# APPENDIX TABLE OF CONTENTS

# APPENDIX A: LITERATURE REVIEW OF BEST PRACTICES

The purpose of the literature review was to identify best practices being used by county, state, and federal agencies that may be applicable to the pilot. This included identifying current data collection, storage, and evaluation tools in use by these agencies. Once these tools, techniques, and methodologies were identified, an assessment was undertaken to determine those which warranted inclusion in the pilot.

A study by the New Mexico Department of Transportation (DOT) determined that out of forty-seven responsive state DOTs, thirty-three states inspect their culverts (structures 20 feet or less), with nineteen having a culvert inspection manual and twenty-one having some form of culvert inspection training. However, each state had a widely varying number of culverts, a variety of culvert materials, varying inspection frequencies, varying condition-rating scales, varying collected inventory data, and varying data collection / storage methods (Villwock-Witte et. al. 2016).

Several state agencies were found to have a complete culvert management system in place for locating, inspecting, and storing data associated with culverts. Alabama (state and county level), Indiana, Los Angeles County, Maryland, Michigan, Minnesota, New Mexico, Ohio, Oregon, Utah, Vermont, and Wisconsin all have published studies or documentation outlining processes and procedures in their respective areas related to culvert data collection and inspection, which were used as the basis for this literature review.

In 2007, the Federal Highway Administration (FHWA) issued a report analyzing Culvert Management Systems specific to Alabama, Maryland, Minnesota, and Shelby County (FHWA 2007). In June 2014, the FHWA issued a similar report titled Culvert Management Case Studies: Vermont, Oregon, Ohio, and Los Angeles (LA) County. These reports summarized best practices from these locations and identified specific details on how they integrate their culvert inventory and evaluations with asset management plans for maintenance of their culverts (Venner 2014).

The FHWA has also released a Culvert Inspection Manual outlining procedures for conducting and documenting culvert inspections regarding the existing hydraulic capacity, structural integrity, and durability of culverts. However, published in 1986, it is noted that this document is dated and an American Association of State Highway and Transportation Officials (AASHTO) replacement document is under development, which will be based on a document released by the National Cooperative Highway Research Program (NCHRP), which suggests new procedures for conducting and documenting culvert inspections. Additionally, there is another system proposed for inventorying and inspecting culverts generated as the result of Midwest Regional University Transportation Center research study that bases condition ratings on a pairwise comparison of culvert components. However, this system provides little reference on how to conduct inspections, focusing instead on proposed condition evaluation procedures. The condition evaluation portions of these systems will be discussed in depth in section 1.1.6.

### 1.1.1. Culvert Sizes Considered

As stated in the FHWA Culvert Inspection Manual, “structures over 20 feet in span parallel to the roadway are usually called bridges; and structures less than 20 feet in span are called culverts even though they support traffic loads directly” (Arnoult 1986). This is the generally accepted culvert definition; the NCHRP report agrees with this definition (Beaver & Richie 2016) and state DOTs inventory and inspect structures under 20 feet as culverts. However, DOTs have varying minimum sizes for inspection of culverts and some DOTs separate inspection levels into different groups of culvert sizes. Generally, most state DOTs are moving towards inventorying and inspecting culverts down to around 1 foot, and separating culvert inspection into groups of 1 to 10 feet and 10 to 20 feet if group separations are made. Specific state practices are presented below.

Oregon has collected culvert data for culverts as small as 3 feet since the mid 1980’s before expanding that to culverts down to 1 foot. Ohio DOT also inventories and evaluates culverts down to 1 foot in two groups; 1 to 10 feet and 10 to 20 feet. Vermont has been collecting data on culverts from 6 to 20 feet for decades and in 2002 started collecting data on smaller culverts. The Maryland State Highway Administration’s Bridge Inspection and Remedial Engineering Division has inventoried and inspected culverts down to a 5 feet span and select culverts in the 3 to 5 feet range. Minnesota DOT separates their culvert management and inspection into two categories: 1-10 feet and 10-20 feet, with the larger spans inspected by their Bridge Inspection Unit and the smaller ones inspected by the Hydraulics Unit. Alabama inventories all culverts between 15 inches and 20 feet (Venner 2014). In 2014, Indiana DOT performed a research project regarding expansion of their culvert management program to include inventorying and inspection of culverts smaller than 48 in, whereas these structures were previously not considered (Bowers et. al. 2014). In 2016, Michigan DOT released a document regarding inventorying and condition assessment of culverts between 1 foot and <10 feet (culverts between 10 and 20 feet were evaluated previously) (MDOT 2016). The Office of Federal Lands Highway inspects all culverts under 20 feet with no grouping of culvert sizes (Hunt et. al. 2010).

### 1.1.2. Frequency of Inspection

The New Mexico DOT study found that state DOTs use varying inspection periods for their culverts; inspections on culverts are made anywhere from annually to every six years, depending on the state. Many states have provisions to their established regular inspection cycles; Colorado, Oregon, and other states inspect culvert structures more frequently if the culvert condition warrants more frequent monitoring, and Utah, Oklahoma, and Nebraska inspect culverts after storm events (Villwock-Witte et. al. 2016). Some inspection frequencies are decided based on culvert size as well. Specific state and county practices are presented below.

LA County (approximately 5,000 culverts) conducts an annual inspection of their culverts and Ohio (approximately 80,000 culverts) conducts inspections every 10 years on culverts between 1 and 4 feet and every five years for culverts between 4 and 10 feet. LA County was the only agency in the case study that used their culvert management system to track maintenance work history and for describing repair/replacement strategy and improvement projects (FHWA 2007). The Maryland State Highway Administration typically inspects culverts on a four-year cycle with two-year inspections if condition warrants. The Minnesota DOT inspects culverts 10 feet and larger located on the state trunk highway system on an annual or biennial basis depending on condition. Minnesota law as of 2007 did not allow inspection intervals greater than two years though they were trying to amend that to four years on some structures like concrete box culverts. Culverts less than 10 feet are inspected as needed - there is no required inspection frequency on these structures. Alabama has no required culvert inspection frequency and performs inspections as-needed, though annual inspections are recommended if deemed necessary. Shelby County (Alabama) conducts culvert inspections on a regular two-year cycle in conjunction with their National Bridge Inspection Standards (NBIS) inspection program (Venner 2014). Indiana DOT performs annual inspection of their culverts, but only inspects one fourth of their culverts annually (Bowers et. al. 2014). In Michigan, culverts 10 to 20 feet are also inspected on a regular two-year cycle in conjunction with the NBIS rating system, while the condition of culverts 1 to <10 feet governs their inspection frequency (MDOT 2016).

The FHWA Culvert Inspection Manual suggests that culverts be inspected every two years, but allows less frequent inspection if justified (Arnoult 1986). The NCHRP report recommends establishing an inspection frequency based on both the condition and size of the culvert, but leaves the frequency decision to the agency. Under the recommended system, culverts greater than 10 feet should be inspected every two years regardless of condition and culverts less than 10 feet should be inspected at intervals depending on their size and last reported condition. This recommended system also suggests that all culvert sizes should be inspected prior to or during regular maintenance activities on the roadway where the culvert is located. It also provides other criteria for agencies to consider when deciding inspection frequency, including age of the structure, ADT, environmental conditions, and consideration of extra criteria for special function structures (Beaver & Richie 2016).

