Footings/Anchors | Channel Alignment<br>Scour Presence<br>Blockage of Waterway |

be considered during large culvert inspections were identified based on the information their condition can provide. A list of the 11 components, placed in their respective categories, is provided in Table 6.1.

The 11 components are divided into the major and minor component scales. These scales are described in the following subsections. The complete set of scales for these components is provided in Part 3 of the proposed large culvert inspection manual found in Appendix B.

### *6.2.1 Major Component Scales*

The major components of a culvert include (1) barrel condition, (2) inlet/outlet, (3) end treatments, and (4) channel condition. Condition rating values for the major component scales are based on the 0–9 scale that is currently used for the overall evaluation of large culvert structures. Through a review of existing literature and inspector experience, it was determined that using the 0–9 scale, as opposed to a scale with fewer values, for evaluation of the major components was warranted due to the importance of the components to the structural and hydraulic functions of the culvert. Furthermore, because most inspectors in Indiana who inspect culverts also inspect bridges, which are also evaluated based on a 0–9 scale, using a familiar scale was of key importance.

The barrel condition scales were previously discussed in Section 6.1 and are specific to the culvert material. For barrel condition, the scales are applied to the entire length of the culvert to assess the overall condition of the structure. The inlet/outlet components are rated using the same scale as the barrel and are defined as the first 5 ft of the culvert barrel at either end of the structure as long as the sections are not directly under the roadway. If the portion of the barrel not directly under the roadway is less than 5 ft, the portion of the culvert not under the roadway is treated as the inlet/outlet. The inlet/outlet are specifically evaluated as there is a noticeable trend in older structures of deterioration being more severe toward the ends of the structure than in the interior. This observation can be attributed to multiple possible factors such as varying degrees of environmental exposure, exposure to chemicals such as deicing salts, and the presence of a physical streambed disruption at the entrance and exit of the culvert structure causing a change in sediment and water flow.

End treatments and channel condition are each assessed using unique condition rating scales. End treatments include headwalls and wingwalls. The scale for end treatments adapts portions of the descriptors for concrete barrels as similar criteria can be used to evaluate concrete headwalls and wingwalls. In addition to the presence of the deterioration mechanisms identified in concrete structures, the end treatment scale also considers the rotation and displacement of the end treatment relative to the barrel of the structure as defined in the ODOT *Conduit Management Manual* (ODOT, 2021).

The scale for channel condition is modified from the scale provided for waterways under bridges in the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995). The modifications were needed so that the scale better corresponds to small waterways.

### *6.2.2 Minor Component Scales*

The minor components of a culvert include (1) roadway and shoulder, (2) embankment, (3) alignment and joints/seams, (4) footings/anchors, (5) channel alignment, (6) scour presence, and (7) blockage of waterway. The minor components are assessed using three-point scales that include descriptors for the condition of the components. The use of a three-point scale is similar to the four condition states implemented with element level inspections for bridge structures as defined by FHWA (FHWA, 2014) and allows for a sufficient level of information to be collected for these components.

For the components of roadway and shoulder, embankment, alignment and joints/seams, footings/anchors, channel alignment, and scour presence, the descriptors of good/fair/poor are used to describe the condition of the component for blockage of waterway, the descriptors are modified to open/partially blocked/submerged or blocked. Furthermore, for the components of scour presence and blockage of the waterway, additional information is collected, consisting of the location and maximum depth of scouring and the estimated percentage of the culvert cross section that is blocked. The collection of information for these minor components is expected to assist asset engineers when evaluating the importance and priority of replacement and repair work for culvert structures by differentiating the condition of culverts with similar barrel condition ratings. Condition rating descriptors for the minor components are based in part on information from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020).

## 6.3 Inspection Frequency Based on Risk

To develop guidelines for risk-based inspection frequencies, the approach described by Washer et al. (2014) for the determination of inspection frequency of bridge structures based on risk, which incorporates the likelihood of failure and the consequences of failure, was considered. The method outlined by Washer et al. (2014) includes the use of a risk matrix. By defining an occurrence factor and an importance factor for a bridge, the required inspection frequency is determined based on risk using the established risk matrix. The study demonstrates that the inspection of bridge structures can be optimized to place more focus on structures associated with greater risk (Washer et al., 2014). The benefits of implementing a risk-based approached for large culvert structures was recognized by the research team, and the framework described by Washer et al. (2014) was adapted for large culvert structures.

### *6.3.1 Adaptation of the Occurrence Factor*

The occurrence factor described by Washer et al. (2014) was developed based on identifying the possible failure mechanisms for a specific bridge type and determining the likelihood of a failure of the structure occurring between the current inspection period and the next inspection. In place of developing occurrence factors based on possible failure mechanisms that may be experienced by different types of large culvert structures, the use of the current condition rating value of the barrel is proposed. The use of the condition rating value to measure the risk of failure for a culvert was determined to be adequate due to inspectors' familiarity with the value as well as its compatibility with the inspection interval framework that is already established by INDOT. Three categories were created to assess the likelihood of failure between the current inspection period and the next scheduled inspection for the large culvert inventory. These categories are labeled as Low, Medium, and High and correspond to condition values assigned to the barrel of the structure. Low likelihood of failure corresponds to ratings of 7 to 9, medium likelihood of failure corresponds to ratings of 5 and 6, and high likelihood of failure corresponds to ratings of 4 or lower. These groupings are consistent with the groupings of rating values currently used by INDOT to determine culvert inspection frequencies (INDOT, 2020) and were therefore determined to be the preferred categorization as it would require less alteration to the established framework.

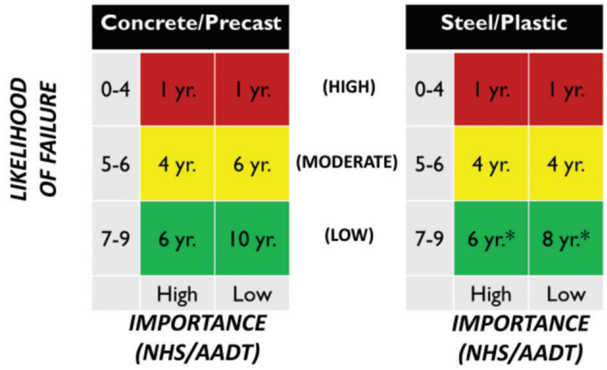
### *6.3.2 Adaptation of the Importance Factor*

The importance factor described by Washer et al. (2014) measured the impact on safety that an identified failure would have on the affected population. Due to the redundancies present in bridge structures, the severity of failures encompasses a wide range. For culvert structures, designs are generally simpler compared to bridges, and one of the primary impacts of a culvert failure is closure of the parent roadway. The proposed importance factor for large culverts is therefore based on the impact a failure would have on the overall transportation network in the state of Indiana. To define impact on the transportation network, a combination of the average annual daily traffic (AADT) values recorded by traffic collection stations in 2019 along each route in Indiana and National Highway System (NHS) status were used. Importance of a culvert structure was divided into two categories: (1) higher importance and (2) lower importance. To be classified as a higher importance structure, the parent roadway must either be part of the NHS or have AADT values of 10,000 or greater. If these criteria were not met, the structure is classified as a lower importance structure.

The AADT value of 10,000 vehicles was selected based on groupings present in INDOT's Traffic Count Database System (TCDS) at the time of categorization. A lower value for annual average daily traffic (AADT) volume could be selected if deemed appropriate for defining roadway importance.

### *6.3.3 Applying Risk-Based Inspection to the Large Culvert Inventory*

The suggested inspection frequencies for large culverts are presented in Figure 6.1 in the form of a simplified risk matrix. The frequency values were determined by analyzing both the condition rating data available for large culvert structures in the BIAS database and year-built data collected as described in Section 4.3. As indicated in Figure 6.1, inspection frequencies are similar between the two levels of importance when the overall condition rating is low but are different as the condition rating values increase. The inspection frequency values for low importance structures are also different based on the material groupings. These decisions were made following the analysis of the available condition rating histories described in Chapter 5. It is noted in Figure 6.1 that large metal culverts with flowing water present should be limited to a maximum inspection interval of 48 months. This limitation is recommended due to the potential for relatively rapid deterioration caused by the flowing water. A similar limitation of 48 months is also placed on all plastic lined structures due to the use of the material being relatively new for large culvert structures.




Notes:
Regardless of condition, large metal culverts with flowing water present should be limited to a maximum inspection interval of 48 months.
All plastic lined structures are restricted to a maximum inspection interval of 48 months.

**Figure 6.1** Recommended inspection frequencies using a risk-based approach.

TABLE 6.2
**Proposed Inspection Frequencies**

| | |
|---|---|
| 72 Months[1] | All major scale condition ratings are 7 or greater.<br>AND<br>No more than two minor scales receive ratings of fair. No minor scales are rated poor. |
| 48 Months | All major scale condition ratings are 5 or greater.<br>AND<br>No more than two minor scales receive ratings of poor. |
| 24 Months | All major scale condition ratings are 5 or greater.<br>AND<br>Only three or four minor scales receive ratings of poor. |
| 12 Months | Any major scale condition rating is 4 or less.<br>OR<br>More than four minor scales receive ratings of poor, regardless of barrel condition.<br>OR<br>Structure is completely submerged. |

[1]Regardless of condition, large metal culverts with flowing water present should be limited to a maximum inspection interval of 48 months. All plastic lined structures are restricted to a maximum inspection interval of 48 months.

### *6.3.4 Alternative Inspection Frequency Recommendations*

As an alternative to the proposed inspection frequencies presented in Figure 6.1, a second option is introduced in Table 6.2. This alternative is suitable if a distinction of culverts based on AADT and NHS status is not desired. The proposed frequencies are modified from the current inspection frequencies for large culverts followed by INDOT (INDOT, 2020) and incorporate the consideration of the condition of the multiple components of a culvert instead of relying solely on the condition of the barrel to determine the allowable inspection frequency. The modified inspection frequencies in Table 6.2 provide weighted preference to the condition rating values of the major components of the structure while also incorporating limitations for the ratings of the minor components to account for scenarios with disparate wearing of these culvert features.

## 6.4 Equipment List

Through conversations with INDOT inspectors, INDOT management, and personnel from external transportation agencies, the need for all large culvert inspectors to have access to standard equipment was identified. By implementing a standard list of equipment, the quality and consistency of inspections across the state are expected to be enhanced. Access to the equipment will also help with increasing the safety of the inspectors working in the field.

The suggested standard equipment list is provided in Part 3 of the large culvert inspection manual found in Appendix B. The equipment is divided into four categories: general use, safety, entry, and assessment. The general use category includes items that have multiple purposes during the inspection process. Items included in the general use category range from the inspection vehicle and a GPS capable device to navigate the state of Indiana to a camera and permanent marker to document the condition state of large culvert structures. The safety category includes items that are considered essential for taking necessary safety precautions while working in the field as a culvert inspector. The category includes items such as personal protection equipment (PPE), snake gaiters, and a portable first aid kit. The entry category includes tools and equipment that may be considered necessary for approaching and entering a large culvert structure. Items include hip waders or tall waterproof boots and brush clearing tools to enter culvert structures in addition to a rope and carabiners to traverse slopes. The final category of assessment equipment contains items that are expected to be used during the evaluation and documentation process. These items include crack comparator cards and digital calipers as well as sounding mallets to check for voids behind the structure in the soil envelope.

## 6.5 National Survey Recommendations

Upon further evaluation during the research project, the research team determined the feasibility of implementing the identified potential practices based on the national survey results and listed in Section 3.3. Furthermore, additional ideas were developed based on observations that were gathered during tasks that followed the administration of the survey. In the end, nine core ideas impacted the direction of focus during the data analysis and guided the development of the proposed culvert inspection guidelines and procedures. These nine ideas are listed as follows.

1. Divide culvert condition rating into more than one value.
2. Consider higher frequency for culverts located on NHS routes.
3. Lengthen the interval of inspection for culverts with good condition ratings (7–9).
4. Base inspection frequency on a combination of material type and condition rating.
5. Perform an inspection within 12 months after the construction of a new culvert is completed before shifting to routine inspection frequency.
6. Add a field to the inspection form for indicating if the culvert is submerged, partially submerged, or not submerged at the time of inspection.
7. Add a pH field to the inspection form to record pH values when water is present.
8. Modify culvert condition rating scale descriptors to be more quantitative.
9. Create a visual scale corresponding to the adjusted condition rating scale to aid inspectors.

Considering the initial seven recommendations that were collected from the national survey results and listed in Section 3.3, five were determined to be adaptable without the need for major modifications. Of the remaining two ideas, one (create varying levels of inspection requiring different degrees of detail) was modified and expanded upon and ended up resulting in items 3 and 4 on the final list, while the other idea (separate the evaluation procedures for slab-bridge culverts with spans greater than 10 ft from the evaluation procedures for large culvert structures) was determined to not be compatible with the current direction of INDOT's large culvert inspection program. Items 8 and 9 on the final list were developed during the analysis of the large culvert condition rating histories and were further expanded upon after the realization that the condition rating descriptors currently being used contain subjective language that is interpreted differently across the state.

## 6.6 Inspection Manual

Following the development and adaptation of guidelines for INDOT based on the information collected throughout the research project, the recommendations for the large culvert inspection program in the state were compiled into a comprehensive proposed inspection manual. This manual is separated into three parts: (1) data collection and inspection, (2) evaluation and condition rating, and (3) inspection forms and condition rating scales. An overview of the contents of the manual includes the following:

- abbreviations and terminology,
- equipment list,
- inventory data collection,
- inspection and documentation procedure,
- inspection frequency,
- condition rating scales, and
- inspection forms and accompanying visual aids.

Part 1 of the proposed large culvert inspection manual consists of information related to data collection and inspection. This portion of the manual outlines the procedures of the inspection process and defines types of inspections. Collection of initial inventory data through the expected practices of a routine inspection and the proper documentation of findings are also described. Part 2 of the manual consists of information related to evaluation and condition rating scales. This portion of the manual provides background details for the major and minor components of the structure as well as the recommended inspection frequency intervals based on the assigned condition rating. Part 3 of the manual contains inspection forms, the standardized equipment list, visual scales to accompany the new condition rating scales, and a consolidated location for all of the condition rating scales. Information such as recommendations for when to mark a structure for rehabilitation or replacement or recommendations for maintenance actions to be taken are outside the scope of the current study and thus are not included in the inspection manual. The proposed large culvert inspection manual is provided in Appendix B.

## 7. CONCLUDING REMARKS

Over the course of the research project described in this report, multiple areas for potential improvement within the current large culvert inspection practices in Indiana were identified. By adopting the recommendations provided in the proposed large culvert inspection manual, INDOT will be able optimize its large culvert inspection program by standardizing inspection procedures across the state and improving the quality of data recorded for the large culvert structure inventory. The recommendations are intended to improve inspectors' understanding of deterioration within culvert structures and their impact to both their structural and hydraulic functionality. Separation of culverts into multiple components and the implementation of condition rating descriptors with increased objectivity are expected to aid asset engineers by improving the quality of data that are available for decision-making purposes.

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# APPENDICES

**Appendix A. National Large Culvert Survey: Identifying Best Practices for Culvert Inspections**

**Appendix B. Proposed INDOT Large Culvert Inspection Manual**

# APPENDIX A. NATIONAL LARGE CULVERT SURVEY: IDENTIFYING BEST PRACTICES FOR CULVERT INSPECTIONS

**SURVEY DESCRIPTION:**
The Indiana Department of Transportation in collaboration with Purdue University is conducting a research project to develop guidelines for the inspection of culverts based on risk. The guidelines are expected to result in increased efficiency of culvert inspection practices. As part of the research effort, this survey is being distributed to better understand culvert inspection procedures followed in other states and identify best practices that have resulted in efficient culvert inspection programs.

**CONTACT INFORMATION:**
Contact Information for follow-up questions based on responses provided.

DOT Represented ________________________________________

Respondent(s) Name ________________________________________

Job Title(s) ________________________________________

Phone Number(s) ________________________________________

Email Address(es) ________________________________________

**INSTRUCTIONS**:
Please answer the questions as thoroughly as possible, providing details where necessary. Only Questions P.1, P.2, and P.3 are required to be answered. No other questions are required to be answered to proceed to the next question, meaning if a question is not applicable, the respondent is free to skip the question.

Your response to the following survey will be invaluable to the research team. The research results will be available in a final project report. Your time and effort are greatly appreciated.

**NOTE: Please answer the questions in order. The responses to some questions determine if related follow-up questions will appear.**

## A.1 Part 1: Culvert Definition

The purpose of this section is to understand culvert-related terminology used by your DOT as compared to the definitions used by INDOT.

---

**CULVERT DEFINITION**:
In the context of the following question, INDOT defines "culvert" and "large-culvert" as follows:

**Culvert:**
Structures with a span length measured along the roadway centerline less than or equal to 20 feet in length.

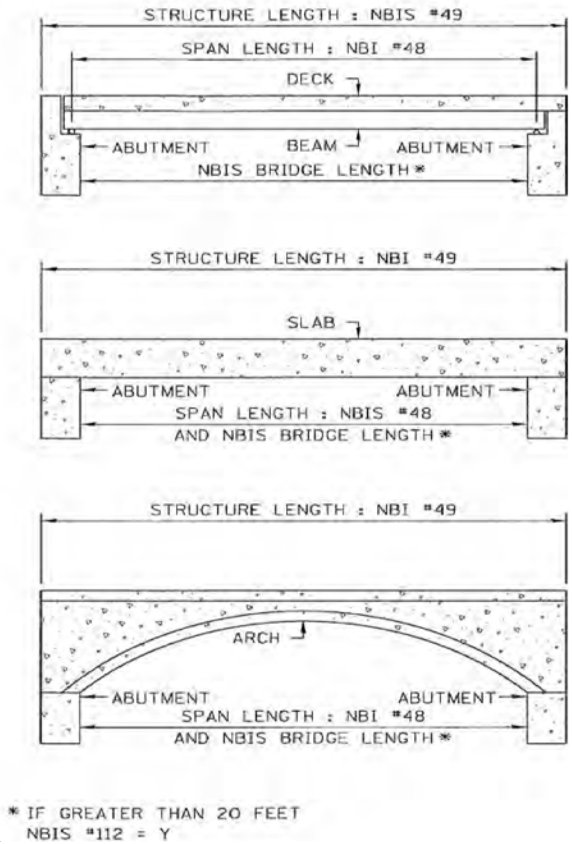
**Large culvert:**
Culverts (structures) with spans equal to or greater than four feet and less than or equal to 20 feet, and with clear openings (measured perpendicular to the clear opening of the culvert) not less than 48 inches.
Large culvert structures shall include multiple pipes placed side by side where the extreme measured ends of openings are equal to or greater than 48 inches, so long as the clear distance between openings is less than half of the smallest contiguous opening. The skew of the culvert structure is not considered to determine the culvert length.

The following figure illustrates the measurement of **span length** as used by INDOT for definition purposes.

---

**SPAN ILLUSTRATION:**

Figure A.1 Bridge Structure Measurements from INDOT Bridge Inspection Manual




---

**1.1** Based on the text and visual definitions provided for the terms "culvert" and "large culvert," select all that apply:

- ☐ My DOT defines the term "culvert" similarly to the definition above
- ☐ My DOT defines the term “large culvert” similarly to the definition above
- ☐ My DOT does NOT define "culvert" and/or "large culvert" similarly to the definitions above

---

**1.1A** If your DOT defines either "culvert" or "large culvert" differently, please provide your DOT's definition of these or similar terms.

____________________________________________________________

---

**1.1B** If a graphic is needed for the definition of these terms, please upload the graphic here. (Note: If additional files are needed, the opportunity to upload the files will be provided at the end of the survey.)

**FILE UPLOAD LINK** **(Present on Online Survey)**

---

**DEFINITION USAGE:**
For the remaining questions on this survey, please use your DOT's definition for terms that may vary between DOTs (e.g., culvert, large culvert, small structure, small bridge, pipe).

---

**P.1** Does your DOT have an inventory of state-owned culverts?

- O Yes
- O No (If No, skip questions 2.7, 2.8, & 3.3)

---

**P.2** Does your DOT inspect state-owned culverts (either in-house or via consultants)?

- O Yes
- O No (If No, skip questions 2.1, 2.2, 2.3, 3.1, 3.2, 3.4, & 3.5)

---

**P.3** Does your DOT sometimes use structural liners to lengthen the lifespan of culverts when they exhibit poor performance or fail to perform as expected?

- O Yes
- O No (If No, skip questions 2.5, 2.6, & 3.7)

---

## A.2 Part 2: Understanding Policy

The questions in this section are related to the reasoning behind inspection procedures and asset management decisions made by the DOT.

---

**2.1** Does your DOT have a culvert inspection manual or written guidance specifically for culvert inspections?

- O Yes (Please provide an accessible link or upload file to **1.2A**)

  ______________________________________________

- O No

---

**2.1A** File upload for culvert inspection manual or written guidance.
FILE UPLOAD LINK **(Present on Online Survey)**

---

**2.2** Do inspection frequency intervals for culverts depend on any of the following criteria? Please select all that apply. Select "None of these" if inspection frequency is solely based on a set time interval.

- ☐ Age of structure
- ☐ Average daily traffic
- ☐ Condition rating
- ☐ Depth of fill/Cover depth
- ☐ Environmental conditions
- ☐ Hydraulic capacity
- ☐ Location
- ☐ Material of culvert (e.g., metal, concrete, plastic, etc.)
- ☐ Shape/Type of culvert (e.g., pipe, box, arch, etc.)
- ☐ Other ________________________________________
- ☐ None of these

---

**2.2A** Are culverts in the state system replaced at specific time intervals? (e.g., culverts are replaced after 75 years of service)

- O Yes (Please elaborate) ________________________________________
- O No

---

**2.3** What are your DOT's current culvert inspection frequencies? In your response, please explain how inspection frequencies vary based on any of the criteria that you selected in Question **2.2**.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**2.3A** Please explain the reasoning behind current culvert inspection frequencies.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**2.3B** Does your DOT have an inspection interval that applies specifically to new culvert system construction?

- O Yes (Please elaborate) ____________________________________________
- O No. After the initial inspection, new culverts are treated the same as all other culverts.

**2.4** Does your DOT have written guidelines for determining when to rehabilitate a deficient culvert rather than replace it?

- O Yes (Please provide accessible link or upload file to **2.4A**)

  ____________________________________________

- O No

**2.4A** File upload for culvert rehabilitation/replacement written guidelines.
**FILE UPLOAD LINK** **(Present on Online Survey)**

**2.4B** If your DOT does not have written guidelines for Question **2.4** but does have informal guidelines, please describe them below.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**2.5** Does your DOT have written guidelines for when a structural liner should be used for rehabilitation of a culvert?

- O Yes (Please provide accessible link or upload file to **2.5A**)

  __________________________________________________

- O No

**2.5A** File upload for culvert liner written guidelines.
**FILE UPLOAD LINK** **(Present on Online Survey)**

**2.5B** If your DOT does not have written guidelines for Question **2.5** but does have informal guidelines, please describe them below.

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

---

**2.6** Does implementation of a structural liner depend on any of the following criteria? Please select all that apply:

- ☐ Age of structure
- ☐ Average daily traffic
- ☐ Condition rating
- ☐ Depth of fill/Cover depth
- ☐ Environmental conditions
- ☐ Hydraulic capacity
- ☐ Location
- ☐ Material of culvert (e.g., metal, concrete, plastic, etc.)
- ☐ Shape/Type of culvert (e.g., pipe, box, arch, etc.)
- ☐ Other ____________________________________________
- ☐ None of these

---

**2.6A** Please select all of the following **structural liners** that are used by your DOT for the rehabilitation of culverts.