### 1.1.3. Equipment Used

In the New Mexico study, it was found that states inventorying and inspecting their culverts do not have a common method for recording inventory and condition data. Recording methods include paper reports, laptop, iPad, Trimble, or some combination of these methods. As for software used to record data, some states indicated that they were using AASHTOWare software, some states indicated that they were using Agile Assets, and some states indicated that they were using a state-specific inventory program (Villwock-Witte et. al. 2016). In one of the FHWA studies, it was found that of states inventorying and inspecting their culverts, eight states use Pontis (AASHTOWare), thirteen use an in-house developed (state-specific) database, and eight states use a combination of these methods. It should be noted that no state uses the FHWA Culvert Management System to record data (FHWA 2007),2 however one county studied, Shelby County, uses the software (Davidson & Grimes 2006).

LA County uses cameras with built-in GPS to both document culvert condition and provide location information (Venner 2014). Indiana DOT provides their inspection crews with a digital camera, personal protective equipment (PPE), a measuring tape, a measuring wheel, flashlights, and a shovel (Bowers et. al. 2014). Michigan DOT provides their inspection crew with measuring tools, hand tools, an approved data collection device (such as a tablet or laptop), flashlight, PPE, properly sized waders, and a stability pole (MDOT 2016).

The Office of Federal Lands Highway recommends a full list of equipment for inspection, separating equipment into on-person equipment and in-vehicle equipment. On-person equipment for a two-person crew includes an assessment form, a clipboard, a geologist pick hammer, a 25-foot measuring tape or folding carpenters ruler, a digital camera (shock-resistant and waterproof), a flashlight (500k to 1m candle) and/or head lamp, a handheld mirror, a probing rod (graduated survey rod section), personal air monitoring devices, traffic safety vests and personal field safety gear, extra car keys, tool belts for hands-free carrying of inspection equipment, cell phones and/or field radios, and a concrete crack comparator card. In-vehicle equipment for a two-person crew includes a Global Positioning System (GPS) device, project files & maps, an assessment guide, a culvert entry guide, a first aid kit w/snake bite and poisonous vegetation provisions, OSHA traffic cones, extra batteries, bulbs, and storage cards for camera, GPS, and lights, waders and life jackets, a 100-foot tending line, hardhats or climbing helmets, crack gauge or calipers, a folding shovel, a machete, a pry-bar, emergency contact information and equipment, a 100-foot measuring tape, a distance wheel, or a range finder, and an inclinometer (Hunt et. al. 2010).

### 1.1.4. Pilot Studies

Best practices identified in a 2014 FHWA study stress the importance of getting a system in place. Once locations are established with some capacity for condition assessment, the assessment portion can be improved with time by adding additional data. "Internal groups and stakeholders can identify large lists of potential data to be collected; however, the agency should make sure it knows how the data will be used and how often it may be used" (Venner 2014).

Oregon DOT conducted a culvert inventory and inspection pilot study in 2006. By 2010, Oregon DOT had refined their collection assessment to include 45 data fields for the site, 27 for condition, and 13 photos per culvert. In 2011, they chose to use a smaller number of fields noting the "delicate balance between collecting enough data to provide useful information and the time and resources necessary to collect, manage, and maintain the data." Their management system still has the ability to capture additional fields but they are not mandatory or regularly collected (Venner 2014).

Like Oregon, Utah performed a 2004 pilot study on how to create a system for monitoring culvert condition based on qualitative and quantitative measures, based on a numerical 0-9 scale (Beaver et al. 2004). However, based on the New Mexico study, they have not yet developed an inspection manual, and still use a qualitative scale to rate culverts rather than a numerical scale (Villwock-Witte et. al. 2016).

A pilot program on culverts under 48 in. was performed in Indiana in a trial region, the goal was to inventory and inspect culverts based on existing rating scales and look for improvements. The study found that under the current 0-9 rating scale, a majority of the culverts were rated as a 9 (highest rating), and there was ambiguity between what constitutes a specific rating, such as the difference between an 8 and a 9. The results of the pilot proposed that the scale be modified for small culverts, using a 1-9 scale that only considers odd numbers and more descriptive rating definitions. These changes were proposed so that the range of rating values matched the existing 1-9 scale while reducing ambiguity between ratings. The study also recommended that photos be implemented into the inventory process, and that improvements be made to the inventory database (Bowers et. al. 2014).

In New Jersey, a pilot program was performed to switch asset management of culverts from a simple linear depreciation model to a condition based model that complies with the then new Governmental Accounting Standards Bureau (GASB) regulations (GASB-34). This pilot proposed a 1-5 rating method (1 being an excellent rating, 5 being a very poor rating), with ratings based on the level of overall deterioration. It also proposed that frequency of inspections be based on sediment damage to the culvert, pH levels, corrosivity/erosion potential of the area, and age vs design life. Many different culvert liners and materials were considered, and the results were used to predict remaining service life for use in asset management decisions (Meegoda et al. 2009).

In September 2016, MDOT published the Asset Collection & Condition Assessment Guide for 1 to <10 feet Span Culverts. This assessment guide highlights the pilot project to collect location and assessment data for 1-10 feet culverts under MDOT owned roadways in six counties; Eaton, Ingham, Isabella, Mackinac, Osceola, and Saginaw. Isabella County was inventoried under a separate pilot program in 2016 and condition evaluation was performed as part of the larger pilot in 2017. The MDOT report describes the Transportation Asset Management System (TAMS) interaction and integration in the collection of culvert data. In addition to the data collection process using TAMS, the guide provides information on attribute and condition assessment. The guide provides a comprehensive overview of the process of locating and assessing culverts and associated attributes (end treatments, footings, etc.). It should be noted that MDOT effectively considers 10 – 20 feet culverts as bridges, and inspections are included as a subset of their bridge inventory (MDOT 2016).

## 1.1.5. Inventory Data Collected

The New Mexico study identified key inventory data fields from their literature review and survey of state practices, as well as the frequency of their appearance. A summary of these findings are presented in Table 1 (Villwock-Witte et. al. 2016).

Table 1: Key Inventory Data Field (Villwock-Witte et. al. 2016)

| Field | Frequency in Literature | Frequency in State Review | Total |
|---|---|---|---|
| Culvert Shape | 8 | 11 | 19 |
| Culvert Material | 8 | 10 | 18 |
| Culvert Length | 7 | 10 | 17 |
| Comments | 6 | 8 | 14 |
| Current Overall Condition Rating | 8 | 5 | 13 |
| Inspection Date | 7 | 5 | 12 |
| Asset Identification | 6 | 5 | 11 |
| County Code | 4 | 7 | 11 |
| Mile Marker | 5 | 6 | 11 |
| Inspector Name | 6 | 5 | 11 |
| Culvert Latitude | 4 | 6 | 10 |
| Culvert Longitude | 4 | 6 | 10 |
| Road Name | 3 | 7 | 10 |
| Depth of Cover | 5 | 4 | 9 |
| Construction Date | 5 | 3 | 8 |
| Culvert Width | 2 | 6 | 8 |
| Culvert Span | 3 | 4 | 7 |
| Culvert Height | 2 | 5 | 7 |
| Number of Barrels | 1 | 6 | 7 |
| Road ID | 2 | 5 | 7 |
| Average Daily Traffic of Roadway Above Culvert | 4 | 1 | 5 |
| Culvert Diameter | 2 | 3 | 5 |
| Maintenance Responsibility | 2 | 3 | 5 |
| Municipality | 2 | 3 | 5 |
| Inlet Condition Rating | 2 | 3 | 5 |
| Outlet Condition Rating | 2 | 3 | 5 |
| Inventory Date | 1 | 4 | 5 |
| Roadway Surface Condition Rating | 4 | 1 | 5 |

Additionally, some agencies, such as Indiana (Bowers et. al. 2014), LA County (Venner 2014), and the Office of Federal Lands Highway (Hunt et. al. 2010), are finding that photographs of the culvert conditions are useful. In their small culvert pilot study, Indiana DOT recommended that a minimum of four photos be taken of every small culvert inspected; a wide angle overview photo of both the culvert inlet and outlet, and one inside view photo from both the culvert inlet and outlet. They also suggest taking additional pictures of irregular or concerning conditions in the culvert or on the roadway above the culvert (Bowers et. al. 2014).