- ▢ Multi-plate or structural plate
- ▢ Smooth metal pipe
- ▢ Corrugated metal pipe
- ▢ Smooth plastic pipe
- ▢ Corrugated plastic pipe
- ▢ Cured-in-place (CIP) pipe
- ▢ Spray applied material
- ▢ Other (Please specify) ________________________________________________
- ▢ None of these

---

**2.7** What system does your DOT use to manage culvert assets?

- O Bentley Management Software
- O Pontis
- O FHWA Culvert Management System (CMS)
- O AASHTOWare Bridge Management System (BrM)
- O In-house software
- O Other (Please specify) ________________________________________________

---

**2.8** In addition to managing the data of culverts owned by the state, does your DOT manage culvert inspection data collected by local entities (e.g., counties)?

- O Yes
- O No

---

**2.8A** Does your DOT utilize the collected data by local entities in any specific manner?

- O Yes (Please elaborate) ________________________________________________
- O No

---

## A.3 Part 3: Inspection Procedures

The questions in this section focus on identifying current best practices for culvert inspections and inspection procedures.

---

**3.1** Who conducts culvert inspections in your state system?

- O DOT personnel
- O Outside consultants
- O A combination of DOT personnel and outside consultants
- O Other (Please specify) ______________________________________________

---

**3.1A** What are the qualifications of culvert inspectors for your DOT?

- ☐ Culvert inspectors are expected to have previous experience with the design, maintenance, and/or construction of culverts
- ☐ Culvert inspectors are required to complete **culvert** inspection training
- ☐ Culvert inspectors are required to complete **bridge** inspection training
- ☐ There are no specific qualifications for culvert inspectors except on-the-job training by experienced personnel
- ☐ Other (Please elaborate) ______________________________________________

---

**3.2** Which of the following best describes the role of culvert inspectors and maintenance workers within your DOT? Please select all that apply.

- ☐ Culvert inspectors are only responsible for inspecting culvert structures
- ☐ Inspectors are responsible for a mixture of culvert and bridge inspections
- ☐ Maintenance personnel are responsible for **inspecting** culvert structures
- ☐ Culvert maintenance personnel are solely responsible for **maintaining** culvert structures
- ☐ Maintenance personnel are responsible for a mixture of culvert and bridge work orders
- ☐ Other (Please specify) ______________________________________________

---

**3.3** How are culvert related issues communicated between necessary parties (e.g., inspectors, maintenance personnel, and construction personnel, etc.)? What forms of communication are available for relaying these issues (e.g., use of asset management system, structure work log, e-mail, or phone contact, etc.)?

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

**3.4** Which of the following best describes your DOT's current approach when evaluating the condition rating of a culvert system?

- O It is based on the condition at an elemental level. Multiple values are assigned for the various elements of a culvert system.
- O It is based on the overall structure. One value is assigned to reflect the overall condition of the culvert system.
- O Other (Please specify) ____________________________________________

**3.4A** What elements are considered when rating the condition of the culvert system?

_______________________________________________________________

**3.4B** How is the overall condition value determined? (e.g., worst-performing aspect, not based on a particular aspect but based on overall safety and functionality of the system, etc.)

_______________________________________________________________

**3.5** Which of the following best describes your DOT's condition rating system for culvert systems?

- O The NBI rating scale for evaluating bridges (0 to 9) is also used for culverts.
- O A point system that is different from the NBI scale is used. (Please explain)

  ____________________________________________________________
- O A binary system is used. Culvert systems are evaluated based on if they are functioning as intended and either receive a rating of functioning/good or not functioning/poor.
- O Other (Please specify) ____________________________________________

**3.6** Please select all of the following NDT equipment/techniques available for use by your DOT during culvert inspections.

- ☐ Laser profiling
- ☐ Ultrasonic thickness gauge
- ☐ Borescope/Videoscope
- ☐ Ground-penetrating radar (GPR)
- ☐ Cover meter
- ☐ Infrared imaging (thermographic imaging)
- ☐ Impact-echo
- ☐ Mechanical impedance testing
- ☐ Acoustic impact testing
- ☐ Ultra-wideband (UWB) radar imaging
- ☐ Remote-controlled inspection vehicles
- ☐ Drones (UAVs)
- ☐ Other (Please specify) ________________________________________________
- ☐ None of these

**3.6A** How effective do you consider the use of the selected NDT equipment/techniques when compared to inspection without the NDT equipment?

| | Data collected is essential for accurately rating culvert conditions | Data collected is useful for accurately rating culvert conditions, but not essential | Data collected is rarely useful for accurately rating culvert conditions |
|---|---|---|---|
| Laser profiling | O | O | O |
| Ultrasonic thickness gauge | O | O | O |
| Borescope/Videoscope | O | O | O |
| Ground-penetrating radar (GPR) | O | O | O |
| Cover meter | O | O | O |
| Infrared imaging (thermographic imaging) | O | O | O |
| Impact-echo | O | O | O |
| Mechanical impedance testing | O | O | O |
| Acoustic impact testing | O | O | O |
| Ultra-wideband (UWB) radar imaging | O | O | O |
| Remote-controlled inspection vehicles | O | O | O |
| Drones (UAVs) | O | O | O |
| Other (Please specify) | O | O | O |
| None of these | O | O | O |

**3.6B** If you selected "Other" for NDT inspection equipment/techniques, what other equipment/techniques does your DOT use for culvert inspections?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**3.6C** Are inspectors required to use any of the selected NDT equipment/techniques or is it left to the discretion of the inspector?

- O NDT equipment/techniques are available upon request at the discretion of the inspector
- O NDT equipment/techniques are standard and required to be used by inspectors for culvert inspection
- O Other (Please specify) ____________________________________________________

**3.7** Once a structural liner is installed, how does your DOT assign condition ratings to the structure?

- O The structural liner is considered the new culvert type and material, and the condition rating for the culvert is assigned solely based on the liner's performance.
- O The original culvert and structural liner are evaluated independently and assigned condition ratings that are recorded separately.
- O Condition rating values are not assigned to structural liners.
- O Other (Please specify) ____________________________________________________

**4.1** Do you have any questions or comments for the research team?

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

**4.2** Do you have additional files that you wish to upload?

O Yes

O No

**4.2A** If an additional file upload is needed for a previous question, please upload the file here. (One file per upload question)

**FILE UPLOAD LINK** **(Present on Online Survey)**

**4.2B** Which question was this file meant for?

_______________________________

**4.3** Do you have additional files that you wish to upload?

O Yes

O No

**4.3A** If an additional file upload is needed for a previous question, please upload the file here. (One file per upload question)

**FILE UPLOAD LINK** **(Present on Online Survey)**

**4.3B** Which question was this file meant for?

_______________________________

Thank you for completing the survey. Your time is greatly appreciated by INDOT and the research team.

# APPENDIX B. PROPOSED INDOT LARGE CULVERT INSPECTION MANUAL—PART 1: DATA COLLECTION AND INSPECTION

## B.1 List of Acronyms

BIAS – Bridge Inspection Application System

CFS – Cubic Feet per Second

CIP – Cast in Place

CIPP – Cured in Place Pipe

CMP – Corrugated Metal Pipe

FBC – Fully Bituminous Coated

FRP – Fiberglass-Reinforced Plastic

HDPE – High-Density Polyethylene

HIVE – Hydraulic Inspection Vehicle Explorer

INDOT – Indiana Department of Transportation

NBI – National Bridge Inventory

NHS – National Highway System

PBC – Partially Bituminous Coated

PCA – Precast Concrete Arch

PCB – Precast Concrete Box

PCS – Precast Concrete Slab

PP – Polypropylene

PPE – Personal Protective Equipment

PVC – Polyvinyl Chloride

RCA – Reinforced Concrete Arch

RCB – Reinforced Concrete Box

RCS – Reinforced Concrete Slab

SRPE – Steel Reinforced Polyethylene

## B.2 Definitions

Provided definitions for common terms contained within the INDOT Large Culvert Inspection Manual were adopted from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the INDOT *Bridge Inspection Manual* (INDOT, 2020), the ODOT *Conduit Management Manual* (ODOT, 2021), and Youngblood (2017) when available and created when no term was available between these sources.

Abrasion – Wearing or grinding away of material by water containing sand, gravel, or stones.

Abrasive Condition – The presence of granular material accompanied with a stream gradient or flow sufficient to cause movement of the granular material in the streambed.

Barrel – The main body of a culvert structure that transports water beneath the roadway.

Blistering – Process of water infiltrating the first layer of a fiberglass-reinforced plastic large culvert structure causing bubbles to form near the surface.

Channel – A waterway used to transport water from one location to another.

Corrosion – Deterioration or dissolution of a material by chemical or electrochemical reaction with the surrounding environment.

Cover – The depth of backfill present between the top of a culvert structure and the base layer of the roadway.

Culvert – A structure located beneath a roadway where it intersects with a waterway. The structure provides a structural function of support to the roadway above while allowing waterway movement through the embankment below.

Deflection – Change in the original or specified vertical or horizontal measurement of a culvert structure.

Delamination – Separation of a layer of concrete generally through internal cracking parallel to the concrete surface.

Deterioration – Decline in quality over time due to chemical or physical wearing.

Differential Settlement – Uneven settlement between footings or supports.

Efflorescence – Deposits of salts on the surface of a porous material caused by the migration of salt-laden water to the surface.

Embankment – Soil constructed above the natural ground surface that encases a culvert structure and supports a roadway.

Erosion – The removal of a material or surface over time by flowing water.

Exfiltration – The process of water exiting a culvert structure and entering the surrounding soil through unintended openings.

Flexible Culvert – A culvert that relies on a consistent application of pressure from the surrounding soil envelope to develop structural strength.

Galvanization – Application of zinc coating along the surface of a structure.

Infiltration – The process of water or backfill material entering the culvert structure through unintended openings.

Inlet – The initial 5 ft of the upstream end of a culvert structure.

Invert – The bottom or lowest region along the internal surface of a pipe.

Joint – Connection where two sections of a culvert structure meet. Additional material may be present to ensure a watertight connection between sections.

Large Culvert – A culvert structure with a measured span length between 4 ft and 20 ft as measured perpendicular to the centerline of the parent roadway.

Outlet – The final 5 ft of the downstream end of a culvert structure.

Piping – The process of erosion along the exterior perimeter of a culvert barrel.

Pressure Head – Height of water above a plane or point of reference.

Rehabilitation – Repairing a culvert to return it to its initial condition or better.

Replacement – Removal of existing structure and construction of a new culvert.

Rigid Culvert – A culvert that relies on internal material properties to develop structural strength.

Scaling – Disintegration of cement paste caused by chemical attacks or freeze-thaw cycles that erode the concrete surface.

Scour – Erosion of the streambed of a channel where it meets the inlet and outlet of a culvert structure.

Section Loss – Loss of a material’s thickness caused by chemical or physical degradation.

Slabbing – Straightening of rounded concrete sections accompanied by cracking and/or spalls.

Soil Envelope – Soil or backfill encasing a culvert structure and applying pressure due to the weight of the soil.

Spalling – Separation of surface concrete due to fractures within the material.

Spring Line – A line connecting the outermost points along the sides of a large culvert structure.

Undermining – Erosion process that removes material from below and threatens the structural integrity of the above member; typically occurs around footings and other supports.

Vertical Offset – Displacement of an object from its original position in the vertical direction.

## B.3 Introduction

The INDOT Large Culvert Inspection Manual is a comprehensive set of guidelines for large culvert inspection that applies to all state-owned structures with opening spans between 4 ft and 20 ft in length. This inspection manual is separated into three parts: Data Collection & Inspection, Evaluation & Condition Rating, and Inspection Forms & Condition Rating Scales. Between these three parts, the inspection process is outlined and defined from start to finish. The purpose of this document is to provide large culvert inspectors across the state of Indiana with a standardized set of guidelines for inspection. Inspection of these structures is necessary to ensure the safety of the public similar to inspection guidelines established by the federal government for bridge structures. The guidelines within this document were developed for the state of Indiana and only apply to large culvert structures under the jurisdiction of INDOT.

While the guidelines within this manual apply only to state-owned large culvert structures, county and local agencies are encouraged to adopt the inspection guidelines within this document for use during inspection of large culvert structures. For large culvert structures housed along Indiana toll roads, these guidelines should be followed during the inspection process.

Note: Content in this manual is based in part on information from the *Culvert and Storm Drain System Inspection Guide*, by the American Association of State Highway and Transportation Officials, Washington, D.C. (AASHTO, 2020), used with permission.

## B.4 Overview of Part 1

Part 1 of the large culvert inspection manual includes information on data collection and inspection practices while in the field. More specifically, Part 1 includes information about the equipment necessary for inspections, types of inspection, safety guidelines for inspectors, inventory data collection, inspection procedure, and expected documentation procedure.

To properly inspect large culvert structures, inspectors should be provided with the necessary tools and equipment for the safety of the inspector, accessing the culvert, and assessing the condition of the structure. A standardized list of equipment with details about the usage of each item can be found in Part 3.

Three main types of inspection exist for large culverts: initial, routine, and damage/event. Initial inspections are performed on a large culvert structure following construction work to collect detailed information about the properties of the structure for inventory purposes. Routine inspections comprise the bulk of inspections performed on a large culvert structure over its lifetime. These inspections are performed to evaluate the condition of large culvert components and identify needs for replacement or rehabilitation of the structure before failure occurs. Damage/event inspections are performed following a report of collision or concern of safety from a firsthand account to evaluate the integrity of the structure.

Safety guidelines for inspectors are concerned with mitigating the risk of injury associated with hazards present in the field. Acceptable practices during an inspection and the methods of inspection that can be performed for a large culvert structure based on its characteristics are outlined in this document. A list of data fields that should be collected for proper inventory data collection during inspections is also outlined. Recommended inspection procedures are included along with the expected documentation procedure while performing an inspection of the structure.

## B.5 Equipment List

When inspecting large culvert structures, every inspector is expected to have access to the necessary tools and equipment to properly perform their duties. The equipment list is separated into four categories: general use, safety, entry, and assessment. Detailed explanations for equipment use and purposes can be found in Part 3.

### B.5.1 General Use Equipment

Equipment included in the general use category is considered to be of use throughout the entire process of large culvert inspection. Many of the items included in this section are necessary for navigation to the structure as well as documentation of the condition of the structure during the inspection.

| **General Use Equipment** | | |
|---|---|---|
| Digital camera | pH measuring tools/strips | GPS-capable device |
| Headlamp/helmet light | High-powered flashlight | Inspection vehicle |
| Lg. Culvert Inspection Manual | Permanent markers | Radio/walkie-talkie |
| Range rod | Tape measure (25 ft min.) | |

### B.5.2 Safety Equipment

Equipment included in the safety category is meant to protect the inspector from hazards that are present in large culvert environments. Personal protective equipment such as gloves, high-visibility vest, hardhat, safety glasses, and steel-toe boots should be worn by the inspector at all times when in the field. Other items such as dust masks, repellants, snake gaiters, and high visibility backpacks should be worn or applied as deemed necessary. A compressed gas air horn should be kept handy while in the field to alert inspection partners when separated and in need of assistance. Both a portable first aid kit and a stationary first aid kit should be present with inspection teams when in the field. The portable first aid kit should be kept within a designated compartment of the high-visibility backpack and taken with inspectors when leaving the vehicle to inspect the large culvert structure, while the stationary first aid kit should be placed in a known location within the inspection vehicle that is easily accessible.

| **Safety Equipment** | | |
|---|---|---|
| Compressed gas air horn | Dust masks | First aid kit (portable) |
| First aid kit (stationary) | Gloves | Hardhat |
| High-visibility backpack | High-visibility vest | Insect/wasp/tick repellant |
| Safety glasses | Snake gaiters | Steel-toe boots |

### B.5.3 Entry Equipment

To access the ends of some large culverts within the state, additional equipment is necessary. The need for this equipment is based on the presence of water surrounding the culvert, the slope of the embankment leading to the culvert, and the level of overgrowth present along the right of way. Possible situations encountered during large culvert inspections warrant the need to have access to brush-clearing tools, hip waders, waterproof boots, and ropes and carabiners. Additionally, if an inspector intends to enter the structure for a walkthrough inspection, a personal air monitor should be on the inspector's person to alert the inspector to any changes in air quality that could jeopardize the inspector's safety.

| **Entry Equipment** | | |
|---|---|---|
| Brush-clearing tool | Hip waders | Personal air monitor |
| Rope and carabiners | Waterproof boots | |

### B.5.4 Assessment Equipment

Equipment included in the assessment category should be used when evaluating the condition of the culvert and collecting data. Tools such as calipers and crack comparator cards are used to measure the severity of section loss and cracks in metal and concrete structures, respectively. The scraper, screwdriver, shovel, and wire brush are tools that allow the inspector to assess the condition of the material that is covered by deterioration or sediment deposit. The sounding mallet/hammer can be used to assess voids behind the walls of the culvert structure and the presence of concrete delaminations. Finally, the carpenter's level can be used to identify any differential settlement that has occurred to the structure.

| **Assessment Equipment** | | |
|---|---|---|
| Calipers | Carpenter's level | Crack comparator card |
| Flathead screwdriver | Scraper | Shovel |
| Sounding mallet/hammer | Wire brush | |

## B.6 Overview of Types of Inspection

Three main types of inspections can occur over the life of a large culvert structure. These inspections are initial, routine, and damage/event inspections.

### B.6.1 Initial Inspection

The initial inspection is the type of inspection that is performed after a structure has undergone construction or modification. This inspection is performed to collect inventory information on the culvert structure. The information collected during an inventory inspection can vary depending on if the structure being inspected is a new culvert structure or an existing culvert structure that has received repair or expansion work. Typical information that is collected or reconfirmed depending on the status of the structure includes barrel geometry and material properties, location and geographical information, channel properties, end treatment properties, and rehabilitation or replacement work, if applicable. A more detailed account of the data collected can be found in the Inventory Data Collection section.

### B.6.2 Routine Inspection

#### *B.6.2.1 Routine Inspections*

Routine inspections comprise most of the inspections that a large culvert structure receives throughout its life. During routine inspections, inspectors are tasked with visually evaluating the condition of the components that comprise the large culvert structure to ensure that the structure is performing sufficiently both hydraulically and structurally. Evaluation of a large culvert structure is performed with the help of condition rating scales and descriptors. These descriptors provide objective descriptions of common deterioration markers that indicate how the structure is performing. Based on the ratings assigned, a recommended inspection interval is provided. Inspectors then schedule the next routine inspection of the culvert structure before the end of the recommended inspection interval.

#### *B.6.2.2 First Routine Inspection*

Following the initial inspection, the first routine inspection of the culvert should be performed within 12 months of the completion of construction. The reasoning for this first routine inspection on new culverts is based on research (Helwany et al., 2007) that shows that during the first few months following construction, structures and their surrounding areas tend to shift slightly as soil compresses and moves to support the weight of the structure. These slight shifts can create unforeseen problems that can severely impact the lifespan of the culvert structure. For example, as backfill soil compresses, it can create humps or sags along the length of the culvert that can impede the steady flow of water, possibly resulting in early deterioration or failure of the culvert structure (Geotechnical Engineering Bureau, 2008). The earlier that problems such as these are identified, the faster the identified problems can be addressed. Following this first routine inspection, regular routine inspections will be performed at the defined inspection frequency.

### B.6.3 Damage/Event Inspection

Damage/event inspections are typically unscheduled inspections that are performed on structures after a collision/overtopping event or when a concern from a firsthand account is reported to INDOT. The purpose of these inspections is to evaluate the structural and hydraulic integrity of the culvert structure to ensure that the condition of the structure does not endanger the public. Data collected during damage/event inspections should be reviewed by a licensed engineer to determine whether the structure has been compromised and if immediate action is necessary. If a culvert structure is deemed to be in acceptable condition and a condition rating is assigned during the damage/event inspection, the next routine inspection may be rescheduled based on the recommended inspection interval for the assigned rating at the time of the damage/event inspection.

### B.6.4 Other Inspection

The other inspection category is reserved for unscheduled inspections that are performed for research purposes or other specified reasons. Inspectors may perform these types of inspections as requested by INDOT personnel or other qualified authorities. Similar to damage/event inspections, if inspectors are able to assign condition ratings to the components of the structure during the inspection, the next routine inspection may be rescheduled based on the recommended inspection interval for the assigned rating.

## B.7 Safety Guidelines for Inspection

Inspection of large culvert structures in the field exposes inspectors to a wide range of hazards. Because of this, it is important that all inspectors in the field have proper personal protective equipment (PPE) and that it is always worn when the inspector is in the field. Due to the placement of culverts, inspectors may need to work along roadsides and cross roadways to properly inspect large culvert structures. Crossing the roadway on foot is only permissible when the roadway does not consist of more than two directional through lanes or more than four through lanes in both directions. This does not include turning lanes. When preparing to cross a roadway, inspectors should be aware of traffic approaching from both directions and wait to cross until there are no vehicles immediately approaching.

Large culvert inspections should be performed in pairs. Working alone in roadside environments presents hazards that could result in bodily injury. While working in pairs does not remove the danger of these hazards, it does provide an additional degree of safety by allowing partners to come to the aid of one another in the case of an injury. Inspection in pairs also works to reduce subjectivity in condition rating assignments by allowing a second pair of eyes to assess the condition of the structure.

When navigating the right of way near a culvert structure, some of the hazards to which the inspector is exposed include uneven or steep embankments that can be difficult to navigate, excessive overgrowth that can hide the presence of holes in the embankment, and tall overgrowth that can make it difficult for search parties to locate a downed inspector. Wild animals hiding in the overgrowth or within the barrel of a culvert can also present a danger to inspectors. In addition to inspecting in pairs, inspectors should make use of the safety and entry equipment provided to them to reduce the risk of injury from these hazards. When in areas where snakes or other animals are suspected to reside, snake gaiters should be worn to protect the inspector. When traversing steep slopes, the range rod or rope should be used for assistance. Carabiners can be connected to the rope to carry down necessary equipment while keeping the inspector’s hands free for navigating the embankment. The rope can also be used as a tie-off when choosing to inspect culvert barrels with low levels of water and silty streambeds.

In extreme cases, an individual inspection may be performed if written approval from the Area Engineer is received. In these situations, inspectors should work with their supervisors to develop lone worker guidelines that protect the inspector from environmental hazards.

## B.8 Large Culvert Entry and Inspection Methods

### B.8.1 Entry Classification

Due to the environmental hazards present at some culvert locations, it is not always possible for inspectors to evaluate the condition of the culvert barrel by walking through the structure. The entry of large culvert structures during an inspection is based on the accessibility of the barrel and the determined level of risk placed on the inspector when entering the structure. INDOT recognizes three classifications for culvert structures concerning entry. These classifications are no entry, permit required entry, and non-permit required entry.

#### *B.8.1.1 No Entry Structures*

Structures assigned a no entry classification are not eligible for walk-through visual inspections. This can be due to physical limitations or elevated safety hazards due to the surrounding environment. Physical limitations include situations in which the opening span of the structure is small enough that inspectors are not able to comfortably walk through the structure or the opening has a hatch or grate that is not removable. Elevated safety hazards can include high velocity of waterflow within the structure or unstable soil and can also be present when the structural integrity of the culvert is unconfirmed.

#### *B.8.1.2 Permit Required Entry Structures*

Structures assigned a permit required classification for entry require proper preparation and inspector qualification before a walk-through visual inspection can be performed. These structures are typically categorized as permit required due to uncertain circumstances in the surrounding environment. To be considered qualified to perform a walk-through inspection on a permit required structure, inspectors should complete the confined space training offered by INDOT.

#### *B.8.1.3 Non-Permit Required Entry Structures*

Structures assigned a non-permit required classification for entry are generally eligible for walk-through visual inspection. Inspectors should still evaluate the structure and surrounding environment to ensure that the conditions do not create an elevated risk of injury when performing the walk-through inspection.

### B.8.2 Methods of Inspection

Corresponding with the entry classifications for structures, there are four methods of inspection that inspectors can utilize. These inspection methods are walk-through inspection, end of barrel inspection, non-visual inspection, and remote-controlled vehicle inspection.

#### *B.8.2.1 Walk-Through Inspection*

When permitted by the necessary entry conditions, inspectors are encouraged to perform a walk-through inspection. Walk-through inspections are performed by walking the length of the culvert structure and inspecting the entire barrel. This type of inspection allows for inspectors to evaluate all joints and seams within the structure for damage or leakage and also allows for more detailed observation of any deterioration within the structure.

#### *B.8.2.2 End of Barrel Inspection*

End of barrel inspections should be performed when it is not possible to walk through the culvert due to entry permissions. During an end of barrel inspection, the inspector should evaluate the culvert from each end of the structure and note any visible or suspected deterioration within the structure from their vantage point. Additional information collected from the exterior components can also reveal information about deterioration within the structure.

#### *B.8.2.3 Non-Visual Inspection*

Non-visual inspection refers to inspections where entry conditions do not allow for walk through of the structure and other methods involving visual inspection of the culvert barrel are not possible. This can occur when a culvert structure is either submerged or temporarily obstructed or when an inspector is not able to visually inspect the culvert barrel due to other circumstances. During non-visual inspections, inspectors are expected to evaluate all applicable components of the culvert structure that are visible and note the reason why the barrel of the structure was not able to be visually inspected. For structures with a barrel that is not visible, inspection should occur annually to ensure that the structure and parent roadway are safe for continued use. If non-visual inspections are continually performed on a structure, inspectors should determine if the structure is a candidate for remote-controlled vehicle inspection.

#### *B.8.2.4 Remote-Controlled Vehicle Inspection*

When visual inspection is limited or not possible for a structure, inspectors are encouraged to evaluate whether the culvert is a candidate for remote-controlled vehicle inspection. Use of remote-controlled vehicles allow for inspectors to evaluate the full-length of the barrel when walk-through inspection is not possible. Structures that are dry may be candidates for remote-controlled cars or HIVE vehicles, while structures with waterflow may be candidates for remote-controlled boats or submersible vehicles. Inspectors should check with their supervisors to determine what remote-controlled vehicles are available for inspection.

## B.9 Inventory Data Collection

During inspections, inspectors are expected to collect or verify information about the culvert structure that can be used by asset management to better understand culvert performance relative to its properties. By grouping culvert structures with similar characteristics and properties, asset management can better model the expected deterioration cycle of large culvert structures and more efficiently lengthen the life expectancy of structures with properly timed rehabilitations. The data collected during an initial inspection are outlined in the following subsections. Data fields with NBI values listed in parenthesis indicate the information field is similar to a National Bridge Inventory item (FHWA, 1995). Therefore, many of the items in the following subsections include information from the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995).

### B.9.1 General Structure Data

Collect the fields below following the completion of construction.

*Year Built (NBI 027)*

Record the year the culvert was originally constructed. If unknown, record 0000 in this field.
Ex. 1997

*Structure Number (NBI 008)*

Record the structure number assigned to the large culvert structure.
Ex. 93005398

*Asset Name*

Record the asset name of the structure.


*Former Culvert ID*

Record the former culvert ID (if applicable).
Ex. 065-91-193.38

### B.9.2 Condition Rating and Routine Inspection

Collect condition rating data about the large culvert structure after evaluating the current state.

*Date of Inspection (NBI 090)*

Record the date of current inspection in MM/DD/YYYY format.
Ex. 04/31/2022

*Inspection Frequency (NBI 091)*

Record the maximum eligible inspection frequency of the structure in months based on the barrel condition rating.

See inspection frequency table in Part 2 of the INDOT Large Culvert Inspection Manual.
Ex. 72

*Executive Summary*

Record a brief overview of the structure and its condition during the inspection.

*Channel Condition (NBI 061)*

Record the condition of the culvert channel using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Channel Condition Comments (NBI 061a)*

Record additional observations about the condition of the channel component.

*Culvert Barrel Condition (NBI 062)*

Record the condition of the large culvert barrel using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Culvert Barrel Condition Comments (NBI 062a)*

Record additional observations about the condition of the culvert barrel.

*Inlet and Outlet Condition*

Record the condition of the inlet and outlet of the large culvert structure using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Inlet and Outlet Condition Comments*

Record additional observations about the condition of the inlet and outlet (first 5 ft) of the culvert barrel component.

*Headwall Condition*

Record the condition of the headwall using the End Treatments condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual (if applicable).

*Wingwall Condition*

Record the condition of the wingwalls using the End Treatments condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual (if applicable).

*Footing/Anchor Condition*

Record the condition of the footings/anchors using the Footing/Anchor condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual (if applicable).

*End Treatment & Footing/Anchor Condition Comments*

Record additional observations about the condition of the end treatments and footings/anchors (if applicable).

*Roadway Condition*

Record the condition of the roadway above the large culvert structure using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Embankment Condition*

Record the condition of the embankment slopes of the large culvert structure using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Above Structure Condition Comments*

Record additional observations about the condition of the roadway and embankment of the structure.

*Joints and Seams Condition*

Record the condition of the culvert barrel joints and seams using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Joints and Seams Condition Comments*

Record additional observations about the condition of the joints and seams of the barrel.

*Channel Alignment Condition*

Record the condition of the channel alignment using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual.

*Scour Presence*

Record the presence of scour using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual. Record the depth of any scour present at the inlet and outlet in feet and inches.
Ex. 3′-0″

*Waterway Blockage*

Record the condition of the culvert barrel opening and presence of any blockage using the appropriate condition rating scale found in Part 2 of the INDOT Large Culvert Inspection Manual. Record the estimated percentage of the culvert opening this is blocked.

*Below Structure Condition Comments*

Record additional observations about the condition of the channel, channel alignment, scour presence, and waterway blockages.

### B.9.3 Geometry and Material Characteristics

Collect general information about the appearance of the large culvert structure.

*Material Type (NBI 043)*

Record the type of material present in the culvert structure.

| Code | Material |
|---|---|
| 0 | Other |
| 1 | Concrete |
| 2 | Precast Concrete |
| 3 | Steel |
| 4 | Plastic |
| 5 | Prestressed Concrete |
| 8 | Masonry or Stone |
| 9 | Aluminum, Wrought Iron, or Cast Iron |

*Secondary Material Type*

Record the secondary type of material present in the culvert structure (if applicable).

Refer to *Material Type* for recording codes.

*Shape Type*

Record the shape category of the culvert structure.

| Code | Shape | Code | Shape |
|---|---|---|---|
| 0 | Other | 4 | Pipe Arch |
| 1 | Arch | 5 | Round |
| 2 | Box | 6 | Slab |
| 3 | Elliptical | | |

*Structure Type (NBI 043)*

Record the structure type category of the maximum span.

| Code | Structure Design Type | Code | Structure Design Type |
|---|---|---|---|
| 00 | Other | 07 | 3-Sided Culvert (Flat or Arch) |
| 01 | Slab | 11 | Arch |
| 02 | Stringer/Multi-Beam or Girder | 19 | 4-Sided Box Culvert |
| 03 | Pipe | 22 | Channel Beam |
| 05 | Box Beam Adjacent | | |

*Type of Pipe Protection*

Record the type of pipe protection present on the material (if applicable).

| Code | Material | Code | Material |
|---|---|---|---|
| 00 | Other | 07 | Asbestos Bond Coated |
| 01 | Unprotected | 08 | Asbestos Bond Coated & Paved |
| 02 | Galvanized | 09 | Vitrified Lined |
| 03 | Partially Bituminous Coated | 10 | Field Paved Inlet |
| 04 | Fully Bituminous Coated | 11 | Coal Tar Resin |
| 05 | Partially Bituminous Coated & Paved | 12 | Thermoplastic |
| 06 | Fully Bituminous Coated & Paved | 13 | Aluminum Coated |

*Maximum Vertical Opening Width*

Record the length of the largest vertical opening in the culvert to the nearest inch.
Ex. 60″

*Maximum Horizontal Opening Width*

Record the length of the largest horizontal opening in the culvert to the nearest inch. The opening width is measured perpendicular to the longitudinal centerline of the culvert.

- Pipe culverts use the diameter of the opening at its largest point.
- Box culverts are measured from inside wall to inside wall.
- Arches are measured at the spring line.
- For multi-span culverts, the maximum horizontal opening is the largest barrel span length.

Ex. 60″

*Structure Additional Description*

Record structure type and material along with its dimensions in width-by-height form. Include additional descriptive information as deemed necessary.
Ex. RCB 6′ × 2′

*Total Span Length*

Record the total span length of the culvert to the nearest inch. If the total span exceeds 240 in. (20 ft) or is less than 48 in. (4 ft), the structure is not classified as a large culvert, and the responsible group should be notified.
If the large culvert is comprised of multiple barrels, the total span length is the sum of the horizontal openings of all the barrels and the horizontal distance between the spans.
Ex. 150″

*Length of Barrel*

Record the length of the culvert structure from opening to opening along the longitudinal centerline to the nearest foot.
Estimations provided by publicly available online maps may be used based on collected GPS data for inlet and outlet if in-person measurement is not possible.
Ex. 78′

*Number of Barrels/Cells*

Record the number of barrels the culvert structure contains.
This field applies to culverts consisting of multiple structures with clear distance separating adjacent structures that is less than half the distance of the smaller horizontal span length.
Ex. 2

*Gage Thickness*

Record the gage thickness of the walls of the culvert barrel (if applicable).

| Gage | in. | mm | Gage | in. | mm |
|---|---|---|---|---|---|
| 16 | 0.064 | 1.63 | 7 | 0.188 | 4.78 |
| 14 | 0.079 | 2.01 | 5 | 0.218 | 5.54 |
| 12 | 0.109 | 2.77 | 3 | 0.249 | 6.32 |
| 10 | 0.138 | 3.51 | 1 | 0.280 | 7.11 |
| 8 | 0.168 | 4.27 | | | |

*Minimum Cover Depth*

Record the total cover depth over the culvert to the nearest foot.
The measurement should correspond to the smallest vertical measurement of cover.

Use 8* for culvert structures under more than 8 ft of fill.
Ex. 5′

*Skew (NBI 034)*

Record the angle of skew of the culvert to the nearest degree.
The skew is measured relative to the axis that is perpendicular to the parent roadway.
Ex. 30°

*Slope*

Record the slope of the pipe in percent to the nearest tenth of a percent (if applicable).

$$\frac{Fall}{Length} \times 100 = Slope$$

Ex. 1.3%

*Asbestos Presence*

Record whether asbestos is present in the culvert structure.

- N – Asbestos is not present
- Y – Asbestos is present.

*Entry Classification*

Record the entry classification of the culvert structure.

| **Code** | **Entry Type** |
|---|---|
| 0 | No Entry |
| 1 | Permit Required Entry |
| 2 | Non-Permit Required Entry |

### B.9.4 Location and Geographical Markers

Collect information about the location of the structure and the roadway it carries.

*District (NBI 001)*

Record the INDOT district in which the large culvert is located.

| Code | District | Code | District |
|---|---|---|---|
| 1 | Crawfordsville | 4 | LaPorte |
| 2 | Fort Wayne | 5 | Seymour |
| 3 | Greenfield | 6 | Vincennes |

*Subdistrict (NBI 002)*

Record the INDOT subdistrict in which the large culvert is located.

*INDOT subdistrict numbering can be found in Part 3.*

*County (NBI 003)*

Record the INDOT county in which the large culvert is located.

*INDOT county numbering can be found in Part 3.*

*Features Intersected (NBI 006)*

Record the feature(s) intersected by the culvert structure.
Ex. Potato Creek

*Facility Carried by Structure (NBI 007)*

Record the Interstate, US, or State Route number of the feature carried by the culvert.

- For Interstates, begin the Interstate number with I-
- For US Routes, begin the US Route number with US-
- For State Routes, begin the State Route number with SR-

Ex: I-465

*Location Additional Description (NBI 009)*

Record additional details about the location of the large culvert structure.
Ex. Inlet of the structure located 150′ east of white farmhouse.

*Milepoint (NBI 011)*

Record the milepoint of the structure along the route to the nearest hundredth of a mile.
Ex: 72.64

*GPS Latitude & Longitude Inlet (NBI 016 & 017)*

Record the latitude and longitude of the inlet opening of the structure.

*GPS Latitude & Longitude Outlet (NBI 016 & 017)*

Record the latitude and longitude of the outlet opening of the structure.

*Functional Class of Inventory Route (NBI 026)*

Record the functional classification of the roadway.

| Rural | | Urban | |
|---|---|---|---|
| **Code** | **Functional Classification** | **Code** | **Functional Classification** |
| 01 | Principal Arterial – Interstate | 11 | Principal Arterial – Interstate |
| 02 | Principal Arterial – Other | 12 | Principal Arterial – Other Freeways or Expressways |
| 06 | Minor Arterial | 14 | Other Principal Arterial |
| 07 | Major Collector | 16 | Minor Arterial |
| 08 | Minor Collector | 17 | Collector |
| 09 | Local | 19 | Local |

*Traffic Safety Features (NBI 036)*

Record whether the following traffic safety features meet acceptable standards.

- Bridge Railings (NBI 036A)
- Approach Guardrail (NBI 036C)
- Transitions (NBI 036B)
- Approach Guardrail Ends (NBI 036D)

| Code | Inventory Status |
|---|---|
| 0 | Inspected feature does not meet currently acceptable standards or a safety feature is required but none is provided. |
| 1 | Inspected feature meets currently acceptable standards. |
| N | Not applicable or a safety feature is not required. |

*Type of Service Under Bridge (NBI 042B)*

Record the type of service provided under the culvert structure.

| Code | Service | Code | Service |
|---|---|---|---|
| 01 | Highway with or without Pedestrian | 06 | Highway – Waterway |
| 02 | Railroad | 07 | Railroad – Waterway |
| 03 | Pedestrian – Bicycle | 08 | Highway – Waterway – Railroad |
| 04 | Highway – Railroad | 09 | Relief for Waterway |
| 05 | Waterway | 00 | Other |

*Highway System Inventory Route (NBI 104)*

Record whether the parent roadway is part of the National Highway System.

| Code | Inventory Status |
|---|---|
| 0 | Not along the NHS |
| 1 | Along the NHS |

### B.9.5 Channel Properties

Collect information about the channel such as energy dissipaters present, the pH level of the water, and the water level during the inspection. Additional fields such as drainage area and design discharge should be completed by INDOT Hydraulics during the design of the structure.

*Drainage Area*

Record the area draining through the culvert crossing to the nearest acre.
Ex. 100

*Design Discharge*

Record the design flow rate for the conduit to the nearest cubic foot per second (CFS).
Ex. 195

*Abrasive Conditions*

Record whether the channel is capable of abrasive conditions.
An abrasive condition is defined as the presence of granular material accompanied by a stream gradient or flow sufficient to cause movement of the granular material in the streambed.

- N – Nonabrasive
- Y – Abrasive

*pH Level*

Record the pH level of the water at the inlet of the culvert structure to the nearest tenth.
Ex. 6.5

*Energy Dissipaters*

Record the type of energy dissipaters used along the waterway in the vicinity of the culvert.

| Code | Energy Dissipaters | Code | Energy Dissipaters |
|---|---|---|---|
| 00 | Other | 06 | Concrete Block Mat |
| 01 | Riprap (Loose) | 07 | Concrete Paving or Panels |
| 02 | Riprap (Grouted) | 08 | Earthen Dikes |
| 03 | Flowable Grout | 09 | Engineered Vegetation |
| 04 | Bags Filled w/ Concrete or Sand | 10 | Natural Vegetation |
| 05 | Gabions | N | None |

- Use B in front of the code to indicate if the energy dissipaters are present at both the inlet and outlet.
- Use I in front of the code to indicate if the energy dissipaters are present only at the inlet.
- Use O in front of the code to indicate if the energy dissipaters are present only at the outlet.

Ex. B02

*Channel Approach Angle*

Record the approximate angle at which the channel approaches the structure.
The approach angle is measured relative to the longitudinal axis of the culvert.
Ex. 45°

*Water Level*

Record the observed water level.

| Code | Observation |
|---|---|
| 0 | Dry |
| 1 | Slow Flow |
| 2 | Fast Flow |
| 3 | Stagnant Water |
| 4 | Full/Submerged |

*Overtopping Frequency (NBI 071)*

Record the expected overtopping frequency of the structure if the information is available.

| Code | Frequency |
|---|---|
| 1 | Remote – greater than 100 years |
| 2 | Slight – 11 to 100 years |
| 3 | Occasional – 3 to 10 years |
| 4 | Frequent – less than 3 years |
| N | No Waterway Present |

### B.9.6 End Treatment Properties

Collect information about the type of end treatments that are present, if they differ between inlet/outlet, and their position relative to the structure.

*Inlet End Treatment*

Record the type of end treatment present at the inlet end of the culvert.

| Code | End Treatment | Code | End Treatment |
|---|---|---|---|
| 00 | Other | 05 | Metal Grate |
| 01 | Headwall Only | 06 | Manhole |
| 02 | Wingwalls Only | 07 | Metal Apron/Scoop |
| 03 | Headwall & Wingwalls | 08 | Mitered End |
| 04 | Full Height End Wall | N | None |

*Inlet End Treatment Position*

Record the positioning of the inlet end treatment(s) (if applicable).

- Use I to indicate that the end treatments are in-line with the opening of the inlet.
- Use A to indicate that the end treatments are angled along the opening of the inlet.
- Use P to indicate that the end treatments are perpendicular to the opening of the inlet.

*Outlet End Treatment*

Record the type of end treatment present at the outlet end of the culvert.

| Code | End Treatment | Code | End Treatment |
|---|---|---|---|
| 00 | Other | 05 | Metal Grate |
| 01 | Headwall Only | 06 | Manhole |
| 02 | Wingwalls Only | 07 | Metal Apron/Scoop |
| 03 | Headwall & Wingwalls | 08 | Mitered End |
| 04 | Full Height End Wall | N | None |

*Outlet End Treatment Position*

Record the positioning of the outlet end treatment(s) (if applicable).

- Use I to indicate that the end treatments are in-line with the opening of the outlet.
- Use A to indicate that the end treatments are angled along the opening of the outlet.
- Use P to indicate that the end treatments are perpendicular to the opening of the outlet.

### B.9.7 Rehabilitation History

Collect information on previous repair work including the year performed, the modification type, the material used for the modification, and the reason for the work.

*Year Modified*

Record the year repair work was performed on the culvert.
Ex. 2016

*Modification Type*

Record the type of modification made to the culvert structure.

| Code | Modification |
|---|---|
| I | Invert Paving |
| J | Installing Bands at Joints |
| L | Lining of Culvert |
| S | Replacing or Adding Sections |
| W | Widening or Extension |
| O | Other |

*Modification Material*

Record the material present in the modification.

| Code | Material | Code | Material | |
|---|---|---|---|---|
| 00 | Other | 06 | Thermoplastic Pipe (PVC or HDPE) | |
| 01 | Concrete | 07 | Folded PVC Liner | |
| 02 | Corrugated Steel Rib | 08 | CIPP PVC Liner | |
| 03 | Corrugated Steel Spiral | 09 | Steel Casing Pipe | |
| 04 | Corrugated Aluminum Rib | 10 | Spray Applied Liner | |
| 05 | Corrugated Aluminum Spiral | 11 | Spiral Wound PVC | |

*Modification Comments*

Record a brief explanation of the reason for the modification.

## B.10 Inspection Procedure

During a routine inspection, it is recommended that inspectors begin each inspection with the same component and work through the structure linearly to ensure that the entirety of the structure is inspected and that all applicable fields of the inspection form are updated.

### B.10.1 Above Structure Components

As inspectors reach the location of the large culvert with their inspection vehicles, the first components of the structure that are encountered are the roadway and embankment. These two large culvert components are grouped in the "Above Structure" components category. Beginning with the evaluation of the roadway directly above the large culvert structure, inspectors should refer to the condition rating scale descriptors for the roadway component and determine the condition rating value that best describes the observed condition. Inspectors should then observe the channel and determine the direction of flow. If the direction of flow can be identified, inspection should continue at the upstream side of the culvert. Inspectors should safely traverse the embankment of the roadway to gain better access to the large culvert structure. As inspectors are descending the embankment, evaluation of its condition should be performed by referring to the Embankment Condition Rating Scale. This evaluation should be conducted on both sides of the roadway.

### B.10.2 Channel Components

Following the descent of the embankment, inspection should continue with an assessment of the condition of the upstream portion of the channel by referring to the Channel Condition Rating Scale. Channel alignment should also be evaluated and rated. Along the zone where the channel meets the culvert inlet, inspectors should check for the presence of scour and assign a condition rating value according to the Scour Presence Condition Rating Scale and record the maximum depth of scouring that is observed. Inspectors should also take note of the amount of sediment deposit at the entrance of the culvert structure and any waterway blockages. This same process should then be repeated after descending the embankment on the other side of the roadway.

### B.10.3 Culvert Structure Components

After evaluating the opening of the culvert structure for scouring and assessing the level of sediment build-up, inspectors should then begin an assessment of the structural components of the culvert beginning with end treatments such as headwalls and wingwalls if they are present. After assigning a condition rating value to the end treatments, inspectors should perform an inspection of the culvert barrel. An inspection of the barrel should be performed first from the end of the barrel and then with a walk-through or equivalent method if conditions allow. Inside the barrel, the inspector should check material surfaces for deterioration and also check for potential voids behind walls that indicate a redistribution of the soil envelope. Boundaries of any deterioration that is observed should be marked within the structure using a permanent marker to allow for future inspectors to determine if the deterioration is progressing. Inspectors should also take note of the condition of joints and seams within the structure and evaluate them for signs of deterioration or separation as described within the applicable Joints and Seams Condition Rating

Scale. If the structure has footings or anchors, inspectors should inspect for signs of damage or movement and assess whether localized scour or undermining is occurring along the footings or anchor points. Condition of the inlet and outlet of the structure should be considered as part of the overall barrel condition and should also be evaluated separately to provide insight into the distribution of deterioration within the structure. After inspection of all the components of the large culvert, the inspector should refer to the field inspection form and the previous inspection report to ensure no additional fields need to be evaluated before departing from the location.

## B.11 Documentation Procedure

Large culvert inspection reports should include both written and visual documentation of the condition state of all components that are inspected. Collection of this information will be of use for future inspections of the structure as well as to asset management personnel for determining the priority of a structure for rehabilitation or replacement.

### B.11.1 Written Documentation

Following the process of inspection outlined in the previous section, inspectors should make either written or typed notes of observed deterioration and defects. Information such as the area or length of the deterioration or defect, location of the deterioration or defect with respect to a permanent reference point, and the degree of severity of the deterioration or defect should be documented. Written documentation should include sufficient detail to allow the deterioration being described to be easily located and should provide a benchmark for future inspectors to determine the rate at which the deterioration is progressing. Critical details include the area of delaminations, size of cracks and spalls, depth of scaling and abrasion, presence of exposed reinforcement, loss of protective coatings, amount of corrosion, area of section loss, size of perforations, presence of visible voids within the structure or behind holes in the structure, etc. Inspectors should also note auxiliary information about the structure and its environment such as evidence of high-water marks or the current level of the water compared to normal water levels evidenced by discoloration of culvert surfaces or other indicators. Any other observed changes that may be of use based on inspection experience should also be recorded.