## 1.1.6. Condition Evaluation Methods:

### *1.1.6.1. Federal Highway Administration (FHWA)*

FHWA issued report number FHWA-IP-86-2, Culvert Inspection Manual: Supplement of the Bridge Inspector's Training Manual in 1986. This manual provides information on culvert types, inspection procedures, and a culvert components inspection guide for approaches, end treatments, waterways, corrugated metal, precast concrete, cast-in-place concrete, and masonry culverts. The report provides guidance on data that should be collected for inventory and data that should be collected for condition evaluation of the culverts. The recommended rating system is a 0 to 9 scale, with 9 indicating that no repairs are needed and 0 indicating that the facility is closed for repairs. Condition assessments are made for the following items (Arnoult 1986):

- Approach roadway condition
- End treatment and appurtenant structures
- Waterway adequacy
- Channel and channel protection
- Corrugated metal culverts
- Corrugated metal culvert barrels
- Corrugated metal long-span structures
- Concrete culverts
- Precast concrete culvert barrels
- Cast-in-place concrete culvert barrels
- Masonry culverts
- Overall culvert ratings

### *1.1.6.2. National Cooperative Highway Research Program (NCHRP)/American Association of State Highway Transportation Officials (AASHTO)*

NCHRP 14-26, Culvert and Storm Drain System Inspection Manual, was published in May 2016 and serves as a proposed update to the FHWA Culvert Inspection Manual. The NCHRP report contains several changes from the FHWA method. The largest change is a proposed five-point rating system which the authors feel more directly correlates to observed conditions. Rating descriptions have been reorganized to a component-level evaluation to be consistent with the AASHTO Bridge Element Inspection Manual. Culvert materials including plastic and timber have been added. New rating descriptions were added to focus on incorporating quantitative measures of distress. The final NCHRP report was submitted to AASHTO for adoption (Beaver & Richie 2016).

The Culvert and Storm Drain System Inspection Manual is currently under review by AASHTO. It is not known what changes may be made to the NCHRP report and when publication by AASHTO may occur.

#### *1.1.6.3. 2008 Midwest Regional UTC (Madison)*

This method was developed as the result of a research project performed by the Midwest Regional University Transportation Center (UTC) in an attempt to give more insight for asset management of culverts. In this method, individual element ratings are combined into a single rating value based on a weighted average algorithm that uses an analytical hierarchy process (AHP) based on a pairwise comparison approach (i.e. “this is ___ more important than that”). This method is broken down into two tiers, Basic Condition Assessment (BCA) and Advanced Condition Assessment (ACA). In BCA, individual culvert components such as the invert, structure, and footings are rated on a 1-5 scale (5 being excellent and 1 being failure/critical) and then multiplied by a computed relative weight determined by an algorithm based on the decided importance of the component relative to other culvert components. These weighted component ratings are then summed to achieve an overall culvert rating. Each inspected culvert undergoes a BCA; if the structure scores higher than a 2.5, then the BCA score is assigned as the culvert condition rating. If the structure scores below a 2.5 on the 5-point scale, an ACA is performed to determine the overall culvert rating (Najafi et al. 2008).

In ACA, culvert conditions that lead to deterioration are rated rather than the components of the culvert themselves. These conditions are specific to the culvert material; for example, concrete culverts would be rated based on the conditions of cracking, scouring, settlement, joint openings, misalignment, and the concrete surface. Corrugated metal structures would be rated on different criteria. These conditions are rated on the same 1-5 scale, multiplied by a factor determined during the AHP, and then summed to achieve an overall culvert rating. Both the BCA and ACA culvert ratings are reported if ACA is performed (Najafi et al. 2008).

This analysis tool for condition ratings is more rigorous than other methods and is designed to make a greater distinction between culvert ratings in attempt to be a more useful tool for asset management. Additionally, this system proposes the collection of a specific and extensive set of inventory data, which it titles Culvert Inventory Data Collection Format (CIDCF) (Najafi et al. 2008).

#### *1.1.6.4. Agencies' Methods*

Vermont DOT uses a 0-9 scale National Bridge Inspection Standards (NBIS) rating system to evaluate their culverts between 6 and 20 feet and uses a five-level (excellent, good, fair, poor, critical) system to evaluate culverts less than 6 feet (FHWA 2004). Vermont has been collecting data on culverts between 6 and 20 feet as part of their bridge program for decades. Los Angeles County also uses descriptive condition ratings such as "good", "in need of repair", "blocked", "eroded", or "collapsed" (Venner 2014). Maryland uses the NBIS Item 62 (0-9 scale) for their culvert condition ratings. Minnesota inspects large culverts (10-20 feet) with a condition ratings system based on Pontis and NBIS. Smaller culverts (1-10 feet) are rated using a scale of 1 to 4 with 1 being the best condition. Pipes rated as 4 indicate an immediate fix may be required and those rated as 3 indicate repairs should be conducted as time and resources allow. Alabama does not require formal inspection reports, and written data is not collected or gathered into a database. Inspection is not based on a formal rating or NBIS condition evaluation system. Shelby County (Alabama) uses a condition rating system based on NBIS Item 62 ranging from 0-9 with 9 indicating "no deficiencies" and 0 indicating "structure closed and needing replacement" (FHWA 2007). Michigan's inspection guide uses a 1-9 scale, where 9 equals no repairs needed, and 1 indicates that emergency action is required and the roadway should be closed (MDOT 2016). The Office of Federal Lands Highway uses a good, fair, poor, critical system to rate their culverts, with different condition evaluation rating tables created for varying culvert types (Hunt et. al. 2010).

Ohio DOT had previously collected location and condition data for culverts with 10-20 feet spans using the 0-9 NBIS rating system and opted to continue and adapt that rating system for culverts less than 10 feet (Venner 2014). They have also developed their own Culvert Management System, detailed in their 2017 Culvert Inspection Manual. This document is based on the FHWA system, but provides additional quantitative and qualitative rating descriptors for rating corrugated metal, concrete, masonry, and plastic culvert structures beyond what is described by the FHWA (ODOT 2017).

The 2018 Wisconsin Department of Transportation (WisDOT) Bridge Inspection Field Manual provides descriptors for condition rating timber bridges whereas timber culvert condition ratings are not covered under the existing FHWA system. These condition ratings relate to deterioration problems experienced by culverts as well, and thus is a useful resource in developing a timber culvert condition rating system (WisDOT 2018).

### *1.1.7. Training Programs*

A few states provide explanations of their training processes. Ohio DOT conducts a focused one-day training on their 0-9 culvert rating system (Venner 2014). Minnesota DOT does not require NBIS training for inspectors of 1-10 feet culverts; however, most participate in a one-day course focused on condition, codes, problems, and data formatting (FHWA 2007).