### B.11.2 Visual Documentation

Inspection reports should include photographic documentation of the condition state of all components that are inspected. During the process of inspection, inspectors are expected to take pictures of the components being evaluated regardless of the condition state. At least one photo of the roadway above the culvert structure, photos of the channel both upstream and downstream, photos of the embankment and end treatments, and photos of the culvert barrel from the inlet and outlet need to be taken. Furthermore, if inspectors are able to walk through the structure, at least one photo should be taken to document the condition of the interior. If localized scour is discovered, inspectors should indicate the depth of scour using a prism pole and take a picture to show relative location and scour depth.

Further visual documentation should occur for any deterioration that is documented in written form to provide visual support for the written descriptors. When documenting conditions of culvert components, inspectors are expected to review photographic documentation to avoid blurry or poorly-lit photos that do not adequately capture the condition of the structure. For close-up photos of deterioration that require more detail, a reference item should be included to allow for the actual size of the deterioration to be understood. Items such as a prism pole, crack comparator card, inspector's hand, or accompanying inspector should suffice. When possible, inspectors should include permanent features in the visual documentation to be used as a reference during future inspections. The written documentation of deterioration should be paired with its respective visual counterpart and should indicate what is being documented, the relative location of the deterioration within the structure, and all applicable measurements.

# APPENDIX B. PROPOSED INDOT LARGE CULVERT INSPECTION MANUAL—PART 2: EVALUATION AND CONDITION RATING

## B.12 Overview of Part 2

Part 2 of the large culvert inspection manual includes information related to the evaluation and condition rating process of large culvert inspection. More specifically, Part 2 includes information about the components of a culvert structure that should be considered during an inspection, inspection frequency guidelines, and condition rating scales and descriptors for the components.

The components of a large culvert are separated into two categories, major and minor, based on the impact of the component on the ability of the culvert to perform its hydraulic and structural functions. Different levels of detail are provided within the condition rating scales based on whether the component being evaluated is classified as major or minor. Guidelines for inspection frequency are based on the assigned rating for the barrel. Additional information about the deterioration markers that are included in the descriptors of the condition rating scale for each component is provided in the respective section of the manual in which the scale is introduced. Accompanying visual scales for concrete and metal barrel conditions are also provided at the end of the manual to aid inspectors with determining the condition rating value that best aligns with the observed condition of the large culvert structure that is being evaluated.

## B.13 Condition Rating System

Inspectors are required to evaluate the condition of a culvert structure and record condition rating values for all applicable components. For assigning condition rating values, culvert components are separated into two categories: major and minor.

The scales for major components use a 10-point rating system with values ranging from 0-9, where a rating of 9 indicates the component is in excellent condition and a rating of 0 indicates that the component has failed to perform its intended function. These scales are used to evaluate the components of a culvert structure that directly impact the functionality of the large culvert structure either hydraulically or structurally. The scales for minor components use a 3-point rating system to evaluate components of a culvert structure that play a more indirect role in the functional performance of the culvert structure.

For each condition rating scale, accompanying descriptors are provided to aid the inspector in assigning a condition rating value to the component. Assigning condition rating values in accordance with the descriptors reduces subjectivity in the evaluation process and allows for a more uniform collection of data to be gathered for asset management purposes.

## B.14 Inspection Frequency

Inspection frequency for large culvert structures in the state of Indiana is determined based on the last known inspection of the structure. Culvert structures that receive lower condition rating values are at greater risk of failure, and these structures should be inspected more often. Determination of inspection frequency relies on the condition rating value assigned to the barrel. Inspection frequencies range from a maximum recommended frequency of 72 months to an inspection frequency of 12 months based on the condition of the large culvert. Recommended inspection frequencies are provided in the following table.

Maximum inspection frequencies:

| | |
|---|---|
| 72 Months | Barrel condition rating of 7 or greater.* |
| 48 Months | Barrel condition rating of 5 or 6. |
| 12 Months | Barrel condition rating of 4 or less.<br>OR<br>Structure is completely submerged. |

*Regardless of condition, large metal culverts with flowing water present should be limited to a maximum inspection interval of 48 months.

*All plastic lined structures are restricted to a maximum inspection interval of 48 months.

## B.15 Major Components

Components assigned major scales are the primary components of a culvert structure. The condition of these components can have direct impact on the structural and hydraulic functions of the structure. Due to this direct impact, more condition rating values are needed to accurately capture the current state of the component, and more detail is provided in the accompanying condition rating descriptors.

Components that are assigned major scales include:

- Culvert Barrel
- Inlet/Outlet
- End Treatments
- Channel Condition

### B.15.1 Culvert Barrel

The condition rating scale used for evaluation of the culvert barrel relies on a 10-point scale. The condition rating value should consider the condition of the entirety of the culvert barrel. Condition rating descriptors for concrete and precast concrete, metal, plastic, and masonry culvert structures are provided in this section. If a structure is comprised of multiple materials, this should be noted in the inspection report, and condition rating values should be assigned for each section based on the applicable descriptors for the material being evaluated. In this case, the lowest rating for the barrel of the structure should be used when determining inspection frequency. For materials other than concrete/precast concrete, metal, plastic, and masonry, a generalized culvert condition rating scale is provided at the end of this section and should be used for evaluation.

### B.15.2 Inlet/Outlet

The inlet and outlet of the culvert barrel use the same 10-point scale as the remainder of the culvert barrel. Evaluation of the inlet and outlet should be limited to the first 5 ft of the structure at both ends so long as the section is not located underneath the roadway. If the portion of the barrel not directly under the roadway is less than 5 ft, the portion of the culvert not under the roadway is treated as the inlet/outlet. The inlet and outlet are evaluated separately from the overall structure to provide a better understanding of how deterioration within the structure is distributed. Isolated evaluation of the inlet and outlet also allows an understanding of the interactions between the culvert structure and the channel/environment.

## Concrete and Precast Concrete

Four deterioration markers are considered and described in the condition rating descriptors for concrete and precast concrete structures. These markers include cracking, scaling and abrasion, delamination and spalling, and the exposure of steel reinforcement. These condition rating descriptors are based in part on information from the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022), the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the ODOT *Conduit Management Manual* (ODOT, 2021), and the FHWA *Culvert Inspection Manual* (FHWA, 1986).

*Cracking*

Cracks in concrete and precast concrete structures are evaluated based on their width, spacing between occurrences, and signs of water infiltration/exfiltration. Limiting values for crack widths range from hairline (0.01 in.) to 0.25 in. (AASHTO, 2020; FHWA, 2022; ODOT, 2021). Accurately measuring the opening width of a crack is important; the larger the crack, the easier it is for soil and water to infiltrate the structure through the opening. Cracks can also increase the rate of the corrosion process of steel reinforcement within the concrete by allowing exposure to moisture and chemicals. Because of this, signs of moisture that emanate from a crack zone such as efflorescence buildup, wetness or leakage, and rust staining are also considered in the condition rating descriptors (ODOT, 2021).

Spacing between cracks that are oriented in the direction transverse to traffic is also considered. The number of unique cracks present in a location could indicate overloading or poor bedding support of the structure in a particular area. Crack spacing limits are based on values given in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020).

*Scaling and Abrasion*

Scaling and abrasion in concrete and precast concrete structures are evaluated based on the depth of the deterioration as well as the percentage of the surface area impacted by the deterioration. Accepted depths and surface coverage range from less than 0.125 in. to greater than 0.25 in. and less than 10% of surface area up to greater than 50% of surface area, respectively (AASHTO, 2020; FHWA, 1986; ODOT, 2021).

Scaling and abrasion cause deterioration in concrete structures by removing the cement paste from a concrete face (AASHTO, 2020). This process will continue until the larger aggregate within the concrete is exposed. Further deterioration around the edges of this aggregate can lead to the dislodging of the aggregate, creating a void where the aggregate once was and exposing more paste. As this process continues, the structural capacity of the material will begin to diminish due to the presence of unsound concrete material.

*Delamination and Spalling*

Delamination and spalling in concrete and precast concrete structures are evaluated based on the depth and length of visible spalls and the percentage of the surface area of the structure that is affected. Limiting values in the descriptors for spalls and delamination along the surface area of the structure range from less than 1% to greater than 50% surface area coverage (ODOT, 2021). These percentages are paired with measurements of spalls along the surface of the structure. Because patches of delamination are not often visible, no length or depth measurements are provided.

Delamination can be difficult to detect due to the separation of layers of concrete taking place beneath the surface layer. This process often does not provide a surface marker that allows delamination to be observable through visual inspection (AASHTO, 2020). To account for this, it is recommended that inspectors use sounding mallets/hammers during an inspection to reveal areas of delamination. Delaminated patches of concrete will produce a hollower sound in comparison with solid concrete when struck (AASHTO, 2020). To document the area of a delamination, an inspector should mark the perimeter of the delaminated area to allow for visual tracking of growth between inspections.

Spalls on the surface of concrete structures indicate that portions of the material have debonded from the whole of the structure and are no longer providing structural strength or chemical protection for the underlying layers. Spalling often occurs along edges or previously formed cracks in a structure. It can also occur when underlying delaminations cause concrete to separate from the body of the structure. One of the major concerns of spalling is the exposure of steel reinforcement lying beneath the surface of the concrete. For spalling, the descriptors instruct inspectors to consider the number of spalls observable in the structure as well as the depth and the diameter of the spall. As indicated in the *FHWA Specifications for the National Bridge Inventory* (FHWA, 2022), a structure with a singular spall that is shallower than 1 in. and less than 6 in. in diameter would generally be considered in better condition than a structure with multiple spalls of which one or more of the spalls are either greater than 1 in. in depth or greater than 6 in. in diameter.

*Exposed Steel Reinforcement*

Steel reinforcement plays a large role in the structural function of concrete culvert structures. The structural capacity of a large culvert begins to diminish once the steel begins the oxidation process. Because of this, exposure of the steel reinforcement is included in the condition rating descriptors. The descriptors related to steel reinforcement were adapted from the ODOT *Conduit Management Manual* (ODOT, 2021) and start with the presence of exposed faces of the reinforcing steel and consider corrosion of the material as well as the extent of exposure. The condition rating value decreases as concrete surrounding the bars wears away and/or as more steel reinforcement become exposed along the structure (ODOT, 2021).

| CONDITION RATING SCALE: CONCRETE AND PRECAST CONCRETE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. ISOLATED DAMAGE FROM INSTALLATION MAY BE PRESENT. |
| 8<br>VERY GOOD | HAIRLINE CRACKING (WIDTHS LESS THAN 0.01 IN.) WITHOUT EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING.<br>NO DETERIORATION FROM SCALING OR ABRASION.<br>NO SPALLING OR DELAMINATIONS. |
| 7<br>GOOD | CRACK WIDTHS LESS THAN 0.02 IN. MINOR EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>SCALING/ABRASION LESS THAN 0.125-IN. DEEP COVERING LESS THAN 10% OF SURFACE AREA.<br>DELAMINATED OR SPALLED AREA LESS THAN 1% OF SURFACE AREA.<br>SINGLE INDIVIDUAL SPALL IS LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
| 6<br>SATISFACTORY | CRACK WIDTHS LESS THAN 0.0625 IN. EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>SPACING OF CRACKS TRANSVERSE TO TRAFFIC 3 FT OR GREATER.<br>SCALING/ABRASION LESS THAN 0.25-IN. DEEP COVERING LESS THAN 20% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 5% OF SURFACE AREA.<br>INDIVIDUAL SPALLS ARE LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
| 5<br>FAIR | CRACKS WIDTHS LESS THAN 0.125 IN. PARALLEL TO TRAFFIC OR LESS THAN 0.0625 IN. TRANSVERSE TO TRAFFIC. EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING PRESENT.<br>SCALING/ABRASION GREATER THAN 0.25-IN. DEEP COVERING LESS THAN 30% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 15% OF SURFACE AREA.<br>SPALLING HAS EXPOSED REINFORCING STEEL.<br>INDIVIDUAL SPALLS ARE GREATER THAN 6 IN. IN DIAMETER OR GREATER THAN 1-IN. DEEP. |
| 4<br>POOR | EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.125 IN.<br>SPACING OF CRACKS TRANSVERSE TO TRAFFIC BETWEEN 1 FT AND 3 FT.<br>SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING LESS THAN 50% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 25% OF SURFACE AREA.<br>SPALLING HAS EXPOSED CORRODED REINFORCING STEEL. |
| 3<br>SERIOUS | SOFT CONCRETE.<br>EXTENSIVE CRACKING WITH CRACK WIDTHS LESS THAN 0.25 IN.<br>DIFFERENTIAL MOVEMENT AT CRACK(S).<br>SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING GREATER THAN 50% OF SURFACE AREA.<br>LESS THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED.<br>SPALLING HAS EXPOSED MUCH OF THE PERIMETER OF REINFORCING BARS. |
| 2<br>CRITICAL | CONCRETE COMPLETELY DETERIORATED IN ISOLATED LOCATIONS CREATING THROUGH-DEPTH HOLES.<br>EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.25 IN.<br>SEVERE DIFFERENTIAL MOVEMENT AT CRACK(S).<br>GREATER THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED.<br>SPALLED AREAS WITH EXPOSED REINFORCING STEEL COVER APPROXIMATELY 25% OF SURFACE AREA.<br>REINFORCING BAR PERIMETER IS COMPLETELY EXPOSED AND BARS EXHIBIT EXTENSIVE SECTION LOSS. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

### Metal

Four deterioration markers are considered and described in the condition rating descriptors for metal pipe structures. These markers include corrosion, section loss and perforations, shape deformation, and impact damage. These condition rating descriptors are based in part on information from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the ODOT *Conduit Management Manual* (ODOT, 2021), the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995), the FHWA *Culvert Inspection Manual* (FHWA, 1986), and the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022).

*Corrosion*

As described in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the development of corrosion in metal structures is evaluated based on visual evidence of discoloration along with flaking or scaling of surface layers of metal that have separated from the remaining material. The stages of the corrosion process that are documented in scale descriptors range from slight discoloration and the wearing of protective coatings to widespread layers of corrosion with large amounts of scaling. The rate of corrosion in metal structures is influenced by the presence of flowing water through the structure (AASHTO, 2020). For structures that carry water consistently throughout the year, corrosion staining is typically visible between ribs (if corrugated) along the waterline and the bottom of the invert of the structure. Corrosion of the metal structure is considered a primary deterioration mechanism because, as the metal oxidizes, its structural capacity diminishes, and the structural functionality of the culvert is impacted (AASHTO 2020).

Protective liners and coatings are common across the INDOT inventory of metal culverts as corrosion is a known process that occurs within metal pipes. These protective treatments can range from galvanized steel surfaces to bituminous coatings and can offset the process of corrosion by preventing water from contacting the susceptible layers of metal. As the protective liners and coatings are removed, the corrosion process begins with a discoloration of the top layer as it starts to oxidize and disintegrate. This process becomes visible as collections of pinpoint or freckled discoloration along the surface layer of the material. The corrosion process will continue until rust is widespread over the surface of the steel and corroded steel easily flakes off with contact (ODOT, 2021). If this layer is not removed, it can act as a protective barrier and slow the corrosion process for the material underneath the surface layer.

*Section Loss and Perforations*

According to the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022), the occurrence of section loss and perforations are common deterioration markers. Descriptors for these mechanisms are based on the surface area of the structure that has been affected. Values are offered in area per square foot for localized occurrences and as a percentage of the entire surface area. The descriptors regarding section loss and perforations were gathered from the ODOT *Conduit Management Manual* (ODOT, 2021). The presence of section loss and perforations is typically prefaced by either corrosion or abrasion in a structure. Corrosion removes layers of the metal structure through chemical processes while abrasion removes material through a physical process (FHWA, 1986). In both cases, the removal of material weakens the structural capacity of the culvert and can result in the presence of an unintended opening from which water can exit the structure and backfill material can enter (AASHTO, 2020).

Section loss is the resulting deterioration marker from repeated removal of material within the structure (AASHTO, 2020; FHWA, 1986). As the metal in an area becomes thinner, the material becomes more penetrable through physical processes and can result in a sizable hole. Because of this, areas of widespread section loss are considered in the condition rating descriptors. The values for section loss/perforation area and the accompanying percentages are based on the condition rating descriptors present in the ODOT *Conduit Management Manual* (ODOT, 2021). Values for section loss range from less than 6 in.$^2$/ft$^2$ or 4% of invert area to less than 15 in.$^2$/ft$^2$ or less than 10% of invert area. Values for the severity of perforations range from less than 30 in.$^2$/ft$^2$ or 20% of invert area to greater than 36 in.$^2$/ft$^2$ or 25% of invert area. The presence of holes larger than 36 in.$^2$/ft$^2$ along the culvert allow for much of the water flowing through the structure to exit into the embankment and backfill soil. Depending on the flow of water in the structure, perforations greater than 36 in.$^2$/ft$^2$ would create concern for instability of the roadway.

*Shape Deformation*

Flexible structures such as metal pipes draw strength from the surrounding soil envelope and rely on evenly applied forces to function structurally. Disruption of these forces can lead to misshapen structures that fail due to a lack of structural capacity (AASHTO, 2020). Descriptors for shape deformation consider the overall appearance as well as vertical deformation of the opening. Descriptions of the overall shape appearance were adopted from the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) and the FHWA *Culvert Inspection Manual* (FHWA, 1986). The values for allowable deflection in the vertical direction are consistent with the recommendations in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020). Descriptors for overall appearance range from retaining a smooth symmetrical shape to extreme distortion where reversed curvature is present. For vertical opening deflection, values range from less than 5% to more than 15% of the original diameter (AASHTO, 2020).

Shape deformations can occur in localized areas or across the entirety of the structure (AASHTO, 2020; FHWA, 1995). Localized deformations typically point to a failure of the material at a specific location. Widespread distortion can stem from an unaddressed local failure or from soil envelope issues such as infiltration/exfiltration or piping which remove the encasing soil and affect the forces being applied to the structure (AASHTO, 2020).

*Impact Damage*

Descriptors for impact damage were developed to account for localized damage that occurs to exposed sections of the structure due to blunt forces from external objects (AASHTO, 2020). While the overall structure may be in good condition based on the typical deterioration markers, depending on the location and extent of the impact damage, failure of functionality either structurally or hydraulically is possible. Descriptors for impact damage are present within the condition rating descriptions corresponding to “7 – Good,” “4 – Poor,” and “2 – Critical.” The descriptors consider whether the damage from the impact forces perforated the material and if signs of infiltration/exfiltration of soil or water are present. Even though impact damage is caused by one-time events, the damage that stems from the force of the foreign object can render the culvert useless either structurally or hydraulically in a fashion similar to long-term deterioration mechanisms.

| CONDITION RATING SCALE: METAL PIPE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. CULVERT RETAINS ORIGINAL SHAPE. |
| 8<br>VERY GOOD | DISCOLORATION OF SURFACE. PROTECTION PARTIALLY GONE ALONG INVERT BUT NO LAYERS OF RUST. |
| 7<br>GOOD | PROTECTION GONE ALONG INVERT. FRECKLED RUST PRESENT.<br>CULVERT RETAINS A SMOOTH SYMMETRICAL CURVATURE.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITHOUT WALL PENETRATION. |
| 6<br>SATISFACTORY | PROTECTION GONE ALONG INVERT. LAYERS OF RUST THROUGHOUT.<br>MODERATE SECTION LOSS LESS THAN 6 $IN.^2/FT^2$ OR 4% OF INVERT AREA.<br>CULVERT RETAINS SMOOTH CURVATURE BUT NON-SYMMETRICAL SHAPE.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 5% LOSS OF ORIGINAL DIAMETER. |
| 5<br>FAIR | HEAVY RUST AND SCALING THROUGHOUT.<br>HEAVY SECTION LOSS: LESS THAN 15 $IN.^2/FT^2$ OR 10% OF INVERT AREA.<br>TOP HALF OF CULVERT RETAINS SMOOTH CURVATURE. MINOR BULGES OR FLATTENING PRESENT IN BOTTOM OF PIPE.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 4<br>POOR | EXTENSIVE RUST AND SCALING THROUGHOUT.<br>MINOR PERFORATIONS/HOLES THROUGHOUT INVERT.<br>MINOR PERFORATION/HOLE AREA LESS THAN 30 $IN.^2/FT^2$ OR 20% OF INVERT AREA.<br>CULVERT HAS SHARP POINTS OR TURNS PRESENT ALONG CURVATURE DUE TO FLATTENING.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 15% LOSS OF ORIGINAL DIAMETER.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION BUT NO SIGNS OF SOIL INFILTRATION. |
| 3<br>SERIOUS | EXTENSIVE RUST AND SCALING THROUGHOUT.<br>MODERATE PERFORATIONS/HOLES LESS THAN 36 $IN.^2/FT^2$ OR 25% OF INVERT AREA.<br>CULVERT HAS EXTREME DISTORTION IN ONE SECTION OF PIPE. LOCAL AREAS OF REVERSED CURVATURE MAY BE PRESENT.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN GREATER THAN 15% LOSS OF ORIGINAL DIAMETER. |
| 2<br>CRITICAL | MAJOR PERFORATIONS/HOLES GREATER THAN 36 $IN.^2/FT^2$ OR GREATER THAN 25% OF INVERT AREA.<br>CULVERT HAS EXTREME DISTORTION IN MULTIPLE SECTIONS OF PIPE.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION ALLOWING SOIL ENVELOPE TO INFILTRATE PIPE. |
| 1<br>IMMINENT<br>FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

## Plastic

The term plastic encompasses many different materials that share a similar set of characteristics. Because of this, deterioration markers listed in this section may present themselves differently based on the material's chemical make-up. According to the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), commonly used plastic materials in large culvert structures include high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), and fiberglass-reinforced plastic (FRP).

Four deterioration markers are considered and described in the condition rating descriptors for plastic pipe structures. These markers include UV radiation and material softening, mechanical splits and tears, abrasion and wearing, and shape deformation. These condition rating descriptors are based in part on information from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the ODOT *Conduit Management Manual* (ODOT, 2021), the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995), and the FHWA *Culvert Inspection Manual* (FHWA, 1986).

### *UV Radiation and Material Softening*

As explained in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), plastic culverts can be susceptible to UV radiation damage from the sun. While most of a culvert structure is expected to be buried and protected from exposure to sunlight, the ends of the culvert structure are typically exposed and can be damaged over time. This deterioration occurs due to oxidation of the plastic material and results in a more brittle material that can be fractured when struck with a hammer (AASHTO, 2020). UV protective coatings can be applied to plastic materials but weaken over time. Signs of UV radiation damage in a plastic structure can be visually identified by a distinct discoloration or mottled appearance of the material (AASHTO, 2020). Furthermore, FRP structures are susceptible blistering (AASHTO, 2020), which is also incorporated into the condition rating scale for plastic culverts.

### *Splits and Tears*

According to the ODOT *Conduit Management Manual* (ODOT, 2021), as plastic materials age, splits or tears can occur within the material. These splits or tears can be complete or partial openings in the material. While these openings may not be at water level, they can allow for exfiltration of water during high flow periods or the infiltration of backfill depending on whether the plastic material is being used as a liner or a standalone structure.