In 2006, Alabama conducted a training program for engineers and engineering technicians from the Alabama DOT and local agencies on the use of asset management software. The format was three separate full-day seminars where attendees were introduced to culvert asset management, introduced to the FHWA Culvert Management System software, and performed practice problems regarding use of the software. Responses to this training session yielded mostly positive results from attendees (Davidson & Grimes 2006).

# APPENDIX B: PRE-CULVERT PILOT SURVEY

Which of the following best describes your current culvert inventory and condition evaluation program:

Culverts have not been inventoried or condition evaluated.

- What is your best estimate for the number of culverts in your jurisdiction?

A portion of agency culverts have been inventoried, but none or very few have had their condition evaluated on a routine basis (at least once every 5 years).

- How many culverts have been inventoried?
- What percentage of the culverts in your jurisdiction do you feel this represents? (Note: enter 100% if you believe every culvert is included in your inventory data)
- Culverts may be subdivided into categories to facilitate various needs such as condition evaluation techniques, asset management, or maintenance. If your agency subdivides culverts, what criteria is used and what benefit is gained?
- What culvert characteristics do you record?

a. Inventory ID
b. Waterway
c. GPS Coordinates
d. Material Type
e. Asset Collection Date
f. Date Installed
g. Shape
h. Entrance Structure
i. Exit Structure
j. Skew Angle
k. Length
l. Span
m. Rise
n. Depth of Cover
o. Height/Diameter
p. Width
q. Culvert Rating
r. Maintenance
s. Work Orders
t. Photos
u. Other -

- How do you organize and store your culvert inventory data? (e.g., paper files, spreadsheet, database, asset management software, etc.)
- If some of your culverts have had their condition evaluated, please describe your strategy for evaluating culverts and the rating system that you used.

Most culverts have been inventoried and their condition evaluated on a routine basis (at least once every 5 years)

- How many culverts have been inventoried?
- What percentage of the culverts in your jurisdiction do you feel this represents? (Note: enter 100% if you believe every culvert is included in your inventory data)
- Culverts may be subdivided into categories to facilitate various needs such as condition evaluation techniques, asset management, or maintenance. If your agency subdivides culverts, what criteria is used and what benefit is gained?
- What culvert characteristics do you record?

    a. Inventory ID
    b. Waterway
    c. GPS Coordinates
    d. Material Type
    e. Asset Collection Date
    f. Date Installed
    g. Shape
    h. Entrance Structure
    i. Exit Structure
    j. Skew Angle
    k. Length
    l. Span
    m. Rise
    n. Depth of Cover
    o. Height/Diameter
    p. Width
    q. Culvert Rating
    r. Maintenance
    s. Work Orders
    t. Photos
    u. Other -

- How do you organize and store your culvert **inventory** data? (e.g., paper files, spreadsheet, database, asset management software, etc.)
- How many culverts have been condition evaluated?

- What rating system do you currently use? (please note if different rating systems are used for different subcategories of culverts, for example culverts 1 – 9.9 feet vs 10 – 19.9 feet)
    - FHWA (1986) (the system used by RoadSoft)
    - Other, please provide more information:
- What components of the culvert system are considered in your overall condition evaluation? (e.g., upstream end, culvert pipe, downstream end, apron, etc.)
- How frequently do you evaluate the condition of your culverts? Does the frequency vary depending on culvert size, material, condition of roadway above, or other properties?
- What tools and equipment do you use to conduct condition evaluation of culverts?
- How do you organize and store your culvert **condition** data? (e.g., paper files, spreadsheet, database, asset management software, etc.)

Other comments you would like to share with the TAMC Bridge Committee regarding the Michigan Culvert Mapping Pilot Program or your agency's current culvert inventory and condition evaluation program:

Would you be interested in participating in the pilot? We are looking for agencies with all levels of existing culvert inventory and condition data. Participants must be able to complete their inventory, condition evaluation, and reporting by August 2018.

Agency –
Name –
Email –
Phone number –
May we contact you with any questions?

# APPENDIX C: PARTICIPATING LOCAL AGENCIES

| Agency | County | Tier |
|---|---|---|
| Antrim County Road Commission | Antrim County | Tier 1 |
| Baraga CRC | Baraga County | Tier 1 |
| Charter Township of Clayton | | Tier 1 |
| Charter Township of Ypsilanti | | Tier 1 |
| Charter Township of Flushing | | Tier 1 |
| City of Battle Creek | | Tier 1 |
| City of Benton Harbor | | Tier 1 |
| City of Brown City | | Tier 1 |
| City of Burton | | Tier 1 |
| City of Clio | | Tier 1 |
| City of East Tawas | | Tier 1 |
| City of Fenton | | Tier 1 |
| city of ironwood | | Tier 1 |
| City of Lake Angelus | | Tier 1 |
| City of Munising | | Tier 1 |
| City of Southfield | | Tier 1 |
| City of West Branch | | Tier 1 |
| City of Whitehall | | Tier 1 |
| Farmington Hills | | Tier 1 |
| Houghton County Road Commission | Houghton County | Tier 1 |
| Lake County Road Commission | Lake County | Tier 1 |
| Leelanau County Road Commission | Leelanau County | Tier 1 |
| Marquette County Road Commission | Marquette County | Tier 1 |
| Marquette CRC | Marquette County | Tier 1 |
| Missaukee County Road Comm. | Missaukee County | Tier 1 |
| Montcalm County Road Commission | Montcalm County | Tier 1 |
| Networks Northwest | | Tier 1 |
| Village of Vermontville | | Tier 1 |
| village of  Carsonville | | Tier 1 |
| Village of Caledonia | | Tier 1 |
| village of Daggett | | Tier 1 |
| Village of Fairgrove | | Tier 1 |
| Village of Holly | | Tier 1 |
| Village of Howard City | | Tier 1 |
| Village of Lincoln | | Tier 1 |
| Village of Morrice | | Tier 1 |
| Village of Newberry | | Tier 1 |

| Agency | County | Tier |
|---|---|---|
| Village Of Pentwater | | Tier 1 |
| Village of Sanford | | Tier 1 |
| Village of Walkerville | | Tier 1 |
| Roscommon Co. Road Comm. | Roscommon County | Tier 2 |
| Tuscola County Road Commission | Tuscola County | Tier 2 |
| City of Tecumseh | | Tier 2 |
| Cass County Road Commission | Cass County | Tier 2 |
| City of Cadillac | | Tier 2 |
| Oceana County Road Commission | Oceana County | Tier 2 |
| Oceana County Road Commission | Oceana County | Tier 2 |
| Oscoda County Road Commission | Oscoda County | Tier 2 |
| Shiawassee County Road Commission | Shiawassee County | Tier 2 |
| City of Muskegon Heights | | Tier 2 |
| Kalkaska County Road Commission | Kalkaska County | Tier 2 |
| Hillsdale County Road Commission | Hillsdale County | Tier 2 |
| Lapeer County Road Commission | Lapeer County | Tier 2 |
| Barry CRC | Barry County | Tier 2 |
| Saginaw County Road Commission | Saginaw County | Tier 2 |
| City of Marysville DPW | | Tier 2 |
| City of Big Rapids | | Tier 2 |
| City of St. Louis | | Tier 2 |
| Road Commission of Kalamazoo County | Kalamazoo County | Tier 2 |
| Van Buren County Road Commission | Van Buren County | Tier 2 |
| Village of Lennon | | Tier 2 |
| HRC - City of Bloomfield Hills | | Tier 2 |
| St. Clair County Road Commission | St. Clair County | Tier 2 |
| City of Coldwater | | Tier 2 |
| Branch County Road Commission | Branch County | Tier 2 |
| City of Mt. Pleasant | | Tier 2 |
| Grand Traverse County Road Commission | Grand Traverse County | Tier 2 |
| Ottawa County Road Commission | Ottawa County | Tier 2 |
| Benzie County Road Commission | Benzie County | Tier 2 |
| Mecosta County Road Commission | Mecosta County | Tier 2 |
| Allegan County Road Commission | Allegan County | Tier 2 |
| Ingham County Road Department | Ingham County | Tier 2 |
| Dickinson County Road Commission | Dickinson County | Tier 2 |
| St Clair County Road Commission | St. Clair County | Tier 2 |
| Muskegon County Road Commission | Muskegon County | Tier 2 |