### *Abrasion and Wearing*

The AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020) states that plastic materials such as HDPE, PVC, and PP exhibit abrasion resistance. Nevertheless, abrasion and wearing can still occur. Initial abrasion and wearing that does not cause disruption to waterflow or pooling of water in a structure are not a significant concern (AASHTO, 2020). As the deterioration continues, inspectors may need to consider repair work to avoid complete section loss of the material.

*Shape Deformation*

Large culvert structures made of plastic tend to have flexible behavior and therefore draw their strength from the forces exerted by the surrounding soil envelope. Disruption of these forces can lead to misshapen structures that fail due to a lack of structural capacity (AASHTO, 2020). The same descriptors for overall appearance in metal pipes are used for plastic pipes (FHWA, 1986; FHWA, 1995). Vertical deformation values range from less than 5% to greater than 10% of the original diameter due to differences in material properties when compared to metal structures. Similar to the metal deflection descriptor percentages, the percentages for plastic structure deflections are based in part on values found in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020).

| CONDITION RATING SCALE: PLASTIC PIPE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. CULVERT RETAINS ORIGINAL SHAPE. |
| 8<br>VERY GOOD | MINOR DISCOLORATION PRESENT IN ISOLATED LOCATIONS.<br>ISOLATED RIP OR TEAR LESS THAN 6 IN. IN LENGTH CAUSED BY FLOATING DEBRIS OR CONSTRUCTION. |
| 7<br>GOOD | SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH LESS THAN 0.25 IN. ALONG SPLIT.<br>CUTS, GOUGES, OR DISTORTION TO END SECTIONS FROM CONSTRUCTION OR MAINTENANCE.<br>CULVERT RETAINS A SMOOTH SYMMETRICAL CURVATURE.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 5% LOSS OF ORIGINAL DIAMETER. |
| 6<br>SATISFACTORY | MINOR STAINING OR DISCOLORATION FROM UV RADIATION DAMAGE PRESENT.<br>BLISTERING PRESENT ALONG LESS THAN 25% OF PIPE SURFACE (FRP).<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH LESS THAN 0.5 IN. ALONG SPLIT.<br>CULVERT RETAINS SMOOTH CURVATURE, BUT NON-SYMMETRICAL SHAPE. |
| 5<br>FAIR | WIDESPREAD STAINING OR DISCOLORATION FROM UV RADIATION DAMAGE PRESENT ALONG EXPOSED ENDS OF PIPE.<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 0.5 IN. AT LESS THAN THREE LOCATIONS ALONG SPLIT.<br>SECTION LOSS CAUSED BY ABRASION VISIBLE THROUGHOUT PIPE.<br>TOP HALF OF CULVERT RETAINS SMOOTH CURVATURE. MINOR BULGES OR FLATTENING PRESENT IN BOTTOM OF PIPE.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 7.5% LOSS OF ORIGINAL DIAMETER. |
| 4<br>POOR | BLISTERING PRESENT ALONG MORE THAN 25% OF PIPE SURFACE (FRP).<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 0.5 IN. AT SEVERAL LOCATIONS ALONG SPLIT.<br>PERFORATIONS CAUSED BY ABRASION LOCATED THROUGHOUT PIPE.<br>CULVERT HAS SHARP POINTS OR TURNS PRESENT ALONG CURVATURE DUE TO FLATTENING.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 3<br>SERIOUS | UV RADIATION DAMAGE/BLISTERING HAS CAUSED MATERIAL TO CRACK OR PUNCTURE.<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 1 IN. AT LESS THAN THREE LOCATIONS ALONG SPLIT.<br>SPLITS CAUSING LOSS OF BACKFILL MATERIAL.<br>CULVERT HAS EXTREME DISTORTION IN ONE SECTION OF PIPE. LOCAL AREAS OF REVERSED CURVATURE MAY BE PRESENT.<br>VERTICAL DEFORMATIONS RESULTING IN GREATER THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 2<br>CRITICAL | SPLIT LARGER THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 1 IN. AT SEVERAL LOCATIONS ALONG SPLIT.<br>CULVERT HAS EXTREME DISTORTION IN MULTIPLE SECTIONS OF PIPE.<br>SECTION LOSS CAUSED BY ABRASION HAS COMPLETELY ERODED PLASTIC MATERIAL IN LOCATIONS THROUGHOUT PIPE. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

### Masonry

Four deterioration markers are considered and described in the condition rating descriptors for masonry and stone structures. These markers include damaged or missing bricks/stones, damaged or missing mortar, infiltration and exfiltration, and alignment. The original scale used for evaluation of masonry structures can be found in the FHWA *Culvert Inspection Manual* (FHWA, 1986) and was slightly modified to develop the scale provided herein.

#### *Damaged or Missing Masonry Units*

Masonry brick and stone structures are comprised of masonry units and mortar. The masonry units provide structural strength while the mortar holds the individual units together. Forces applied to masonry structures are distributed across the individual units through the mortar. If individual units are damaged or missing, the surrounding units must redistribute the applied forces in the localized area. As more masonry units are damaged or missing, applied forces from vehicles and the surrounding soil may exceed the structural capacity of the masonry structure, resulting in failure.

#### *Distressed or Missing Mortar*

As previously mentioned, masonry mortar is used to connect individual masonry units to one another and distribute applied forces across units. As this mortar deteriorates over time, its ability to transfer forces and hold masonry units in place diminishes. Deterioration of the mortar can lead to dislodged masonry units and infiltration or exfiltration of soil and water (FHWA, 1986).

#### *Infiltration and Exfiltration*

Signs of infiltration or exfiltration of material through masonry structures indicate that there are either missing or damaged masonry units or deteriorated mortar. As water infiltrates the cracks or openings surrounding a masonry unit, it can begin to erode the material and accelerate the deterioration of the structure. As gaps grow larger, issues pertaining to infiltration and exfiltration of the soil behind the masonry structure can become an issue that threatens the structural integrity of the culvert (FHWA, 1986).

#### *Alignment*

As the soil around the structure is disturbed by scouring and undermining, alignment of the masonry units within the structure may change. Changes in alignment can be harmful to the overall condition of the structure as additional stress may be applied to the connective mortar between individual masonry units. Shifting caused by localized scour can also result in differential settlement or undermining of the soil beneath the structural footings (AASHTO, 2020; FHWA, 1986). Misalignment of the structure can indicate a threat to the integrity of the structure and parent roadway. Inspectors should note any changes in alignment of the structure or any structural misalignments as these may be an indicator of disruptions in the soil beneath the culvert.

| CONDITION RATING SCALE: MASONRY OR STONE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. |
| 8<br>VERY GOOD | NO CRACKING OR MISSING/DISLOCATED MASONRY PRESENT.<br>MORTAR TIGHT WITH NO DEFECTS.<br>NO SETTLEMENT OR MISALIGNMENT OF STRUCTURE.<br>NO INVERT SCOUR. |
| 7<br>GOOD | SURFACE DETERIORATION OF MASONRY AT ISOLATED LOCATIONS.<br>SHALLOW MORTAR DETERIORATION AT ISOLATED LOCATIONS.<br>MINOR MISALIGNMENT AT JOINTS. NO SETTLEMENT OF STRUCTURE.<br>MINOR INVERT SCOUR. |
| 6<br>SATISFACTORY | MINOR CRACKING OF MASONRY UNITS.<br>MISSING MORTAR AT ISOLATED LOCATIONS. EXTENSIVE AREAS OF SURFACE DETERIORATION.<br>POSSIBLE SIGNS OF INFILTRATION OR EXFILTRATION THROUGH MINOR CRACKS.<br>MINOR MISALIGNMENT OR SETTLEMENT OF STRUCTURE.<br>MINOR SCOUR NEAR FOOTINGS. |
| 5<br>FAIR | MINOR CRACKING. SLIGHT DISLOCATION OF MASONRY UNITS.<br>LARGE AREAS OF SURFACE SCALING.<br>MORTAR GENERALLY DETERIORATED. LOOSE OR MISSING MORTAR AT ISOLATED LOCATIONS.<br>INFILTRATION STAINING PRESENT.<br>MINOR MISALIGNMENT OR SETTLEMENT OF STRUCTURE.<br>MODERATE SCOUR ALONG FOOTING. PROTECTIVE MEASURES MAY BE REQUIRED. |
| 4<br>POOR | SIGNIFICANT DISPLACEMENT OF INDIVIDUAL MASONRY UNITS.<br>MORTAR SEVERELY DETERIORATED/SIGNIFICANT LOSS OF MORTAR.<br>SIGNIFICANT INFILTRATION OR EXFILTRATION BETWEEN MASONRY UNITS.<br>SIGNIFICANT SETTLEMENT AND MISALIGNMENT OF STRUCTURE.<br>SCOUR ALONG FOOTING WITH SLIGHT UNDERMINING. PROTECTION REQUIRED. |
| 3<br>SERIOUS | INDIVIDUAL MASONRY UNITS IN LOWER PART OF STRUCTURE MISSING OR CRUSHED.<br>EXTENSIVE AREAS OF MISSING MORTAR.<br>INFILTRATION OR EXFILTRATION CAUSING MISALIGNMENT OF CULVERT AND SETTLEMENT OR DEPRESSIONS IN ROADWAY.<br>PONDING OF WATER DUE TO SAGGING OR MISALIGNMENT.<br>SEVERE UNDERMINING WITH SLIGHT DIFFERENTIAL SETTLEMENT CAUSING MINOR CRACKING OR SPALLING IN FOOTING AND MINOR DISTRESS IN WALLS. |
| 2<br>CRITICAL | INDIVIDUAL MASONRY UNITS IN UPPER PART OF STRUCTURE MISSING OR CRUSHED.<br>CULVERT NOT FUNCTIONING DUE TO SEVERE MISALIGNMENT.<br>SEVERE UNDERMINING WITH SIGNIFICANT DIFFERENTIAL SETTLEMENT CAUSING SEVERE CRACKS IN FOOTING AND DISTRESS IN WALLS. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

## Other

For structures that do not fall into the previously mentioned categories, a generalized condition rating scale should be used. Inspectors should note in the inspection report that the large culvert structure was evaluated using this scale and provide a brief explanation for why a specific material scale was not applied. This scale is adapted from Item #062 of the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995).

| CONDITION RATING SCALE: OTHER MATERIAL BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. |
| 8<br>VERY GOOD | NO NOTICEABLE OR NOTEWORTHY DEFICIENCIES.<br>MARKS AND SCRAPES MAY BE PRESENT ALONG SURFACE FROM DRIFT. |
| 7<br>GOOD | LIGHT SURFACE DAMAGE THAT DOES NOT IMPACT STRUCTURAL PERFORMANCE.<br>SURFACE DAMAGE CAUSED BY DRIFT THAT DOES NOT REQUIRE CORRECTIVE ACTION.<br>FLEXIBLE CULVERTS HAVE A SMOOTH SYMMETRICAL CURVATURE. |
| 6<br>SATISFACTORY | INTITIAL SIGNS OF DETERIORATION OR DISINTEGRATION ARE STARTING TO APPEAR.<br>FLEXIBLE CULVERTS HAVE A SMOOTH CURVATURE OR NON-SYMMETRICAL SHAPE. |
| 5<br>FAIR | SIGNS OF DETERIORATION OR DISINTEGRATION ARE CLEARLY PRESENT.<br>MINOR SETTLEMENT OR MISALIGNMENT OF STRUCTURE IS OBSERVABLE.<br>FLEXIBLE CULVERTS HAVE SIGNIFICANT DISTORTION AND DEFLECTION IN ONE SECTION. |
| 4<br>POOR | SIGNS OF DETERIORATION ARE BEGINNING TO DISRUPT THE FLOW OF WATER OR PERMIT LOSS OF BACKFILL MATERIAL.<br>CONSIDERABLE SETTLEMENT OR MISALIGNMENT OF STRUCTURE IS OBSERVABLE.<br>FLEXIBLE CULVERTS HAVE SIGNIFICANT DISTORTION AND DEFLECTION THROUGHOUT. |
| 3<br>SERIOUS | UNADDRESSED DETERIORATION HAS CREATED OPENINGS IN STRUCTURE FOR INFILTRATION/EXFILTRATION. LARGE PERFORATIONS MAY EXIST.<br>SEVERE MOVEMENT OR DIFFERENTIAL SETTLEMENT PRESENT ALONG SEGMENTS OF THE STRUCTURE.<br>FLEXIBLE CULVERTS HAVE EXTREME DISTORTION AND DEFLECTION IN ONE SECTION. |
| 2<br>CRITICAL | SECTION OF CULVERT MAY HAVE FAILED OR CANNOT PERFORM INTENDED FUNCTIONS HYDRAULICALLY OR STRUCTURALLY.<br>CORRECTIVE ACTION REQUIRED TO KEEP ROADWAY IN SERVICE.<br>FLEXIBLE CULVERTS HAVE EXTREME DISTORTION AND DEFLECTION THROUGHOUT WITH EXTENSIVE OPENINGS ALLOWING FOR INFILTRATION/EXFILTRATION. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

### B.15.3 End Treatments (Headwall/Wingwall)

End treatments are evaluated using some of the same deterioration markers considered when evaluating the condition of the barrel and inlet/outlet of the structure with the addition of descriptors that consider markers such as rotation or separation from the barrel and embankment. For headwalls and wingwalls, the descriptors used for cracking do not vary significantly from those used for concrete and precast concrete barrels. For other markers considered for concrete and precast concrete barrels, however, the values differ to reflect the specific functions of the components. While headwalls and wingwalls still serve both a structural and hydraulic function, they are used as barriers between the water and the embankment and backfill soil that are needed to guide water toward the culvert opening. The condition rating descriptors for end treatments are based in part on information from the FHWA *Specifications for the National Bridge Inventory* (FHWA, 2022), the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), the ODOT *Conduit Management Manual* (ODOT, 2021), and the FHWA *Culvert Inspection Manual* (FHWA, 1986).

*Cracking*

Limiting values for crack widths range from hairline cracks (0.01 in.) to 0.25 in (AASHTO, 2020; FHWA, 2022; ODOT, 2021). While headwalls and wingwalls are typically positioned in a way that makes them less susceptible to large-scale infiltration from water carried through the channel, these structures are more exposed to environmental elements and runoff from the roadway above than the inside of the culvert barrel (AASHTO, 2020). Furthermore, headwalls and wingwalls retain similar levels of soil behind them when compared to the barrel itself. In this way, the risk of infiltration/exfiltration from the soil is similar to that of the barrel (AASHTO, 2020). Therefore, signs of water infiltration/exfiltration included in the descriptors are the same as those specified for concrete and precast concrete culvert barrels (ODOT, 2021).

*Scaling and Abrasion*

Values for scaling and abrasion are evaluated based on both the depth of individual occurrences as well as the overall area that is affected. These values range from less than 5% to greater than 50% of wall area and depths less than 0.125 in. to depths greater than 0.25 in. (AASHTO, 2020; FHWA, 1986; ODOT, 2021).

Similar to its effect on concrete material in the culvert barrel, scaling and abrasion of the headwalls and wingwalls of a structure reduce the condition of the end treatment by removing the amount of concrete cover that exists for the reinforcing steel. The descriptors based on the surface area affected by scaling and abrasion are somewhat more limiting for end treatments than the descriptors provided in the condition rating scale for concrete barrels. This is in part due to the difference in the level of energy present in the water when it first contacts the surface of the end treatment compared to the inside of the barrel (AASHTO, 2020).

*Delamination and Spalling*

Delamination and spalling in concrete headwalls and wingwalls are evaluated based on the depth and length of visible spalls using tolerances based on the FHWA *Specifications for the National*

*Bridge Inventory* (FHWA, 2022), the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), and the FHWA *Culvert Inspection Manual* (FHWA, 1986). The percentage of the wall area that is affected by delamination and spalling is defined using values based on the ODOT *Conduit Management Manual* (ODOT, 2021). Identification of delamination by visual inspection can be difficult due to the process taking place beneath the concrete surface. To inspect for delamination in locations where deterioration makers are not present, a sounding mallet/hammer should be used to strike the surface of the material to search for hollow-sounding regions (AASHTO, 2020).

*Exposed Steel Reinforcement*

When considering exposure of steel reinforcement in headwalls and wingwalls, descriptors are based on the number of continuous bars exposed, the section loss of the steel reinforcing bars, and the area of the wall with exposed reinforcement. This method of evaluation is based on descriptors found in the ODOT *Conduit Management Manual* (ODOT, 2021). Similar to the barrel, exposure of the steel reinforcement present in the headwall or wingwalls reduces the structural capacity of the component and increases the risk of failure (AASHTO, 2020).

*Rotation and Displacement*

In addition to shared deterioration markers between the barrel and the end treatments, rotation or displacement of the members should be considered during evaluation. Descriptors for rotation and displacement are taken from the ODOT *Conduit Management Manual* (ODOT, 2021). Limits for rotation and/or displacement of end treatments are measured in in./ft. Measurable gaps between the end treatments and the barrel are also considered. Gaps between the barrel and end treatments provide flowing water with alcoves to erode soil and undermine the stability of both the slope of the embankment and the culvert structure. Rotation of the end treatments relative to initial placement may indicate erosion or uneven settlement of the soil surrounding the structure. Continued rotation of these members may indicate that water is finding alternate routes through the soil embankment or otherwise not interacting with the structure as intended (ODOT, 2021).

| CONDITION RATING SCALE: END TREATMENTS | |
|---|---|
| 9<br>EXCELLENT | NO SIGNS OF DISTRESS, DISCOLORATION, OR ROTATION. |
| 8<br>VERY GOOD | HAIRLINE CRACKING (WIDTHS LESS THAN 0.01 IN.) WITHOUT RUST STAINING OR DELAMINATION. NO DAMPNESS, LEAKAGE, OR SPALLING.<br>MINOR SCALING/ABRASION LESS THAN 0.125 IN. DEEP AND ON LESS THAN 5% OF WALL AREA.<br>ROTATION LESS THAN 0.5 IN./FT. |
| 7<br>GOOD | CRACK WIDTHS LESS THAN 0.02 IN. MINOR EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>LIGHT SCALING/ABRASION LESS THAN 0.125-IN. DEEP AND ON LESS THAN 10% OF WALL AREA.<br>DELAMINATED/SPALLED AREA LESS THAN 1% OF WALL AREA.<br>INDIVIDUAL SPALL IS LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP.<br>ROTATION LESS THAN 1 IN./FT. |
| 6<br>SATISFACTORY | HORIZONTAL AND DIAGONAL CRACK WIDTHS LESS THAN 0.0625 IN. EFFLORESCENCE AND/OR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>MODERATE SCALING/ABRASION LESS THAN 0.25-IN. DEEP AND ON LESS THAN 20% OF WALL AREA.<br>DELAMINATED/SPALLED AREAS LESS THAN 10% OF WALL AREA.<br>SPALLED AREAS WITH EXPOSED REINFORCEMENT LESS THAN 5% OF EXPOSED AREA.<br>INDIVIDUAL SPALLS ARE LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP.<br>BARREL PULLING AWAY FROM HEADWALL RESULTING IN LESS THAN 0.5-IN. GAP. |
| 5<br>FAIR | HORIZONTAL AND DIAGONAL CRACK WIDTHS LESS THAN 0.125 IN. EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING PRESENT.<br>SCALING/ABRASION LESS THAN 0.25-IN. DEEP AND ON LESS THAN 30% OF WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 20% OF WALL AREA.<br>SPALLED AREAS WITH EXPOSED REINFORCEMENT LESS THAN 10% OF EXPOSED AREA.<br>INDIVIDUAL SPALLS ARE GREATER THAN 6 IN. IN DIAMETER OR GREATER THAN 1-IN. DEEP.<br>BARREL PULLING AWAY FROM HEADWALL RESULTING IN LESS THAN 1-IN. GAP. |
| 4<br>POOR | SEVERAL HORIZONTAL AND DIAGONAL CRACKS WITH WIDTHS GREATER THAN 0.125 IN. WITH EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING.<br>EXTENSIVE SCALING/ABRASION LESS THAN 0.25-IN. DEEP ON LESS THAN 50% OF WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 25% OF WALL AREA.<br>ADJACENT REINFORCING STEEL BARS ARE EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS IS GREATER THAN 10% OF ORIGINAL DIAMETER.<br>DIFFERENTIAL OR ROTATIONAL SETTLEMENT LESS THAN 2 IN./FT. |
| 3<br>SERIOUS | SEVERAL CRACKS WITH WIDTHS GREATER THAN 0.25 IN. WITH EFFLORESCENCE AND RUST STAINING.<br>MAJOR SCALING/ABRASION GREATER THAN 0.25-IN. DEEP ON MORE THAN 50% OF THE WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 50% OF WALL AREA.<br>MORE THAN 5 ADJACENT REINFORCING STEEL BARS EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS GREATER THAN 20% OF ORIGINAL DIAMETER.<br>SEVERE DIFFERENTIAL OR ROTATIONAL SETTLEMENT LESS THAN 4 IN./FT. |
| 2<br>CRITICAL | TOTAL AREA WITH DELAMINATIONS, SPALLS, MAP CRACKING, AND UNSOUND CONCRETE IS GREATER THAN 50% OF WALL AREA.<br>MORE THAN 10 ADJACENT REINFORCING STEEL BARS EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS GREATER THAN 30% OF ORIGINAL DIAMETER.<br>CRITICAL DIFFERENTIAL OR ROTATIONAL SETTLEMENT GREATER THAN 4 IN./FT. |
| 1<br>IMMINENT<br>FAILURE | PARTIALLY COLLAPSED HEADWALL. |
| 0<br>FAILED | TOTAL FAILURE OF HEADWALL. |

### B.15.4 Channel

Four deterioration markers are considered and described in the condition rating descriptors for the channel. These markers include channel protection, channel bank erosion, embankment erosion, and drift/settlement. The condition rating descriptors provided are based on the channel condition rating descriptors present in the FHWA *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) with updates made using portions of the descriptors found in the ORITE *Risk Assessment and Update of Inspection Procedures for Culverts* (Mitchell et al., 2005). The modifications to descriptors and wording allow the scale to better correspond to small waterways as opposed to rivers.

*Channel Protection*

Channel protection encompasses both natural and artificial forms of energy dissipaters that may be present in the channel to control scour and erosion. Inspectors should evaluate the condition of these energy dissipaters and whether they are sufficient for the channel as expressed in the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995). During evaluation of the channel protectors, inspectors should check to see if widespread erosion or undercutting is present along the channel leading to and from the openings of the structure to determine sufficiency.

*Channel Bank Erosion*

Descriptors for channel bank erosion consider the walls of the channel that guide the waterway toward the large culvert structure as described in the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995). In areas where the waterway abruptly changes direction while approaching or departing from the culvert structure, inspectors should evaluate the surrounding banks to identify any erosion or undercutting that may be occurring. If erosion or undercutting is occurring, inspectors should note that channel protection should be increased in these locations to help preserve the state of the channel.

*Embankment Erosion*

Descriptors for embankment erosion consider the condition of the end treatment protection and the soil surrounding the opening of the large culvert structure as required in the condition rating descriptors of the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995). Inspectors should note damage to the embankment or end treatments of the structure if it is caused primarily by the channel or lack of channel protection near the culvert opening.

*Drift/Settlement*

Descriptors for drift/settlement within the channel consider the accumulation of deposits and debris as well as large buoyant materials not naturally found in streams and waterbeds. As drift and sediment accumulate in the channel bed, the water stream may split into separate flows around areas of large deposit, resulting in an alteration of the direction of flow in the channel (ODOT, 2021). Modifications to the condition rating descriptors found in the FHWA *Recording* *and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) to include more detailed condition states for drift and settlement are based on descriptors provided by Mitchell et al. (2005).

| CONDITION RATING SCALE: CHANNEL | |
|---|---|
| N<br>NOT APPLICABLE | CULVERT DOES NOT INTERSECT WITH A WATERWAY OR CHANNEL. |
| 9<br>EXCELLENT | NO NOTICEABLE DEFICIENCIES PRESENT. |
| 8<br>VERY GOOD | CHANNEL BANKS ARE WELL VEGETATED.<br>INSTALLED PROTECTION AND EMBANKMENT PROTECTION ARE SUFFICIENT FOR CHANNEL FLOW. |
| 7<br>GOOD | CHANNEL BANK PROTECTION IS IN NEED OF MINOR REPAIRS.<br>MINOR DAMAGE IS PRESENT IN ISOLATED AREAS OF INSTALLED PROTECTION AND EMBANKMENT PROTECTION.<br>BANKS AND/OR CHANNEL HAVE MINOR AMOUNTS OF DRIFT.<br>SEDIMENT BUILDUP IN CHANNEL IS BEGINNING TO ALTER FLOW. |
| 6<br>SATISFACTORY | CHANNEL BANK IS BEGINNING TO SLUMP.<br>MINOR DAMAGE IS WIDESPREAD ALONG INSTALLED PROTECTION AND EMBANKMENT PROTECTION.<br>DEBRIS BUILDUP IS BEGINNING TO SPLIT THE CHANNEL INTO SEPARATE FLOWS UPSTREAM OF CULVERT. |
| 5<br>FAIR | CHANNEL BANK PROTECTION IS BEING ERODED.<br>MAJOR DAMAGE IS PRESENT IN INSTALLED AND/OR EMBANKMENT PROTECTION.<br>CHANNEL FLOW IS CONTACTING EMBANKMENT OUTSIDE OF HEADWALLS/WINGWALLS.<br>TREES AND BRUSH RESTRICT CHANNEL FLOW. |
| 4<br>POOR | CHANNEL BANK AND/OR EMBANKMENT PROTECTION IS SEVERELY UNDERMINED. EROSION HAS BEGUN ALONG EMBANKMENT.<br>CHANNEL FLOW HAS EXPOSED PREVIOUSLY COVERED FOOTING OF CULVERT.<br>FLOW ENTERS PIPE THROUGH MEANS OTHER THAN THE DESIGNED OPENING.<br>LARGE DEPOSITS OF DEBRIS HAVE CHANGED CHANNEL ALIGNMENT TO IMPACT EMBANKMENT DIRECTLY. |
| 3<br>SERIOUS | CHANNEL BANK PROTECTION HAS FAILED AND/OR INSTALLED PROTECTION HAS BEEN DESTROYED.<br>EMBANKMENT EROSION CONTINUES TO OCCUR, APPROACHING ROADWAY.<br>EMBANKMENT MATERIAL LOCATED BEHIND HEADWALL/WINGWALL IS BEGINNING TO ERODE.<br>STREAMBED AGGRADATION, DEGRADATION, OR LATERAL MOVEMENT HAS CHANGED THE CHANNEL ALIGNMENT TO NOW THREATEN THE CULVERT AND/OR APPROACH ROADWAY. |
| 2<br>CRITICAL | CHANNEL FLOW IS PIPING AROUND CULVERT OR INSTALLED PROTECTION.<br>EMBANKMENT EROSION HAS REACHED ROADWAY SURFACE.<br>CHANNEL HAS CHANGED TO THE EXTENT THE CULVERT IS NEAR A STATE OF COLLAPSE. |
| 1<br>IMMINENT FAILURE | CULVERT CLOSED BECAUSE OF CHANNEL FAILURE.<br>MAJORITY OF CHANNEL FLOW CIRCUMNAVIGATES CULVERT.<br>CORRECTIVE ACTION MAY ALLOW CULVERT TO BE PUT BACK INTO LIGHT SERVICE. |
| 0<br>FAILED | CULVERT CLOSED BECAUSE OF CHANNEL OR STRUCTURE FAILURE.<br>REPLACEMENT NECESSARY. |

## B.16 Minor Components

Components assigned minor scales play a more indirect role in the functional performance of a culvert structure. The minor components encompass parts of a culvert that may be considered less critical but that still affect the function of the culvert over time. Considering the role of the minor components, fewer values are needed to describe the current state of the component. In combination with other components, these minor components can help identify if there is a structural or hydraulic underperformance that is impacting the rate of deterioration.

Components that are assigned minor scales include:

- Roadway
- Embankment
- Joints and Seams
- Footings and Anchors
- Channel Alignment
- Scour Presence
- Waterway Blockage

The condition rating descriptors for the minor scales are based in part on information from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020).

### B.16.1 Roadway

The roadway above a large culvert structure can provide insight into how the soil envelope surrounding the structure is performing (AASHTO, 2020). This information is important as direct assessment of the condition of the backfill soil around the structure is not feasible during a visual inspection. When evaluating the roadway, the portion of the roadway that should be considered extends a length of two times the culvert span measured in both directions from the centerline of the culvert. According to the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020), deterioration markers such as narrow cracks, depressions, or indentations may indicate that soil has shifted around the structure. The shifting of soil can result in unequal forces being applied to the culvert profile and can impact its structural capacity (AASHTO, 2020). The shifting of the soil below may also create voids between the roadway and the soil surrounding the structure. Over time, these voids will create openings in the roadway that can allow for water to infiltrate the soil envelope and compromise the integrity of the structure and roadway (AASHTO, 2020).

The following descriptors are used to assign a condition rating to the roadway.

| Rating | Descriptor |
|---|---|
| Good | Roadway does not show any signs of distress. |
| Fair | Roadway has narrow cracks, sags, and/or humps above culvert indicating displacement of soil below. |
| Poor | Roadway has wide cracks and/or openings that reveal a void beneath roadway. |

### B.16.2 Embankment

The embankment is responsible for housing the culvert structure and creating a path for runoff to traverse from the roadway down to the waterway below. Like the roadway, the observable embankment on either end of a culvert structure can provide insight into the performance of the soil envelope surrounding the structure. Surface markers such as ruts and gullies along the slope of the embankment are evidence of erosion that should be noted (AASHTO, 2020). During piping, the waterway begins to circumnavigate the structure opening by flowing through the soil around the perimeter of the structure (AASHTO, 2020). As it continually moves through the soil, it begins to erode the soil, creating a void between the structure and the surrounding soil. This process can allow for dislodging of the culvert structure from its current position if not properly anchored (AASHTO, 2020).

Another important marker is the slope stability. Erosion and large cracking in the soil along the slope of the embankment may indicate that the soil along the slope is moving during periods of rainfall (AASHTO, 2020). As the slope continues to erode, large sheets of soil may become displaced in a single movement, risking the structural stability of the roadway above (AASHTO, 2020).

The following descriptors capture these processes and are used to assign a condition rating to the embankment based on the severity of the deterioration.

| Rating | Descriptor |
|---|---|
| Good | Embankment slope shows no signs of erosion or backfill displacement. |
| Fair | Minor depressions of soil are observable along embankment slope. Beginning stages of piping or evidence of backfill displacement may also be present. |
| Poor | Evidence of water infiltration by piping or large depressions above the culvert structure are present. Large surface soil cracks, sheet movement of soil, or other signs that indicate slope instability are present. |

### B.16.3 Joints and Seams

The joints and seams present along the interior of a culvert structure play an important role in keeping water from exfiltrating the culvert before reaching the outlet as well as keeping surrounding soil from infiltrating the structure (AASHTO, 2020). For flexible culverts, the integrity of the joints and seams of the structure help to provide continuity of shape along the length of the culvert. Damage to the fasteners or the separation of the structure at a joint or seam has the potential to jeopardize the stability of the roadway above.

In concrete structures, markers such as cracks and spalls that originate at a joint can indicate an unequal distribution of force caused by the surrounding soil envelope. Over time, these cracks and spalls can produce an opening that is large enough for water and soil to move through, allowing for undesired infiltration/exfiltration that may compromise the integrity of the soil envelope encasing the structure (AASHTO, 2020).

In metal structures, connections between sections of material are often accomplished by overlapping the ends and using fasteners. As water interacts with these fasteners and the corrosion process begins, rust can begin to build up between the overlapping sections. As the rust continues to build up in these locations, the pressure exerted can be great enough that it damages or dislodges the fastener. As fasteners are dislodged or damaged, the seal formed by the fasteners and the overlapping regions of the material will loosen and can allow for water exfiltration and soil infiltration. As the soil around the structure begins to shift, the forces applied by the soil envelope can become uneven and cause shape deformation in the structure (AASHTO, 2020; FHWA, 1986).

Two versions of the scale for joints and seams are provided as follows. The descriptors are used to assign a condition rating based on the material type of the structure.

**Concrete and Precast Concrete Structures**

| Rating | Descriptor |
|---|---|
| Good | No cracks emanating or extending from joints. No separation or gaps between sections present. |
| Fair | Cracks emanating from joints are present in structure. Small gaps between sections are present. Evidence of small amounts of water infiltration, but no voids are present in the soil envelope. |
| Poor | Cracks have created spalls that reveal reinforcement at joints/seams. Separation of sections allows for soil infiltration and has created voids in soil envelope. |

**Metal Structures**

| Rating | Descriptor |
|---|---|
| Good | No missing/broken fasteners. No separation or gaps between sections present. |
| Fair | Some missing fasteners at joints/seams. Small gaps between sections are present. Evidence of small amounts of water infiltration, but no voids are present in the soil envelope. |
| Poor | Missing fasteners allow shape deformation at seams/joints. Separation of sections allows for soil infiltration and has created voids in soil envelope. |

### B.16.4 Footings and Anchors

Footings and anchors play a vital role in stabilizing and grounding large culvert structures. For rigid culverts, footings should evenly support the structure and should not be undermined by the water channel or experience differential settlement as these actions can compromise the structural integrity of the large culvert (AASHTO, 2020). For flexible culverts, anchors are commonly used to prevent the buoyant force exerted at the opening of the structure by the waterway from lifting the structure. If the anchors for a flexible culvert are damaged, the buoyant forces exerted can result in an upward vertical deflection of the inlet of the culvert that prevents the channel from crossing the roadway as originally intended (AASHTO, 2020).

| Rating | Descriptor |
|---|---|
| Good | No differential settlement. Only hairline cracking. No abrasion or delamination/spalling present. No noticeable scour or undermining threatens the soil supporting the footings/anchors. |
| Fair | Only minor differential settlement with no vertical offset at cracks. Crack widths less than 0.1 in. without exposed reinforcement. Scaling/abrasion less than 0.25 in. in depth. Local spalls less than 6 in. in diameter without exposed reinforcement. Scour has exposed covered footing/anchor. No undermining or rotation/displacement. |
| Poor | Excessive differential settlement or vertical offset at cracks greater than 0.25 in. Crack widths greater than 0.1 in. or with exposed reinforcement. Widespread exposure of aggregate from scaling/abrasion. Spalls greater than 6 in. in diameter or revealing reinforcement. Scour has created undermining or has exposed large portion of anchor or vertical face of covered footing. Rotation of the footing or displacement of anchor has occurred. |

### B.16.5 Channel Alignment

Channel alignment is an important factor to consider when evaluating a culvert structure because the angle at which a waterway approaches can cause uneven wear of both the structure and the surrounding soil. Uneven wear within the opening of a culvert structure can reduce the expected lifespan by accelerating the rate at which material along one side of the structure deteriorates. When designing culverts where the channel is expected to enter the structure at an angle, modifications can be made to account for the expected uneven wearing through placement of energy dissipaters in the channel bed surrounding the structure opening (AASHTO, 2020).

When considering the surrounding soil, changes in channel angle when approaching the opening of a culvert can result in the dissipation of channel speed and energy at the expense of channel banks and the embankment that holds the culvert structure. As flowing water repeatedly contacts these surfaces before being redirected towards the opening of the culvert, these components can begin to erode (AASHTO, 2020). This erosion process will continue until a slope failure occurs along the contacted surface. Over time, the continual erosion of the embankment can create pockets of empty space along the outside of the culvert structure, promoting piping and soil erosion along the length of the structure.

The following descriptors are used to assign a condition rating based on channel alignment and are based in part on information from the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020) and the Ohio *Conduit Management Manual* (ODOT, 2021).

| Rating | Descriptor |
|---|---|
| Good | Channel approach appears to be as originally designed with no interruptions. |
| Fair | Channel approaches culvert at an angle different from original design. |
| Poor | Angle at which channel approaches culvert is causing erosion along the channel or damage at the entrance of the structure. |

### B.16.6 Scour Presence

The presence of scour at the inlet or outlet of a culvert structure should be monitored using a range rod as it can be difficult to visually inspect for scour in murky or deep channels. Scour can lead to differential movement of the structure or removal of anchorage for flexible culverts resulting in buoyant forces lifting the inlet of the culvert structure above the waterline (AASHTO, 2020). Deep scour along the outlet should also be monitored as removal of material supporting the outlet can result in a loss of structural integrity of the end section.

The following descriptors are used to assign a condition rating based on the presence of scour. In addition to assigning a rating, the observed maximum depth of scour at the inlet and outlet of the structure should be recorded during the inspection.

| Rating | Descriptor |
|---|---|
| Good | No scour presence along inlet or outlet of structure. |
| Fair | Scour presence along inlet and/or outlet is observable but does not threaten structural stability of culvert. |
| Poor | Presence of scour has revealed vertical face of previously buried footings and/or threatens structural stability of culvert. |

### B.16.7 Waterway Blockage

Waterway blockage can occur over time in channels that carry high levels of sediment or after heavy rainfall due to floating debris that can become trapped along the opening of a large culvert structure. While some sediment buildup is natural in culvert structures based on the channel properties, the resulting effects of excessive opening constriction from sediment deposits can reduce the effectiveness of the structure and create the risk of significant damage (AASHTO, 2020). The descriptors provided for waterway blockage are based on the percentage of the culvert diameter affected by the blockage. These percentage values are adopted from descriptors provided in the AASHTO *Culvert and Storm Drain System Inspection Guide* (AASHTO, 2020). Sediment buildup less than 10% of the height of the structure is typically considered to have negligible effects on a normal flow, while sediment buildup ranging between 10% and 30% of the height of the structure can force water to flow faster. Buildup over 30% of the height of the structure can be dangerous for the structure and parent roadway in the case of heavy rainfall.

Waterway blockage is a significant concern for large culvert structures because as the opening for a waterway becomes restricted, water must flow faster to move the same volume through a smaller opening. Faster flowing water carries more energy and can cause local scouring at both the inlet and outlet of a structure (AASHTO, 2020). As the culvert opening continues to narrow from blockage, water from the upstream channel may find other routes around the blockage that result in erosion of the embankment. If the opening becomes completely blocked, the water level upstream of the structure will begin to rise and create a large pressure head. The uniformly applied force from the increasing water pressure head can be strong enough to dislodge culvert structures from the surrounding soil envelope, resulting in a culvert failure and a closed roadway.

Another situation that can be a concern for culvert structures is complete submergence of the culvert barrel. This scenario can occur for structures that are used to regulate water levels in adjacent fields that regularly flood and structures where the surrounding landscape has changed since initial design. When these structures are filled with water, visual inspection of the interior of the culvert barrel is not possible without remote-controlled equipment or a confined space permit and proper equipment. Evaluation of the exterior components of a submerged culvert can still provide information about the performance and condition of the culvert, allowing for an inspection to occur, but a culvert that is habitually submerged should be inspected using specialized equipment to properly assess its condition (AASHTO, 2020).

The following descriptors are used to assess the waterway based on the level of sediment buildup/water level that is observed.

| Rating | Descriptor |
|---|---|
| Open (Good) | Waterway is open and flow of water into and out of structure is uninterrupted. Debris accumulation is less than 10% of diameter. |
| Partially Blocked (Fair) | Culvert is partially blocked, restricting waterflow due to debris or sediment deposit. Debris accumulation is between 10% and 30% of diameter. |
| Submerged or Blocked (Poor) | Culvert is submerged or blocked, resulting in water retention outside of structure. Debris accumulation is more than 30% of diameter. |

## B.17 Visual Scales

Visual condition rating scales were developed to aid inspectors in the evaluation of metal and concrete barrels of large culvert structures. The visual scales represent examples of conditions and deterioration markers corresponding to condition rating values of 2 through 9 with the assumption that a structure that qualifies for a rating of 0 or 1 will be easily identified due to the failure of the culvert structure.

These visual scales consist of images collected from previous inspection reports from culvert structures in the INDOT large culvert inventory stored in BIAS. Photos showcase the common deterioration markers described in the condition rating scales for concrete/precast concrete and metal culvert barrels.

## APPENDIX B. PROPOSED INDOT LARGE CULVERT INSPECTION MANUAL—PART 3: INSPECTION FORMS AND CONDITION RATING SCALES

### B.18 Equipment List

General Use Equipment

| Equipment | Description |
|---|---|
| Digital Camera | A camera should be used to gather visual documentation of culvert condition during an inspection. |
| pH Measuring Tools/Strips | The pH meter can be used to gather information about the acidity of the water present in the inlet and outlet of a culvert structure. |
| GPS-Capable Device | GPS-capable devices should be carried with inspectors to collect accurate location data of culverts for inventory purposes. |
| Headlamp/Helmet Light | A headlamp can be used for visual assessment of the interior condition of a culvert structure when natural light is not available. |
| High-Powered Flashlight | A high-powered flashlight can be used to provide a light source where natural light is not available to assess the interior condition of a culvert structure. |
| Inspection Vehicle | An inspection vehicle is used to travel to culvert locations as well as to store equipment for culvert inspections. |
| Large Culvert Inspection Manual | The INDOT Large Culvert Inspection Manual should be readily available either in physical or digital form for easy reference when evaluating large culvert structures. |
| Permanent Markers | Permanent markers can be used to make a marking on the culvert surface for documentation purposes and direct attention to specific locations within a culvert. |
| Radio/Walkie-Talkie | A radio or walkie-talkie should be used to allow for communication between inspectors when separated. |
| Range Rod | A range rod can be used for maneuvering down slopes and through culverts. The rod can also be used as a reference in photos as well as for estimating fill heights and scour depths in the field. Markings on the rod should be at 1-ft increments. |
| Tape Measure (25 ft minimum) | A tape measure can be used to collect culvert structure measurements such as opening lengths/diameters in the horizontal and vertical directions as well as lengths and widths of noted defects within the culvert structure. |

Safety Equipment

| Equipment | Description |
|---|---|
| Compressed Gas Air Horn | A compressed gas air horn should be carried during inspections to draw attention in case of an emergency. |
| First Aid Kit (Portable) | A portable first aid kit should be stored in a designated compartment of the high-visibility backpack to provide basic first aid while in the field. |
| First Aid Kit (Stationary) | A stationary first aid kit should always be kept in an easily accessible location of each inspection vehicle to provide basic first aid while in the field. |
| High-Visibility Backpack | A high-visibility backpack should be used to store necessary inspection equipment to keep inspectors' hands free for maneuvering slopes to gain access to culvert inlets and outlets for inspection. |
| Insect/Wasp/Tick Repellant | Spray repellants should always be applied when in the field to protect inspectors from wasps, ticks, and other insects. |
| PPE (Hardhat, Safety Glasses, Gloves, Hi-Vis Vest, Steel-Toe Boots, Dust Masks) | PPE should always be worn when inspectors and accompanying parties are in the field or along roadways for any reason. |
| Snake Gaiters | Snake Gaiters should always be worn as protection when moving through high brush or locations where evidence of snakes is present. |

Entry Equipment

| Equipment | Description |
|---|---|
| Brush/Overgrowth Clearing Tool | Brush clearing tools can be used by inspectors to create a navigable path to the inlet/outlet of a culvert for inspection. |
| Hip Waders/Waterproof Boots | Hip waders should always be worn when navigating through wet areas to assess culvert conditions. |
| Personal Air Monitors | Personal air monitors should be carried by an inspector when entering confined spaces to monitor for potential changes in air quality. |
| Rope and Carabiners | A rope and carabiners can be used to lower tools down steep grades. The rope can also be used to provide inspectors with an anchor point when determining if sediment in the culvert is stable enough to walk on. |

Assessment Equipment

| Equipment | Description |
|---|---|
| Calipers | Calipers can be used to measure the thickness of metal pipe walls. This measurement can be used to gauge the deterioration of metal culverts. |
| Carpenter's Level | A carpenters level can be used to measure the slope of a culvert and its components. |
| Crack Comparator Card | A crack width gauge can be used for precise measurements of the size of cracks and other defects present in concrete culverts. |
| Flathead Screwdriver | A flathead screwdriver can be used for removal of debris and corrosion in grooves and corners to better assess materials. It can also be used as a probe to check for scour holes and voids behind joints. |
| Scraper | A scraper can be used to remove corrosion and growth from the surface of the structure so that assessment of the material below can be conducted. |
| Shovel | A shovel can be used to uncover portions of a culvert when visual inspection is deemed necessary by the inspector. |
| Sounding Mallet/Hammer | A sounding mallet can be used to check for voids behind culvert walls or for delaminations in concrete. Based on the sound returned from making contact with the structure, inspectors should be able to recognize if voids are present. |
| Wire Brush | A wire brush can be used to remove layers of rust in steel culverts or efflorescent mass in concrete culverts to assess the condition of the surface beneath. |

## B.19 Entry Classification Conditions

| |
|---|
| **No Entry** – Culverts with the following conditions/hazards will not be entered |
| ○ Any culvert with a diameter/opening size of 36″ or less.<br>○ Any size culvert with rushing water such that entry is difficult or impossible due to effort and or footing.<br>○ Culvert with debris dams that can cause a potentially substantial release of water.<br>○ Culverts where the entry is being performed because of a suspected failure in the integrity of the structure, a Licensed Engineer will verify that the culvert is safe for entry. |
| **Permit Required** – Culverts with the following conditions will require permit confined space entry procedures to be met. |
| ○ Blockage or Grade/elevation change (obstructed line of sight through culvert). If blockage is holding back water, see No Entry guidelines.<br>○ Culvert length that prevents unassisted voice contact from being maintained between inspectors.<br>○ Lack of air flow. No breeze detected at opening.<br>○ Any culvert with standing water greater than 25% of the culvert height.<br>○ Any culvert that requires entry via a manhole.<br>○ Any culvert with a diameter/opening size that requires employees to crawl to maneuver within the space.<br>○ Any culvert that is part of a sanitary sewer system. |
| **Non-Permit Required** – Culverts where none of the above conditions are present may be considered non-permit required for entry purposes but must be examined for other potential hazards |
| ○ Entry should not be made without on-site presence of at least one inspector outside the culvert.<br>○ Entrants should have personal air monitors to assess potential changes in air quality.<br>○ At least one entrant should have available an audible signal/alarm device in case of emergency, for example, canned compressed air alarm.<br>○ When water is above ankle height, boots or waders should be worn. Waders and boots with toe protection may be required. Water depth and current should be considered for all entries. Additional dry clothing is desirable.<br>○ Ice poses special hazards of slippery conditions and/or falling objects and should be considered an important risk factor.<br>○ Assess entry areas for potential hazardous plants (i.e., poison ivy).<br>○ Culverts may contain potentially dangerous animals.<br>○ Large culverts may contain debris from homeless encampments and/or drug use paraphernalia. |

**Additional Procedures:**

- All confined space equipment should be on site during all culvert inspections and available for use as needed.
- Each employee entering a confined space should have completed the Confined Space Training prior to entry.
- For permit required entries, notify rescue services and or have rescue services on site before entering the confined space and or contract the work out to vendor/contractor.