| Agency | County | Tier |
|---|---|---|
| Genesee County Road Commission | Genesee County | Tier 3 |
| City of Rochester Hills | | Tier 3 |
| Washtenaw County Road Commission | Washtenaw County | Tier 3 |
| Clinton County Road Commission | Clinton County | Tier 3 |
| Road Commission for Oakland County | Oakland County | Tier 3 |
| Huron County Road Commission | Huron County | Tier 3 |
| Bay County RC | Bay County | Tier 3 |
| Kent County Road Commission | Kent County | Tier 3 |
| Midland County Road Commission | Midland County | Tier 3 |

# APPENDIX D: TRAINING DOCUMENT

## INTRODUCTION

This document will provide guidance on how and what inventory data to collect for the TAMC Michigan local agency culvert pilot, particularly with regards to condition evaluation of culverts. It will outline the inventory data input into Roadsoft as described in the Condition Evaluation webinar presented on April 26, 2018 and May 2, 2018, and provide information regarding what culvert aspects should be inspected for a given culvert type.

For determining a specific condition rating of a culvert, inspectors should use the Culvert Rating Charts provided during the webinars. The purpose of this document is to provide further detail on the condition ratings provided on those rating charts.

It is noted that this pilot considers any structure with a span under twenty feet as a culvert, and any span larger than twenty feet is considered a bridge. Around twenty feet, it may be unclear whether to rate the structure as a bridge or culvert; the inspector should make this judgement. If it is determined to rate a structure as a bridge, the inspector should use the MDOT bridge inspection form.

# INVENTORY DATA INPUT INTO ROADSOFT

Inventory ID – Automatically generated by Roadsoft.

GPS Coordinates – Latitude and longitude of the culvert, measured at the middle of the road overtop the structure and recorded in decimal degrees.

Material Type – The primary material of the culvert structure.

- Undefined
- Aluminum Box Culvert
- Aluminum Long Span Structure
- Cast-in-place Concrete Culvert
- Corrugated Aluminum Pipe
- Corrugated Steel Box Culvert
- Corrugated Steel Pipe
- Long Span Corrugated Steel Structure
- Masonry Culvert
- Other
- Pre-Cast Concrete Pipe
- Structural Plate Aluminum Pipe
- Structural Plate Steel Pipe
- None

**Modified Roadsoft Fields**

- Plastic
- Timber
- Steel
- Aluminum
- Concrete

Asset Collection Date – Date at which the condition ratings were collected.

Shape – Original shape of the culvert, reference Figure 1 for common shapes.

- Undefined
- Arch
- Circular
- High Profile Arch
- Horizontal Ellipse
- Low Profile Arch
- Other
- Pear
- Pipe Arch
- Rectangular
- Underpass
- Vertical Ellipse

**Modified Roadsoft Fields**

- Box
- Multi-cell box
- 3-sided
- Slab/superstructure & abutment

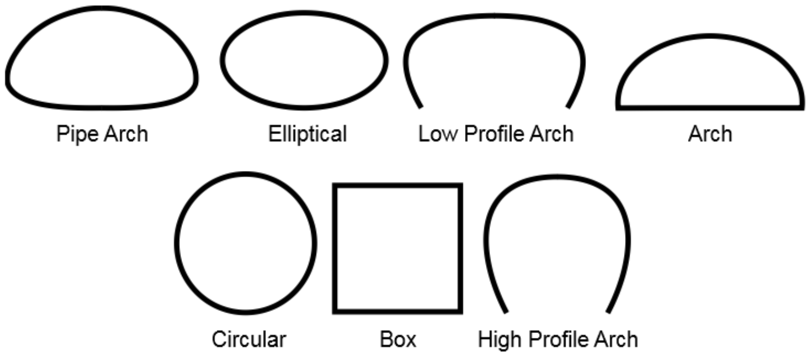


*Figure 1. Common Shapes (Note that arch and box shapes may be 3-sided, supported by footings)*

Skew Angle – The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of the road with the centerline of a culvert. Reference Figure 2.

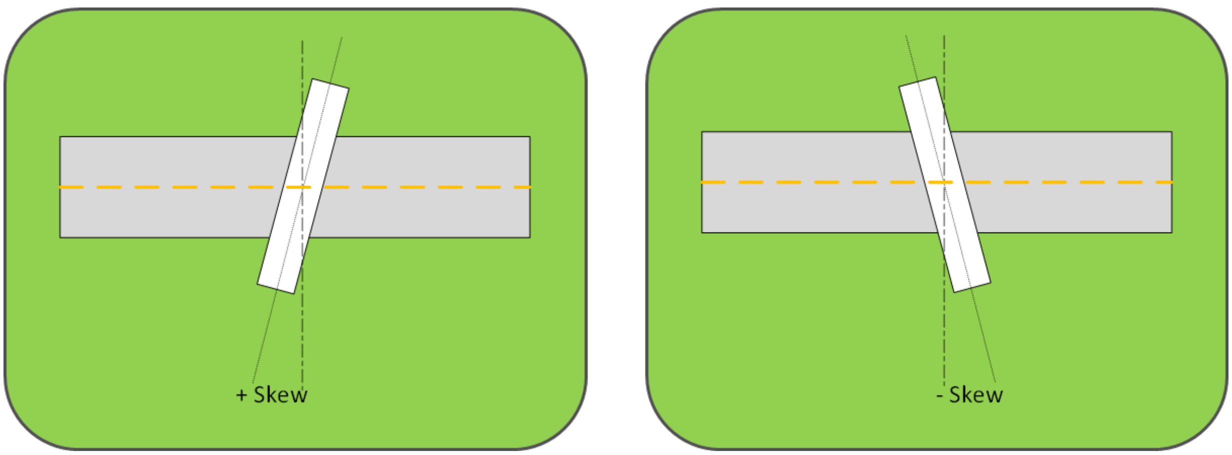


*Figure 2. Positive and Negative Skew Angles*

Length – Horizontal distance of the culvert from inlet to outlet. Reference Figure 3.

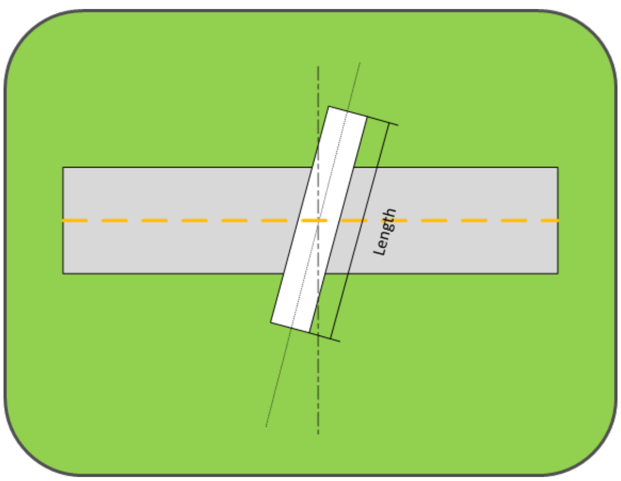


*Figure 3. Length of Culvert*

Width – The original distance of the culvert opening (perpendicular to the length). Reference Figure 4.