## B.20 Inventory Data Collection – Counties and Subdistricts

# INDOT COUNTY NUMBERS AND COUNTY NAMES

| Code | County | Code | County | Code | County | Code | County |
|---|---|---|---|---|---|---|---|
| 1 | Adams | 24 | Franklin | 47 | Lawrence | 70 | Rush |
| 2 | Allen | 25 | Fulton | 48 | Madison | 71 | St. Joseph |
| 3 | Bartholomew | 26 | Gibson | 49 | Marion | 72 | Scott |
| 4 | Benton | 27 | Grant | 50 | Marshall | 73 | Shelby |
| 5 | Blackford | 28 | Greene | 51 | Martin | 74 | Spencer |
| 6 | Boone | 29 | Hamilton | 52 | Miami | 75 | Starke |
| 7 | Brown | 30 | Hancock | 53 | Monroe | 76 | Steuben |
| 8 | Carroll | 31 | Harrison | 54 | Montgomery | 77 | Sullivan |
| 9 | Cass | 32 | Hendricks | 55 | Morgan | 78 | Switzerland |
| 10 | Clark | 33 | Henry | 56 | Newton | 79 | Tippecanoe |
| 11 | Clay | 34 | Howard | 57 | Noble | 80 | Tipton |
| 12 | Clinton | 35 | Huntington | 58 | Ohio | 81 | Union |
| 13 | Crawford | 36 | Jackson | 59 | Orange | 82 | Vanderburgh |
| 14 | Daviess | 37 | Jasper | 60 | Owen | 83 | Vermillion |
| 15 | Dearborn | 38 | Jay | 61 | Parke | 84 | Vigo |
| 16 | Decatur | 39 | Jefferson | 62 | Perry | 85 | Wabash |
| 17 | DeKalb | 40 | Jennings | 63 | Pike | 86 | Warren |
| 18 | Delaware | 41 | Johnson | 64 | Porter | 87 | Warrick |
| 19 | Dubois | 42 | Knox | 65 | Posey | 88 | Washington |
| 20 | Elkhart | 43 | Kosciusko | 66 | Pulaski | 89 | Wayne |
| 21 | Fayette | 44 | LaGrange | 67 | Putnam | 90 | Wells |
| 22 | Floyd | 45 | Lake | 68 | Randolph | 91 | White |
| 23 | Fountain | 46 | LaPorte | 69 | Ripley | 92 | Whitley |

# INDOT SUBDISTRICT NUMBERS AND SUBDISTRICT NAMES

| CRAWFORDSVILLE DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 1000 | Unassigned Sub |
| 1100 | Terre Haute |
| 1200 | Crawfordsville |
| 1300 | West Lafayette |
| 1400 | Frankfort |
| 1500 | Cloverdale |

| GREENFIELD DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 3000 | Unassigned Sub |
| 3100 | Indianapolis |
| 3200 | Greenfield |
| 3300 | Cambridge City |
| 3500 | Tipton |
| 3600 | Albany |

| SEYMOUR DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 5000 | Unassigned Sub |
| 5100 | Aurora |
| 5200 | Bloomington |
| 5300 | Columbus |
| 5400 | Falls City |
| 5500 | Madison |

| FORT WAYNE DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 2000 | Unassigned Sub |
| 2200 | Elkhart |
| 2300 | Fort Wayne |
| 2500 | Wabash |
| 2600 | Bluffton |

| LAPORTE DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 4000 | Unassigned Sub |
| 4100 | Laporte |
| 4200 | Monticello |
| 4300 | Plymouth |
| 4400 | Rensselaer |
| 4700 | Gary |

| VINCENNES DISTRICT | |
|---|---|
| **Code** | **Subdistrict** |
| 6000 | Unassigned Sub |
| 6100 | Linton |
| 6300 | Evansville |
| 6400 | Paoli |
| 6500 | Tell City |
| 6600 | Vincennes |

## B.21 Field Inspection Form

### Evaluation and Condition Rating

#### Above Structure

Roadway Approach ☐ Good ☐ Fair ☐ Poor

Embankment ☐ Good ☐ Fair ☐ Poor

(36A) Bridge Railing ☐ Yes ☐ No (36C) Approach Guardrail ☐ Yes ☐ No

(36B) Transitions ☐ Yes ☐ No (36D) Approach Guardrail Ends ☐ Yes ☐ No

Above Structure Comments:

#### Culvert Structure

Barrel/Box Condition ______ Inlet/Outlet ______

Culvert Rating Comments:

Headwall ______ Wingwalls ______

Footing/Anchor ☐ Good ☐ Fair ☐ Poor

Head/Wingwall & Footing/Anchor Comments:

Joints/Seams ☐ Good ☐ Fair ☐ Poor

Joint/Seam Comments:

#### Channel Condition

Channel Condition ______

Channel Alignment ☐ Good ☐ Fair ☐ Poor

Scour Presence ☐ Good ☐ Fair ☐ Poor Max. Depth of Scour ______ in ☐ Inlet ☐ Outlet

Waterway Adequacy ☐ Open ☐ Partially Blocked ☐ Blocked or Submerged Estimated % of Culvert Blocked ______

Below Structure Comments:

## B.22 Major Condition Rating Scales

| CONDITION RATING SCALE: CONCRETE AND PRECAST CONCRETE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. ISOLATED DAMAGE FROM INSTALLATION MAY BE PRESENT. |
| 8<br>VERY GOOD | HAIRLINE CRACKING (WIDTHS LESS THAN 0.01 IN.) WITHOUT EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING.<br>NO DETERIORATION FROM SCALING OR ABRASION.<br>NO SPALLING OR DELAMINATIONS. |
| 7<br>GOOD | CRACK WIDTHS LESS THAN 0.02 IN. MINOR EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>SCALING/ABRASION LESS THAN 0.125-IN. DEEP COVERING LESS THAN 10% OF SURFACE AREA.<br>DELAMINATED OR SPALLED AREA LESS THAN 1% OF SURFACE AREA.<br>SINGLE INDIVIDUAL SPALL IS LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
| 6<br>SATISFACTORY | CRACK WIDTHS LESS THAN 0.0625 IN. EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>SPACING OF CRACKS TRANSVERSE TO TRAFFIC 3 FT OR GREATER.<br>SCALING/ABRASION LESS THAN 0.25-IN. DEEP COVERING LESS THAN 20% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 5% OF SURFACE AREA.<br>INDIVIDUAL SPALLS ARE LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
| 5<br>FAIR | CRACKS WIDTHS LESS THAN 0.125 IN. PARALLEL TO TRAFFIC OR LESS THAN 0.0625 IN. TRANSVERSE TO TRAFFIC. EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING PRESENT.<br>SCALING/ABRASION GREATER THAN 0.25-IN. DEEP COVERING LESS THAN 30% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 15% OF SURFACE AREA.<br>SPALLING HAS EXPOSED REINFORCING STEEL.<br>INDIVIDUAL SPALLS ARE GREATER THAN 6 IN. IN DIAMETER OR GREATER THAN 1-IN. DEEP. |
| 4<br>POOR | EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.125 IN.<br>SPACING OF CRACKS TRANSVERSE TO TRAFFIC BETWEEN 1 FT AND 3 FT.<br>SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING LESS THAN 50% OF SURFACE AREA.<br>TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 25% OF SURFACE AREA.<br>SPALLING HAS EXPOSED CORRODED REINFORCING STEEL. |
| 3<br>SERIOUS | SOFT CONCRETE.<br>EXTENSIVE CRACKING WITH CRACK WIDTHS LESS THAN 0.25 IN.<br>DIFFERENTIAL MOVEMENT AT CRACK(S).<br>SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING GREATER THAN 50% OF SURFACE AREA.<br>LESS THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED.<br>SPALLING HAS EXPOSED MUCH OF THE PERIMETER OF REINFORCING BARS. |
| 2<br>CRITICAL | CONCRETE COMPLETELY DETERIORATED IN ISOLATED LOCATIONS CREATING THROUGH-DEPTH HOLES.<br>EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.25 IN.<br>SEVERE DIFFERENTIAL MOVEMENT AT CRACK(S).<br>GREATER THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED.<br>SPALLED AREAS WITH EXPOSED REINFORCING STEEL COVER APPROXIMATELY 25% OF SURFACE AREA.<br>REINFORCING BAR PERIMETER IS COMPLETELY EXPOSED AND BARS EXHIBIT EXTENSIVE SECTION LOSS. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

| CONDITION RATING SCALE: METAL PIPE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. CULVERT RETAINS ORIGINAL SHAPE. |
| 8<br>VERY GOOD | DISCOLORATION OF SURFACE. PROTECTION PARTIALLY GONE ALONG INVERT BUT NO LAYERS OF RUST. |
| 7<br>GOOD | PROTECTION GONE ALONG INVERT. FRECKLED RUST PRESENT.<br>CULVERT RETAINS A SMOOTH SYMMETRICAL CURVATURE.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITHOUT WALL PENETRATION. |
| 6<br>SATISFACTORY | PROTECTION GONE ALONG INVERT. LAYERS OF RUST THROUGHOUT.<br>MODERATE SECTION LOSS LESS THAN 6 $IN.^2/FT^2$ OR 4% OF INVERT AREA.<br>CULVERT RETAINS SMOOTH CURVATURE BUT NON-SYMMETRICAL SHAPE.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 5% LOSS OF ORIGINAL DIAMETER. |
| 5<br>FAIR | HEAVY RUST AND SCALING THROUGHOUT.<br>HEAVY SECTION LOSS: LESS THAN 15 $IN.^2/FT^2$ OR 10% OF INVERT AREA.<br>TOP HALF OF CULVERT RETAINS SMOOTH CURVATURE. MINOR BULGES OR FLATTENING PRESENT IN BOTTOM OF PIPE.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 4<br>POOR | EXTENSIVE RUST AND SCALING THROUGHOUT.<br>MINOR PERFORATIONS/HOLES THROUGHOUT INVERT.<br>MINOR PERFORATION/HOLE AREA LESS THAN 30 $IN.^2/FT^2$ OR 20% OF INVERT AREA.<br>CULVERT HAS SHARP POINTS OR TURNS PRESENT ALONG CURVATURE DUE TO FLATTENING.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 15% LOSS OF ORIGINAL DIAMETER.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION BUT NO SIGNS OF SOIL INFILTRATION. |
| 3<br>SERIOUS | EXTENSIVE RUST AND SCALING THROUGHOUT.<br>MODERATE PERFORATIONS/HOLES LESS THAN 36 $IN.^2/FT^2$ OR 25% OF INVERT AREA.<br>CULVERT HAS EXTREME DISTORTION IN ONE SECTION OF PIPE. LOCAL AREAS OF REVERSED CURVATURE MAY BE PRESENT.<br>MEASURED VERTICAL DEFORMATIONS RESULTING IN GREATER THAN 15% LOSS OF ORIGINAL DIAMETER. |
| 2<br>CRITICAL | MAJOR PERFORATIONS/HOLES GREATER THAN 36 $IN.^2/FT^2$ OR GREATER THAN 25% OF INVERT AREA.<br>CULVERT HAS EXTREME DISTORTION IN MULTIPLE SECTIONS OF PIPE.<br>IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION ALLOWING SOIL ENVELOPE TO INFILTRATE PIPE. |
| 1<br>IMMINENT<br>FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

| CONDITION RATING SCALE: PLASTIC PIPE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. CULVERT RETAINS ORIGINAL SHAPE. |
| 8<br>VERY GOOD | MINOR DISCOLORATION PRESENT IN ISOLATED LOCATIONS.<br>ISOLATED RIP OR TEAR LESS THAN 6 IN. IN LENGTH CAUSED BY FLOATING DEBRIS OR CONSTRUCTION. |
| 7<br>GOOD | SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH LESS THAN 0.25 IN. ALONG SPLIT.<br>CUTS, GOUGES, OR DISTORTION TO END SECTIONS FROM CONSTRUCTION OR MAINTENANCE.<br>CULVERT RETAINS A SMOOTH SYMMETRICAL CURVATURE.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 5% LOSS OF ORIGINAL DIAMETER. |
| 6<br>SATISFACTORY | MINOR STAINING OR DISCOLORATION FROM UV RADIATION DAMAGE PRESENT.<br>BLISTERING PRESENT ALONG LESS THAN 25% OF PIPE SURFACE (FRP).<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH LESS THAN 0.5 IN. ALONG SPLIT.<br>CULVERT RETAINS SMOOTH CURVATURE, BUT NON-SYMMETRICAL SHAPE. |
| 5<br>FAIR | WIDESPREAD STAINING OR DISCOLORATION FROM UV RADIATION DAMAGE PRESENT ALONG EXPOSED ENDS OF PIPE.<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 0.5 IN. AT LESS THAN THREE LOCATIONS ALONG SPLIT.<br>SECTION LOSS CAUSED BY ABRASION VISIBLE THROUGHOUT PIPE.<br>TOP HALF OF CULVERT RETAINS SMOOTH CURVATURE. MINOR BULGES OR FLATTENING PRESENT IN BOTTOM OF PIPE.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 7.5% LOSS OF ORIGINAL DIAMETER. |
| 4<br>POOR | BLISTERING PRESENT ALONG MORE THAN 25% OF PIPE SURFACE (FRP).<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 0.5 IN. AT SEVERAL LOCATIONS ALONG SPLIT.<br>PERFORATIONS CAUSED BY ABRASION LOCATED THROUGHOUT PIPE.<br>CULVERT HAS SHARP POINTS OR TURNS PRESENT ALONG CURVATURE DUE TO FLATTENING.<br>VERTICAL DEFORMATIONS RESULTING IN LESS THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 3<br>SERIOUS | UV RADIATION DAMAGE/BLISTERING HAS CAUSED MATERIAL TO CRACK OR PUNCTURE.<br>SPLIT LESS THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 1 IN. AT LESS THAN THREE LOCATIONS ALONG SPLIT.<br>SPLITS CAUSING LOSS OF BACKFILL MATERIAL.<br>CULVERT HAS EXTREME DISTORTION IN ONE SECTION OF PIPE. LOCAL AREAS OF REVERSED CURVATURE MAY BE PRESENT.<br>VERTICAL DEFORMATIONS RESULTING IN GREATER THAN 10% LOSS OF ORIGINAL DIAMETER. |
| 2<br>CRITICAL | SPLIT LARGER THAN 6 IN. IN LENGTH WITH WIDTH GREATER THAN 1 IN. AT SEVERAL LOCATIONS ALONG SPLIT.<br>CULVERT HAS EXTREME DISTORTION IN MULTIPLE SECTIONS OF PIPE.<br>SECTION LOSS CAUSED BY ABRASION HAS COMPLETELY ERODED PLASTIC MATERIAL IN LOCATIONS THROUGHOUT PIPE. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

| CONDITION RATING SCALE: MASONRY OR STONE BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. |
| 8<br>VERY GOOD | NO CRACKING OR MISSING/DISLOCATED MASONRY PRESENT.<br>MORTAR TIGHT WITH NO DEFECTS.<br>NO SETTLEMENT OR MISALIGNMENT OF STRUCTURE.<br>NO INVERT SCOUR. |
| 7<br>GOOD | SURFACE DETERIORATION OF MASONRY AT ISOLATED LOCATIONS.<br>SHALLOW MORTAR DETERIORATION AT ISOLATED LOCATIONS.<br>MINOR MISALIGNMENT AT JOINTS. NO SETTLEMENT OF STRUCTURE.<br>MINOR INVERT SCOUR. |
| 6<br>SATISFACTORY | MINOR CRACKING OF MASONRY UNITS.<br>MISSING MORTAR AT ISOLATED LOCATIONS. EXTENSIVE AREAS OF SURFACE DETERIORATION.<br>POSSIBLE SIGNS OF INFILTRATION OR EXFILTRATION THROUGH MINOR CRACKS.<br>MINOR MISALIGNMENT OR SETTLEMENT OF STRUCTURE.<br>MINOR SCOUR NEAR FOOTINGS. |
| 5<br>FAIR | MINOR CRACKING. SLIGHT DISLOCATION OF MASONRY UNITS.<br>LARGE AREAS OF SURFACE SCALING.<br>MORTAR GENERALLY DETERIORATED. LOOSE OR MISSING MORTAR AT ISOLATED LOCATIONS.<br>INFILTRATION STAINING PRESENT.<br>MINOR MISALIGNMENT OR SETTLEMENT OF STRUCTURE.<br>MODERATE SCOUR ALONG FOOTING. PROTECTIVE MEASURES MAY BE REQUIRED. |
| 4<br>POOR | SIGNIFICANT DISPLACEMENT OF INDIVIDUAL MASONRY UNITS.<br>MORTAR SEVERELY DETERIORATED/SIGNIFICANT LOSS OF MORTAR.<br>SIGNIFICANT INFILTRATION OR EXFILTRATION BETWEEN MASONRY UNITS.<br>SIGNIFICANT SETTLEMENT AND MISALIGNMENT OF STRUCTURE.<br>SCOUR ALONG FOOTING WITH SLIGHT UNDERMINING. PROTECTION REQUIRED. |
| 3<br>SERIOUS | INDIVIDUAL MASONRY UNITS IN LOWER PART OF STRUCTURE MISSING OR CRUSHED.<br>EXTENSIVE AREAS OF MISSING MORTAR.<br>INFILTRATION OR EXFILTRATION CAUSING MISALIGNMENT OF CULVERT AND SETTLEMENT OR DEPRESSIONS IN ROADWAY.<br>PONDING OF WATER DUE TO SAGGING OR MISALIGNMENT.<br>SEVERE UNDERMINING WITH SLIGHT DIFFERENTIAL SETTLEMENT CAUSING MINOR CRACKING OR SPALLING IN FOOTING AND MINOR DISTRESS IN WALLS. |
| 2<br>CRITICAL | INDIVIDUAL MASONRY UNITS IN UPPER PART OF STRUCTURE MISSING OR CRUSHED.<br>CULVERT NOT FUNCTIONING DUE TO SEVERE MISALIGNMENT.<br>SEVERE UNDERMINING WITH SIGNIFICANT DIFFERENTIAL SETTLEMENT CAUSING SEVERE CRACKS IN FOOTING AND DISTRESS IN WALLS. |
| 1<br>IMMINENT<br>FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

| CONDITION RATING SCALE: OTHER MATERIAL BARREL | |
|---|---|
| 9<br>EXCELLENT | NEW CONDITION. |
| 8<br>VERY GOOD | NO NOTICEABLE OR NOTEWORTHY DEFICIENCIES.<br>MARKS AND SCRAPES MAY BE PRESENT ALONG SURFACE FROM DRIFT. |
| 7<br>GOOD | LIGHT SURFACE DAMAGE THAT DOES NOT IMPACT STRUCTURAL PERFORMANCE.<br>SURFACE DAMAGE CAUSED BY DRIFT THAT DOES NOT REQUIRE CORRECTIVE ACTION.<br>FLEXIBLE CULVERTS HAVE A SMOOTH SYMMETRICAL CURVATURE. |
| 6<br>SATISFACTORY | INTITIAL SIGNS OF DETERIORATION OR DISINTEGRATION ARE STARTING TO APPEAR.<br>FLEXIBLE CULVERTS HAVE A SMOOTH CURVATURE OR NON-SYMMETRICAL SHAPE. |
| 5<br>FAIR | SIGNS OF DETERIORATION OR DISINTEGRATION ARE CLEARLY PRESENT.<br>MINOR SETTLEMENT OR MISALIGNMENT OF STRUCTURE IS OBSERVABLE.<br>FLEXIBLE CULVERTS HAVE SIGNIFICANT DISTORTION AND DEFLECTION IN ONE SECTION. |
| 4<br>POOR | SIGNS OF DETERIORATION ARE BEGINNING TO DISRUPT THE FLOW OF WATER OR PERMIT LOSS OF BACKFILL MATERIAL.<br>CONSIDERABLE SETTLEMENT OR MISALIGNMENT OF STRUCTURE IS OBSERVABLE.<br>FLEXIBLE CULVERTS HAVE SIGNIFICANT DISTORTION AND DEFLECTION THROUGHOUT. |
| 3<br>SERIOUS | UNADDRESSED DETERIORATION HAS CREATED OPENINGS IN STRUCTURE FOR INFILTRATION/EXFILTRATION. LARGE PERFORATIONS MAY EXIST.<br>SEVERE MOVEMENT OR DIFFERENTIAL SETTLEMENT PRESENT ALONG SEGMENTS OF THE STRUCTURE.<br>FLEXIBLE CULVERTS HAVE EXTREME DISTORTION AND DEFLECTION IN ONE SECTION. |
| 2<br>CRITICAL | SECTION OF CULVERT MAY HAVE FAILED OR CANNOT PERFORM INTENDED FUNCTIONS HYDRAULICALLY OR STRUCTURALLY.<br>CORRECTIVE ACTION REQUIRED TO KEEP ROADWAY IN SERVICE.<br>FLEXIBLE CULVERTS HAVE EXTREME DISTORTION AND DEFLECTION THROUGHOUT WITH EXTENSIVE OPENINGS ALLOWING FOR INFILTRATION/EXFILTRATION. |
| 1<br>IMMINENT FAILURE | PARTIAL OR COMPLETE COLLAPSE OF STRUCTURE. |
| 0<br>FAILED | STRUCTURE CLOSED. |

| CONDITION RATING SCALE: END TREATMENTS | |
|---|---|
| 9<br>EXCELLENT | NO SIGNS OF DISTRESS, DISCOLORATION, OR ROTATION. |
| 8<br>VERY GOOD | HAIRLINE CRACKING (WIDTHS LESS THAN 0.01 IN.) WITHOUT RUST STAINING OR DELAMINATION. NO DAMPNESS, LEAKAGE, OR SPALLING.<br>MINOR SCALING/ABRASION LESS THAN 0.125 IN. DEEP AND ON LESS THAN 5% OF WALL AREA.<br>ROTATION LESS THAN 0.5 IN./FT. |
| 7<br>GOOD | CRACK WIDTHS LESS THAN 0.02 IN. MINOR EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>LIGHT SCALING/ABRASION LESS THAN 0.125-IN. DEEP AND ON LESS THAN 10% OF WALL AREA.<br>DELAMINATED/SPALLED AREA LESS THAN 1% OF WALL AREA.<br>INDIVIDUAL SPALL IS LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP.<br>ROTATION LESS THAN 1 IN./FT. |
| 6<br>SATISFACTORY | HORIZONTAL AND DIAGONAL CRACK WIDTHS LESS THAN 0.0625 IN. EFFLORESCENCE AND/OR LEAKAGE WITHOUT RUST STAINING PRESENT.<br>MODERATE SCALING/ABRASION LESS THAN 0.25-IN. DEEP AND ON LESS THAN 20% OF WALL AREA.<br>DELAMINATED/SPALLED AREAS LESS THAN 10% OF WALL AREA.<br>SPALLED AREAS WITH EXPOSED REINFORCEMENT LESS THAN 5% OF EXPOSED AREA.<br>INDIVIDUAL SPALLS ARE LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP.<br>BARREL PULLING AWAY FROM HEADWALL RESULTING IN LESS THAN 0.5-IN. GAP. |
| 5<br>FAIR | HORIZONTAL AND DIAGONAL CRACK WIDTHS LESS THAN 0.125 IN. EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING PRESENT.<br>SCALING/ABRASION LESS THAN 0.25-IN. DEEP AND ON LESS THAN 30% OF WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 20% OF WALL AREA.<br>SPALLED AREAS WITH EXPOSED REINFORCEMENT LESS THAN 10% OF EXPOSED AREA.<br>INDIVIDUAL SPALLS ARE GREATER THAN 6 IN. IN DIAMETER OR GREATER THAN 1-IN. DEEP.<br>BARREL PULLING AWAY FROM HEADWALL RESULTING IN LESS THAN 1-IN. GAP. |
| 4<br>POOR | SEVERAL HORIZONTAL AND DIAGONAL CRACKS WITH WIDTHS GREATER THAN 0.125 IN. WITH EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING.<br>EXTENSIVE SCALING/ABRASION LESS THAN 0.25-IN. DEEP ON LESS THAN 50% OF WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 25% OF WALL AREA.<br>ADJACENT REINFORCING STEEL BARS ARE EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS IS GREATER THAN 10% OF ORIGINAL DIAMETER.<br>DIFFERENTIAL OR ROTATIONAL SETTLEMENT LESS THAN 2 IN./FT. |
| 3<br>SERIOUS | SEVERAL CRACKS WITH WIDTHS GREATER THAN 0.25 IN. WITH EFFLORESCENCE AND RUST STAINING.<br>MAJOR SCALING/ABRASION GREATER THAN 0.25-IN. DEEP ON MORE THAN 50% OF THE WALL AREA.<br>TOTAL DELAMINATED/SPALLED AREAS LESS THAN 50% OF WALL AREA.<br>MORE THAN 5 ADJACENT REINFORCING STEEL BARS EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS GREATER THAN 20% OF ORIGINAL DIAMETER.<br>SEVERE DIFFERENTIAL OR ROTATIONAL SETTLEMENT LESS THAN 4 IN./FT. |
| 2<br>CRITICAL | TOTAL AREA WITH DELAMINATIONS, SPALLS, MAP CRACKING, AND UNSOUND CONCRETE IS GREATER THAN 50% OF WALL AREA.<br>MORE THAN 10 ADJACENT REINFORCING STEEL BARS EXPOSED OR SECTION LOSS OF REINFORCING STEEL BARS GREATER THAN 30% OF ORIGINAL DIAMETER.<br>CRITICAL DIFFERENTIAL OR ROTATIONAL SETTLEMENT GREATER THAN 4 IN./FT. |
| 1<br>IMMINENT<br>FAILURE | PARTIALLY COLLAPSED HEADWALL. |
| 0<br>FAILED | TOTAL FAILURE OF HEADWALL. |
| | |