Height / Diameter – The original height of the culvert opening. Reference Figure 4.

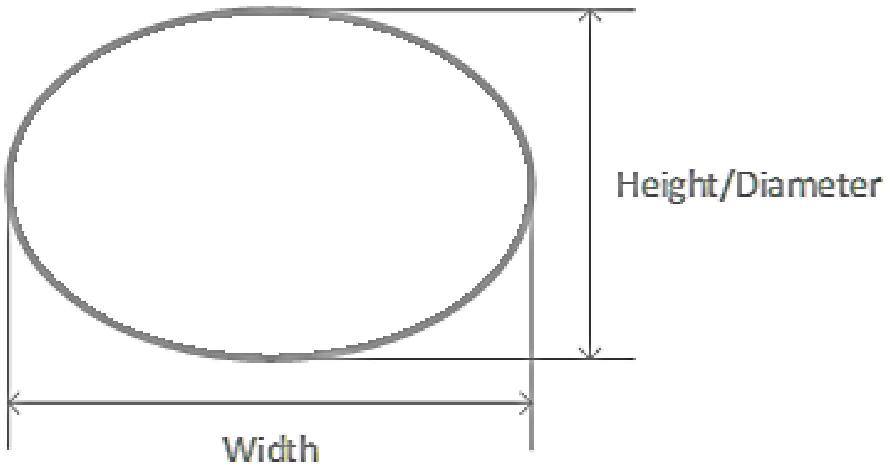


*Figure 4. Width & Height/Diameter of Culvert Structures*

Depth of Cover – The depth of soil from the roadway to the peak of the culvert structure. Reference Figure 5 on how to take measurement.

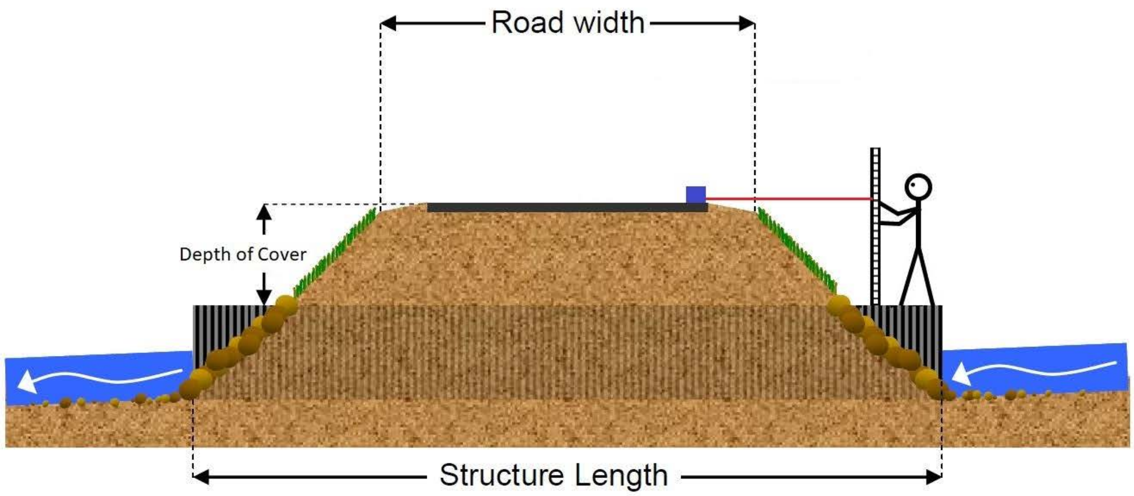


*Figure 5. Measuring Depth of Cover*

Roadway Surface Type – Surface type of the roadway above the culvert.

Culvert Condition Rating – An overall culvert condition rating entered into the statewide database.

- Based on Structural Deterioration, Invert Deterioration, Structural Deformation, Joints/Seams, Blockage, and Scour element ratings for the culvert.
- Generally represents the weakest link.
    - Can be overridden by inspector for site-specific circumstances
    - Please add comment if rating different than the lowest of the 6 element ratings

Photographs (optional) –

- Primary photos:
    - 2 from each end (4 total)
        - One looking at the inlet/outlet and some surroundings
        - One looking into the culvert
- Secondary photos:
    - At the discretion of the inspector
        - Road Surface
        - Blockage
        - Scour
        - Etc.

# CONDITION RATING DEFINITIONS

**Abrasion:** Wearing or grinding away of material by water laden with sand, gravel, or stones. Abrasion is generally most serious in steep areas where high flow rates carry sand and rocks that wear away the culvert invert. Abrasion can also accelerate corrosion by wearing away protective coatings.

**Backfill:** The material used to refill the trench, or the embankment placed over the top of the bedding and culvert.

**Bedding:** The soil used to support the load on the pipe. For rigid pipe, the bedding distributes the load over the foundation. It does the same thing for flexible pipe except that it is not as important a design factor.

**Bed Load:** Sediment that moves by rolling, sliding, or skipping along the bed and is essentially in contact with the streambed.

**Buckling:** A bend, warp, or crumpling in flexible materials (usually as a result of compression).

**Backfill:** The material used to refill the trench, or the embankment placed over the top of the bedding and culvert.

**Capacity:** Maximum flow rate that a channel, conduit, or structure is hydraulically capable of carrying. The units are usually cubic feet per second (CFS) or gallons per minutes (GPM).

**Coating:** Any material used to protect the integrity of the structural elements of a pipe from the environment and add service life to the culvert.

**Cover:** The depth of backfill over the top of the pipe.

**Compaction:** The process by which a sufficient amount of energy is applied to soil to achieve a specific density.

**Corrosion:** Deterioration of metal due to electrochemical or chemical reactions. Culverts are subject to corrosion in certain aggressive environments. Can apply to reinforcement in concrete and masonry structures, or for corrugated metal structures directly.

**Crack:** A fissure in installed precast concrete culvert.

**Crown:** The top or highest point of the internal surface of the transverse cross section of a pipe.

**Culvert:** A drainage opening beneath an embankment, usually a pipe, designed to flow according to open channel equation.

**Debris:** Any material including floating woody materials and other trash, suspended sediment, or bed load, moved by a flowing stream.

**Degradation:** General progressive lowering of the stream channel by erosion.

**Deflection:** A deviation from the original design shape without the formation of sharp peaks or valleys.

**Delamination:** Subsurface separation of concrete into layers. Separation of reinforcement from concrete.

**Differential Settlement:** Unequal movement of structural components previously aligned creating differences in vertical positioning.

**Dimpling:** Used to describe a wavy or waffling pattern that occurs in the inner wall of plastic pipe due to local instability.

**Efflorescence:** Deposits on concrete or brick caused by crystallization of carbonates brought to the surface by moisture in the masonry or concrete

**Embankment:** A bank of earth, rock or material constructed above the natural ground surface over a culvert.

**Erosion:** Wearing away of the streambed (or embankments) by flowing water

**Flexible Structures:** A structure with relatively little resistance to bending. CMP and plastic structures are flexible structures.

**Footings (Foundation):** The in-place material beneath the pipe, arch, or three-sided box. Usually made of concrete and supports the main structure.

**Galvanizing:** A protective coating of zinc applied to corrugated metal to resist corrosion and rust damage

**Hairline cracking:** Very small cracks that form in the surface of the concrete pipe due to tension caused by loading. Small hairline cracks with hardly perceptible widths are common and are not cause for alarm in concrete structures. Moisture, leakage, and staining will make these cracks more severe over time.

**Hinging:** Used to describe yielding of the flexible material due to excessive bending moment in the pipe wall. Pipe wall exhibits a sharp crease pointed inward or outward. Hinges usually form at the 3 o'clock and 9 o'clock positions.

**Honeycombs:** Areas in concrete where mortar has separated and left spaces between the coarse aggregate, usually caused by improper vibration during concrete construction

**Invert:** The bottom or lowest point of the internal surface of the transverse cross section of a pipe.

**Joint:** A connection between two pipe sections, made either with or without the use of additional parts

**Leakage:** Water infill through concrete cracks

**Piping:** A process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around or beneath the culvert.

**Pitting corrosion (pitting):** A form of extremely localized corrosion in corrugated metal that leads to the creation of small holes in the metal.

**Pop-outs:** Conical fragments broken out of a concrete surface by pressure from reactive aggregate particles

**Rigid Structures:** A pipe with a high resistance to bending. Concrete and Masonry structures are rigid structures.

**Rip Rap:** Rough stone of various sizes placed compactly or irregularly to prevent scour by water or debris.

**Scaling:** Gradual but continuing loss of mortar and aggregate over an area due to the chemical breakdown of the cement bond. Occurs in concrete and masonry culverts.

**Scour (Outlet):** Degradation of the channel at the culvert outlet as a result of erosive velocities.

**Seepage:** The escape of water through the soil, or water flowing from a fairly large area of soil instead of from one spot, as in the case of a spring.

**Spalling:** Depressions in concrete caused by a separation of a portion of the surface concrete, revealing a fracture parallel with or slightly inclined to the surface. Exposed reinforcing bars can be present.

**Springline:** The points on the internal surface of the cross section of a pipe intersected by the line of maximum horizontal dimension; or in box sections, the mid-height of the internal vertical wall.

**Wall Crushing:** Used to describe yielding of plastic material in the wall produced by excessive compressive stresses. Pipe wall exhibits a wrinkled effect.

# CORRUGATED METAL PIPE

## Structural Deterioration

Corrosion of the culvert structure can be a serious problem with adverse effects on the culvert's structural performance. Extensive corrosion along the culvert structure is a common indication that the soil surrounding the culvert has corrosive action influenced by the soil's electrical resistivity, chloride content, and pH level. This corrosion can weaken the structural capacity of the culvert over time and can lead to collapse. The condition of the metal in corrugated metal culverts and any coatings, if used, should be considered when assigning a rating to the culvert structure. Extensive pitting corrosion is of critical importance; section loss plays a large role in structural stability depending on location and significance of the pitting.

The inspection should include visual observations of invert metal corrosion and abrasion. As steel corrodes it expands considerably. Relatively shallow corrosion can produce thick deposits of scale. A geologist's pick-hammer can be used to scrape off heavy deposits of rust and scale permitting better observation of the metal. A hammer can also be used to locate unsound areas of exterior corrosion by striking the culvert wall with the pick end of the hammer. When severe corrosion is present, the pick will deform the wall or break through it. The inspector should document the extent & location of surface deterioration problems along the invert.

Localized denting and cracking damage should also be inspected for, especially if this damage occurs under the roadway. When examining dents in corrugated steel culverts, the opposite side of the plate should also be checked, if possible, for cracking or de-bonding of the protective coating.

## Invert Deterioration

*Closed Bottom Structures-*

Corrosion and abrasion of culvert inverts can be serious problems with adverse effects on the culvert's water conveyance. If excessive corrosion and abrasion occur along the invert, the invert can become perforated and significant undercutting can occur. Damage due to corrosion and abrasion is a common cause for culvert replacement. The condition of the metal in corrugated metal culverts and any coatings, if used, should be considered when assigning a rating to the culvert invert.

Corrosion along the invert is commonly due to acidity of water flowing through it and should be inspected for in the same manner as corrosion of the structure. Abrasive damage of the invert is due to soils and/or debris carried through the culvert. The invert and any protective coatings should be examined for abrasion damage, tearing, cracking, and removal.

Corrugated metal culverts may be paved with concrete inverts. Paved concrete inverts are usually floating slabs used to carry water. Invert slabs provide protection against erosion and undercutting and are also used to improve hydraulic efficiency. Concrete inverts are sometimes used in circular, as well as other culvert shapes, to protect the metal from severe abrasive or severe corrosive action. Concrete invert slabs should be checked for undermining and damage such as spalls, open cracks, and missing portions. The significance of the damage will depend on its effect on the corrugated metal. Inspectors should note the condition of any liner if present but should rate the condition of the corrugated metal.

*Arches-*

See *Invert Deterioration – Footings* section

## Structural Deformation

The deformation inspection should begin by approaching the culvert from the ends and sighting the sides and top. Also check for signs of pavement depression, guardrail movement, or gaps between headwalls and the pipe barrel. The cross-sectional shape of the culvert barrel should be observed and measured when inspecting flexible culverts. The deformation rating for the culvert is to account for irregularities transverse to the culvert barrel.

Measurements should be taken at the ends of the structure, and at additional intermediate locations depending on the size and condition of the structure. Monitoring programs might be needed to determine the rate of movement.

Significant changes in shape since the last inspection should be carefully evaluated, even if the structure is still in fairly good condition. Dimensional checks should be made for suspect structures, and these dimensions should be monitored over time. If there is instability of the backfill, the pipe will continue to change shape. When distortion or curve flattening is apparent, the extent of the flattened area, in terms of arc length, length of culvert affected, and the location of the flattened area should be described in the inspection report.

For structures with shallow cover, the inspector shall make observations of the culvert with a few live loads passing over it. Discernible movement in the structure may indicate possible instability and a need for more in-depth investigation. Different culvert shapes will be rated by different criteria.

*Closed Bottom Structures-*

Each closed bottom shape will deform in different manners depending on its geometry. Generally, for round pipes, smooth curvature will start to form on the crown of the structure and flattening will occur in the invert of the structure as deformation occurs. Severity of these deformations will depend on how much the structure has deformed in its horizontal direction and severity of isolated deformations, such as kinks.

Different shapes have different percentages of horizontal direction expansion to indicate severity of damage. For example, a Fair condition round structure can deform 10-15% greater than its original design while a Fair Pipe Arch can deform only 5-7% greater than its original design. Refer to the CMP Section Deformation Rating Chart to rate specific shapes.

*Arches-*

Arches are fixed on concrete footings, usually below or at the springline. The springline is the horizontal line connecting the furthest horizontal extents of the culvert. This difference between pipes and arches is that an arch tends to deflect differently during the placement of backfill. Backfill forces tend to flatten the arch sides and peak its top. As a result, important deformation factors to look for in an arch are flattened sides, peaked crown, and a flattened top arc.

Another important deformation factor in arches is symmetry. If the arch was erected with the base channels not square to the centerline, it can lead to a racking of the cross section. A racked cross-section is one that is not symmetrical about the centerline of the culvert. One side tends to flatten; the other side tends to curve more while the crown moves laterally and possibly upward. If these distortions are not corrected before backfilling the arch, they usually get worse as backfill is placed.