| CONDITION RATING SCALE: CHANNEL | |
|---|---|
| N<br>NOT APPLICABLE | CULVERT DOES NOT INTERSECT WITH A WATERWAY OR CHANNEL. |
| 9<br>EXCELLENT | NO NOTICEABLE DEFICIENCIES PRESENT. |
| 8<br>VERY GOOD | CHANNEL BANKS ARE WELL VEGETATED.<br>INSTALLED PROTECTION AND EMBANKMENT PROTECTION ARE SUFFICIENT FOR CHANNEL FLOW. |
| 7<br>GOOD | CHANNEL BANK PROTECTION IS IN NEED OF MINOR REPAIRS.<br>MINOR DAMAGE IS PRESENT IN ISOLATED AREAS OF INSTALLED PROTECTION AND EMBANKMENT PROTECTION.<br>BANKS AND/OR CHANNEL HAVE MINOR AMOUNTS OF DRIFT.<br>SEDIMENT BUILDUP IN CHANNEL IS BEGINNING TO ALTER FLOW. |
| 6<br>SATISFACTORY | CHANNEL BANK IS BEGINNING TO SLUMP.<br>MINOR DAMAGE IS WIDESPREAD ALONG INSTALLED PROTECTION AND EMBANKMENT PROTECTION.<br>DEBRIS BUILDUP IS BEGINNING TO SPLIT THE CHANNEL INTO SEPARATE FLOWS UPSTREAM OF CULVERT. |
| 5<br>FAIR | CHANNEL BANK PROTECTION IS BEING ERODED.<br>MAJOR DAMAGE IS PRESENT IN INSTALLED AND/OR EMBANKMENT PROTECTION.<br>CHANNEL FLOW IS CONTACTING EMBANKMENT OUTSIDE OF HEADWALLS/WINGWALLS.<br>TREES AND BRUSH RESTRICT CHANNEL FLOW. |
| 4<br>POOR | CHANNEL BANK AND/OR EMBANKMENT PROTECTION IS SEVERELY UNDERMINED. EROSION HAS BEGUN ALONG EMBANKMENT.<br>CHANNEL FLOW HAS EXPOSED PREVIOUSLY COVERED FOOTING OF CULVERT.<br>FLOW ENTERS PIPE THROUGH MEANS OTHER THAN THE DESIGNED OPENING.<br>LARGE DEPOSITS OF DEBRIS HAVE CHANGED CHANNEL ALIGNMENT TO IMPACT EMBANKMENT DIRECTLY. |
| 3<br>SERIOUS | CHANNEL BANK PROTECTION HAS FAILED AND/OR INSTALLED PROTECTION HAS BEEN DESTROYED.<br>EMBANKMENT EROSION CONTINUES TO OCCUR, APPROACHING ROADWAY.<br>EMBANKMENT MATERIAL LOCATED BEHIND HEADWALL/WINGWALL IS BEGINNING TO ERODE.<br>STREAMBED AGGRADATION, DEGRADATION, OR LATERAL MOVEMENT HAS CHANGED THE CHANNEL ALIGNMENT TO NOW THREATEN THE CULVERT AND/OR APPROACH ROADWAY. |
| 2<br>CRITICAL | CHANNEL FLOW IS PIPING AROUND CULVERT OR INSTALLED PROTECTION.<br>EMBANKMENT EROSION HAS REACHED ROADWAY SURFACE.<br>CHANNEL HAS CHANGED TO THE EXTENT THE CULVERT IS NEAR A STATE OF COLLAPSE. |
| 1<br>IMMINENT FAILURE | CULVERT CLOSED BECAUSE OF CHANNEL FAILURE.<br>MAJORITY OF CHANNEL FLOW CIRCUMNAVIGATES CULVERT.<br>CORRECTIVE ACTION MAY ALLOW CULVERT TO BE PUT BACK INTO LIGHT SERVICE. |
| 0<br>FAILED | CULVERT CLOSED BECAUSE OF CHANNEL OR STRUCTURE FAILURE.<br>REPLACEMENT NECESSARY. |

## B.23 Minor Condition Rating Scales

**Roadway Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Good | Roadway does not show any signs of distress. |
| Fair | Roadway has narrow cracks, sags, and/or humps above culvert indicating displacement of soil below. |
| Poor | Roadway has wide cracks and/or openings that reveal a void beneath roadway. |

**Embankment Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Good | Embankment slope shows no signs of erosion or backfill displacement. |
| Fair | Minor depressions of soil are observable along embankment slope. Beginning stages of piping or evidence of backfill displacement may also be present. |
| Poor | Evidence of water infiltration by piping or large depressions above the culvert structure are present. Large surface soil cracks, sheet movement of soil, or other signs that indicate slope instability are present. |

**Joints and Seams Condition Rating Scale: Concrete and Precast Concrete Structures**

| Rating | Descriptor |
|---|---|
| Good | No cracks emanating or extending from joints. No separation or gaps between sections present. |
| Fair | Cracks emanating from joints are present in structure. Small gaps between sections are present. Evidence of small amounts of water infiltration, but no voids are present in the soil envelope. |
| Poor | Cracks have created spalls that reveal reinforcement at joints/seams. Separation of sections allows for soil infiltration and has created voids in soil envelope. |

**Joints and Seams Condition Rating Scale: Metal Structures**

| Rating | Descriptor |
|---|---|
| Good | No missing/broken fasteners. No separation or gaps between sections present. |
| Fair | Some missing fasteners at joints/seams. Small gaps between sections are present. Evidence of small amounts of water infiltration, but no voids are present in the soil envelope. |
| Poor | Missing fasteners allow shape deformation at seams/joints. Separation of sections allows for soil infiltration and has created voids in soil envelope. |

**Footing/Anchor Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Good | No differential settlement. Only hairline cracking. No abrasion or delamination/spalling present. No noticeable scour or undermining threatens the soil supporting the footings/anchors. |
| Fair | Only minor differential settlement with no vertical offset at cracks. Crack widths less than 0.1 in. without exposed reinforcement. Scaling/abrasion less than 0.25 in. in depth. Local spalls less than 6 in. in diameter without exposed reinforcement. Scour has exposed covered footing/anchor. No undermining or rotation/displacement. |
| Poor | Excessive differential settlement or vertical offset at cracks greater than 0.25 in. Crack widths greater than 0.1 in. or with exposed reinforcement. Widespread exposure of aggregate from scaling/abrasion. Spalls greater than 6 in. in diameter or revealing reinforcement. Scour has created undermining or has exposed large portion of anchor or vertical face of covered footing. Rotation of the footing or displacement of anchor has occurred. |

**Channel Alignment Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Good | Channel approach appears to be as originally designed with no interruptions. |
| Fair | Channel approaches culvert at an angle different from original design. |
| Poor | Angle at which channel approaches culvert is causing erosion along the channel or damage at the entrance of the structure. |

**Scour Presence Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Good | No scour presence along inlet or outlet of structure. |
| Fair | Scour presence along inlet and/or outlet is observable but does not threaten structural stability of culvert. |
| Poor | Presence of scour has revealed vertical face of previously buried footings and/or threatens structural stability of culvert. |

**Waterway Blockage Condition Rating Scale**

| Rating | Descriptor |
|---|---|
| Open (Good) | Waterway is open and flow of water into and out of structure is uninterrupted. Debris accumulation is less than 10% of diameter. |
| Partially Blocked (Fair) | Culvert is partially blocked, restricting waterflow due to debris or sediment deposit. Debris accumulation is between 10% and 30% of diameter. |
| Submerged or Blocked (Poor) | Culvert is submerged or blocked, resulting in water retention outside of structure. Debris accumulation is more than 30% of diameter. |

## B.24 Width and Area Comparisons

Crack Width Reference Chart

| Width | Reference Object(s) |
|---|---|
| 0.01 in. | Width of a playing card |
| 0.05 in. | Width of a dime |
| 0.10 in. | Width of two dimes |

Steel Surface Area Reference Chart

| Area | Reference Object(s) |
|---|---|
| 6 $in.^2$ | Driver's license<br>Credit/debit card |
| 15 $in.^2$ | Closed wallet/billfold<br>Open dollar bill<br>Smart phone |
| 30 $in.^2$ | Open wallet/billfold<br>Two open dollar bills<br>Less than half of an iPad |
| 36 $in.^2$ | Standard piece of paper folded in half |

## B.25 Visual Condition Rating Scales

| CONCRETE - 9 | **9 EXCELLENT** NEW CONDITION ISOLATED DAMAGE FROM INSTALLATION MAY BE PRESENT. |
|---|---|


Photo 1


Photo 2


Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Precast concrete culvert structure in new condition. No noticeable deterioration.

Photo 2: Structure is in excellent condition. Some scrape marks can be observed, but are clearly from construction and installation.

Photo 3: Precast concrete culvert structure is in new condition. No noticeable deterioration.

| | |
|---|---|
| CONCRETE - 8 | **8 VERY GOOD** HAIRLINE CRACKING (WIDTHS LESS THAN 0.01 IN.) WITHOUT EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING. NO DETERIORATION FROM SCALING OR ABRASION. NO SPALLING OR DELAMINATIONS. |

Photo 1

*Photo provided by the Indiana Department of Transportation

Photo 1: Hairline cracking (width less than 0.01 in.) can be observed along surface of the material. No other deterioration can be observed.

| CONCRETE - 7 | **7 GOOD** CRACK WIDTHS LESS THAN 0.02 IN. MINOR EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT. SCALING/ABRASION LESS THAN 0.125-IN. DEEP COVERING LESS THAN 10% OF SURFACE AREA. DELAMINATED OR SPALLED AREA LESS THAN 1% OF SURFACE AREA. SINGLE INDIVIDUAL SPALL IS LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
|---|---|

Photo 1

Photo 2

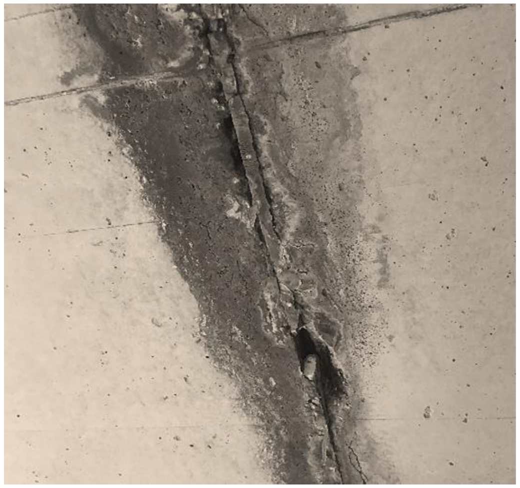


Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Shallow scaling/abrasion can be observed along lower portion of structure walls. Total area affected is less than 10% of surface area of structure.

Photo 2: Moisture is present within crack along surface of material. Crack width is determined to be less than 0.02 in.

Photo 3: Isolated spall can be observed along surface of structure. Spall is less than 6 in. in diameter and less than 1-in. deep.

| CONCRETE - 6 | **6 SATISFACTORY** CRACK WIDTHS LESS THAN 0.0625 IN. EFFLORESCENCE AND/OR MINOR LEAKAGE WITHOUT RUST STAINING PRESENT. SPACING OF CRACKS TRANSVERSE TO TRAFFIC 3 FT OR GREATER. SCALING/ABRASION LESS THAN 0.25-IN. DEEP COVERING LESS THAN 20% OF SURFACE AREA. TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 5% OF SURFACE AREA. INDIVIDUAL SPALLS ARE LESS THAN 6 IN. IN DIAMETER AND LESS THAN 1-IN. DEEP. |
| --- | --- |

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Crack width greater than 0.02 in. but less than 0.0625 in. Moisture is present in crack. Some scaling/abrasion can also be observed along waterline.

Photo 2: Efflorescence is present along crack in concrete surface.

Photo 3: Delaminated and spalled regions can be observed along concrete surface. Spalled region is less than 6 in. in diameter and less than 1-in. deep.

## CONCRETE - 5

**5 FAIR** CRACKS WIDTHS LESS THAN 0.125 IN. PARALLEL TO TRAFFIC OR LESS THAN 0.0625 IN. TRANSVERSE TO TRAFFIC. EFFLORESCENCE, LEAKAGE, AND/OR RUST STAINING PRESENT. SCALING/ABRASION GREATER THAN 0.25-IN. DEEP COVERING LESS THAN 30% OF SURFACE AREA. TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 15% OF SURFACE AREA. SPALLING HAS EXPOSED REINFORCING STEEL. INDIVIDUAL SPALLS ARE GREATER THAN 6 IN. IN DIAMETER OR GREATER THAN 1-IN. DEEP.

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Spalled area and cracking can be observed along concrete surface. Spalled area exceeds 6 in. in diameter.

Photo 2: Scaling/abrasion along concrete surface can be observed. Scaling appears to both exceed 30% of surface area and penetrate further than 0.25 in. in certain locations.

Photo 3: Pattern cracking along surface includes cracks with widths greater than 0.0625 in. but less than 0.125 in. with efflorescence present.

| CONCRETE - 4 | **4 POOR** EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.125 IN. SPACING OF CRACKS TRANSVERSE TO TRAFFIC BETWEEN 1 FT AND 3 FT. SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING LESS THAN 50% OF SURFACE AREA. TOTAL DELAMINATED AND SPALLED AREAS LESS THAN 25% OF SURFACE AREA. SPALLING HAS EXPOSED CORRODED REINFORCING STEEL. |
|---|---|

Photo 1

Photo 2

*Photos provided by the Indiana Department of Transportation

Photo 1: Spalling of concrete surface has exposed reinforcing steel that is visibly corroded.

Photo 2: Spalling of concrete surface has exposed multiple sections of reinforcing steel with visible corrosion. Delamination of material surrounding spalled area is also observable.

| CONCRETE - 3 | **3 SERIOUS** SOFT CONCRETE. EXTENSIVE CRACKING WITH CRACK WIDTHS LESS THAN 0.25 IN. DIFFERENTIAL MOVEMENT AT CRACK(S). SCALING/ABRASION GREATER THAN 0.5-IN. DEEP COVERING GREATER THAN 50% OF SURFACE AREA. LESS THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED.SPALLING HAS EXPOSED MUCH OF THE PERIMETER OF REINFORCING BARS. |
| --- | --- |

Photo 1

Photo 2

*Photos provided by the Indiana Department of Transportation

Photo 1: Spalling and deterioration of concrete surface has revealed partial perimeter of reinforcing bars. Removal of material has also resulted in significant loss of wall thickness.

Photo 2: Significant differential movement in the vertical plane is observed along with extensive cracking along the top concrete surface of the structure.

CONCRETE - 2

**2 CRITICAL** CONCRETE COMPLETELY DETERIORATED IN ISOLATED LOCATIONS CREATING THROUGH-DEPTH HOLES. EXTENSIVE CRACKING WITH CRACK WIDTHS GREATER THAN 0.25 IN. SEVERE DIFFERENTIAL MOVEMENT AT CRACK(S). GREATER THAN 50% OF THE SURFACE AREA IS DELAMINATED OR SPALLED. SPALLED AREAS WITH EXPOSED REINFORCING STEEL COVER APPROXIMATELY 25% OF SURFACE AREA. REINFORCING BAR PERIMETER IS COMPLETELY EXPOSED AND BARS EXHIBIT EXTENSIVE SECTION LOSS.

Photo 1

Photo 2

*Photos provided by the Indiana Department of Transportation

Photo 1: Full perimeter of reinforcing bar has been exposed due to spalling of concrete from area. Exposed reinforcing steel is significantly corroded and exhibits section loss across length of structure.

Photo 2: Partial to full loss of concrete wall thickness with exposed reinforcing bars. Remaining reinforcement appears to have extensive section loss.

## METAL - 9

**9 EXCELLENT** NEW CONDITION. CULVERT RETAINS ORIGINAL SHAPE.

Photo 1

Photo 2

*Photos provided by the Indiana Department of Transportation

Photo 1: Culvert retains original shape and has no noticeable deterioration or deficiencies.

Photo 2: Culvert retains original shape and has no noticeable deterioration or deficiencies.

| | |
|---|---|
| METAL - 8 | **8 VERY GOOD** DISCOLORATION OF SURFACE. PROTECTION PARTIALLY GONE ALONG INVERT BUT NO LAYERS OF RUST. |

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Bituminous protective surface layer is cracking. No observable rust is present.

Photo 2: Bituminous protective surface layer has been partially removed along invert. No observable rust is present.

Photo 3: Bituminous protective surface layer has been partially removed along invert and discoloration is present.

METAL - 7

**7 GOOD** PROTECTION GONE ALONG INVERT. FRECKLED RUST PRESENT. CULVERT RETAINS A SMOOTH SYMMETRICAL CURVATURE. IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITHOUT WALL PENETRATION.

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Wearing of galvanized material along surface is observed, indicating that protection is almost gone along waterline and invert.

Photo 2: Impact damage near end of pipe has created a localized dent along the top of the pipe structure but does not result in a penetration of the structure.

Photo 3: Freckled rust can be observed along interior of pipe structure.

| METAL - 6 | **6 SATISFACTORY** PROTECTION GONE ALONG INVERT. LAYERS OF RUST THROUGHOUT. MODERATE SECTION LOSS LESS THAN 6 IN.$^2$/FT$^2$ OR 4% OF INVERT AREA. CULVERT RETAINS SMOOTH CURVATURE BUT NON-SYMMETRICAL SHAPE. MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 5% LOSS OF ORIGINAL DIAMETER. |
|---|---|

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Shape of pipe structure is observably smooth but not symmetrical.

Photo 2: Layers of rust are observed along waterline of pipe structure.

Photo 3: Buildup of rust layers along pipe structure are beginning to cause section loss along waterline.

| METAL - 5 | **5 FAIR** HEAVY RUST AND SCALING THROUGHOUT. HEAVY SECTION LOSS: LESS THAN 15 IN.$^2$/FT$^2$ OR 10% OF INVERT AREA. TOP HALF OF CULVERT RETAINS SMOOTH CURVATURE. MINOR BULGES OR FLATTENING PRESENT IN BOTTOM OF PIPE. MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 10% LOSS OF ORIGINAL DIAMETER. |
|---|---|

Photo 1

*Photos provided by the Indiana Department of Transportation

Photo 2

Photo 3

Photo 1: Shape of pipe structure exhibits minor bulging along bottom of pipe.

Photo 2: Section loss less than 15 in.$^2$/ft$^2$ is observed along interior of pipe structure. Rust and scaling are also observed.

Photo 3: Heavy rust is observed throughout pipe structure.

METAL - 4

**4 POOR** EXTENSIVE RUST AND SCALING THROUGHOUT. MINOR PERFORATIONS/HOLES THROUGHOUT INVERT. MINOR PERFORATION/HOLE AREA LESS THAN 30 IN.$^2$/FT$^2$ OR 20% OF INVERT AREA.. CULVERT HAS SHARP POINTS OR TURNS PRESENT ALONG CURVATURE DUE TO FLATTENING. MEASURED VERTICAL DEFORMATIONS RESULTING IN LESS THAN 15% LOSS OF ORIGINAL DIAMETER. IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION BUT NO SIGNS OF SOIL INFILTRATION.

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Perforations along invert of pipe structure are present throughout the culvert but do not total more than 30 in.$^2$/ft$^2$.

Photo 2: Impact damage near end of pipe has created a localized area of wall penetration. No evidence of soil infiltration is present.

Photo 3: Shape of structure exhibits flattening and distortion along length. Layers of rust are observed along invert of pipe structure.

| | |
|---|---|
| METAL - 3 | **3 SERIOUS** EXTENSIVE RUST AND SCALING THROUGHOUT. MODERATE PERFORATIONS/HOLES LESS THAN 36 IN.$^2$/FT$^2$ OR 25% OF INVERT AREA. CULVERT HAS EXTREME DISTORTION IN ONE SECTION OF PIPE. LOCAL AREAS OF REVERSED CURVATURE MAY BE PRESENT. MEASURED VERTICAL DEFORMATIONS RESULTING IN GREATER THAN 15% LOSS OF ORIGINAL DIAMETER. |

Photo 1

Photo 2

*Photos provided by the Indiana Department of Transportation

Photo 1: Perforation is observed along wall of pipe structure. Area of perforation is less than 36 in.$^2$/ft$^2$. Shape of pipe wall also appears to be distorted surrounding the perforation.

Photo 2: Shape of pipe structure exhibits extreme distortion in one section of pipe. Shape appears to have reversed curvature along the top right of the structure.

| | |
|---|---|
| METAL - 2 | **2 CRITICAL** MAJOR PERFORATIONS/HOLES GREATER THAN 36 IN.$^2$/FT$^2$ OR GREATER THAN 25% OF INVERT AREA. CULVERT HAS EXTREME DISTORTION IN MULTIPLE SECTIONS OF PIPE. IMPACT DAMAGE RESULTING IN LOCALIZED DENTS WITH WALL PENETRATION ALLOWING SOIL ENVELOPE TO INFILTRATE PIPE. |

Photo 1

Photo 2

Photo 3

*Photos provided by the Indiana Department of Transportation

Photo 1: Visible perforation equal or greater in size than 36 in.$^2$/ft$^2$ along invert of pipe structure is observed.

Photo 2: Holes are present on both sides of fastener line in metal pipe along extent of pipe structure totaling more than 36 in.$^2$/ft$^2$.

Photo 3: Loss of material along right side of structure exceeds 36 in.$^2$/ft$^2$ and has allowed structural material to curl along invert.

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## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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