## Joints/Seams

If there are joints between pipe segments not connected by seams, refer to *Joints* section.

Corrugated metal structures often have overlapping seams bolted together that connect plates at the joints (Circumferential Seams). Additional seams also exist on structural metal plate culverts longitudinal to traffic that link plates together to form a cross section (Longitudinal Seams). All bolted splice seams should be checked for loose or missing bolts, corrosion on the bolts or metal at the connections, and tears or cracks in metal at the bolt lines. Longitudinal seams must be checked for additional criteria. If a structural metal plate culvert is being inspected, the worse rating of the longitudinal and circumferential seams shall be selected as the controlling rating.

Circumferential Seams- The circumferential seams in helical pipe, like joints in factory pipe, do not carry ring compression thrust in the pipe. They do make the conduit one continuous structure. Distress in these seams is rare and will ordinarily be the result of a severe differential deflection or distortion problem or some other manifestation of soil failure. For example, a steep sloping structure through an embankment may be pulled apart longitudinally if the embankment moves down. Plates should be installed with the upstream plate overlapping the downstream plate to provide a “shingle” effect in the circumferential seam. Seam distress is important to note during inspections since it would indicate a basic problem of stability in the fill. Circumferential seam distress can also be a result of foundation failure, but in such cases should be clearly evident by the vertical alignment.

Longitudinal Seam Defects in Structural Metal Plate Culverts - Longitudinal seams should be visually inspected for open seams, cracking at bolt holes, plate distortion around the bolts, bolt tipping, cocked seams, cusped seams, and for significant metal loss in the fasteners due to corrosion. In riveted or spot welded pipes, the seams are longitudinal and carry the full ring compression in the pipe. These seams must be sound and capable of handling high compression forces. When inspecting the longitudinal seams of bituminous-coated corrugated metal culverts, cracking in the bituminous coating may indicate seam separation.

Seam Defects in Structural Plate Culverts:

(1) Loose Fasteners- Seams should be checked for loose or missing fasteners. For steel structural plate structures, longitudinal seams are bolted together with high-strength bolts in two rows; one row in the crests and one row in the valleys of the corrugations. These are bearing type connections and are not dependent on a minimum clamping force of bolt tension to develop interface friction between the plates. Fasteners in steel structural plate may be checked for tightness by tapping lightly with a hammer and checking for movement.

For aluminum structural plate structures, the longitudinal seams are bolted together with normal strength bolts in two rows with bolts in the crests and valleys of both rows. These seams function as bearing connections, utilizing bearing of the bolts on the edges of holes and friction between the plates.

(2) Cocked and Cusped Seams- The longitudinal seams of structural plate are the principal difference from factory pipe. The shape and curvature of the structure is affected by the lapped bolted longitudinal seam. Improper erection or fabrication can result in cocked seams or cusped effects in the structure at the seam. Slight cases of these conditions are fairly common and frequently not significant. However, severe cases can result in failure of the seam or structure. When a cusped seam is significant the structure's shape appearance and key dimensions will differ significantly from the design shape and dimensions. The cusp effect should lead to the structure to receive very low ratings on the shape inspection if it is a serious problem. A cocked seam can result in loss of backfill and may reduce the ultimate ring compression strength of the seam.

(3) Seam Cracking- Cracking along the bolt holes of longitudinal seams can be serious if allowed to progress. As cracking progresses, the plate may be completely severed and the ring compression capability of the seam lost. This could result in deformation or possible failure of the structure. Longitudinal cracks are most serious when accompanied by significant deflection, distortion, and other conditions indicative of backfill or soil problems. Longitudinal cracks are caused by excessive bending strain, usually the result of deflection. Cracking may occasionally be caused by improper erection practices such as using bolting force to “lay down” a badly cocked seam.

(4) Bolt Tipping- The bolted seams in structural plate culverts only develop their ultimate strength under compression. Bolt tipping occurs when the plates slip. As the plates begin to

slip, the bolts tip, and the bolt holes are plastically elongated by the bolt shank. High compressive stress is required to cause bolt tipping. Structures have rarely been designed with loads high enough to produce a ring compression that will lead to bolt tip. However, seams should be examined for bolt tip particularly in structures under higher fills. Excessive compression on a seam could result in plate deformations around the tipped bolts and failure is reached when the bolts are eventually pulled through the plates.

## Blockage

Refer to Blockage Section

## Scour

Refer to Scour Section

# CONCRETE PIPE

## Structural Deterioration

In concrete structures, reinforcing steel is designed to assume some of the imposed loads. Therefore, small hairline cracks (with widths that are hardly perceptible) are expected and are not cause for alarm. Larger cracks, especially those with evidence of efflorescence or rust staining, are a greater cause of concern that will influence the criticality of the cracks. Inspectors should look for cracking and note the extensiveness of the individual cracks, and the number of overall cracks.

The location of cracking in concrete structures can indicate the type of problems being experienced. In concrete pipe, longitudinal cracks at the 3, 6, 9, and 12 o'clock positions indicate flexure cracking caused by poor side support. Longitudinal cracking in the invert at the 5 and 7 o'clock positions indicate shear cracking caused by poor haunch support. Likewise, cracking at the 11 and 1 o'clock positions may be the result of shear forces from above the structure. Cracking at comparable locations in box culverts indicate similar failure types. Transverse cracks may also occur and are usually the result of non-uniform bedding or fill material causing point loads on the pipe. Inspectors should note the locations of cracking in their report for determination of their cause.

Spalling and delamination affect the structural performance of concrete structures as well. Spalled sections indicate failing structural performance of the reinforcement due to corrosion, especially if pop-outs have occurred, which can critically affect structural stability if the spalled section is large enough or there are multiple spalled sections. Delamination is similar to spalling, if the concrete delaminates, the structural performance is reduced significantly, especially if the reinforcement separates from the concrete. Inspectors should note any and all sections with evidence of spalling and delamination and note any exposed rebar and visible corrosion of the reinforcement.

Abrasion leading to scaling should be noted in the inspection as well. Surface scaling allows for continued abrasion to be more destructive to the concrete and can wear away at the material more quickly. This can expose reinforcement, reduce the structure's durability, and shorten the service life of the culvert. The inspector should note the amount of scaling and its depth along the invert.

## Invert Deterioration

*Closed Bottom Structures-*

Invert deterioration of closed bottom structures should be rated using the same criteria as structural deterioration.

*Open Bottom Structures-*

See *Invert Deterioration – Footings* section

## Structural Deformation

Not Applicable

## Joints/Seams

Refer to *Joints* section

## Blockage

Refer to *Blockage* section

## Scour

Refer to *Scour* section

# PLASTIC PIPE

## Structural Deterioration

Plastic pipe materials may experience splits that can affect structural performance of the culvert. A split, rip, tear, or crack is any separation in the wall material other than at a designed joint. Inspectors should note any split in the plastic material; their criticality will depend on the size and number of splits. Larger splits and multiple splits have a larger chance of structural failure.

Buckling damage, such as bends, warps, or crumpling, are reported under the section deformation rating and should not be considered in the Structural Deterioration rating.

## Invert Deterioration

Plastic pipe materials are prone to abrasive damage due to soils and debris flowing through the culvert; perforations due to abrasion on the invert should control for plastic invert inspection. The severity of these perforations depends on their location along the length of the culvert, and the size and amount of perforations.

## Structural Deformation

There are several things to be considered determining shape deformations in plastic pipe. Deflection, or a deviation from the original design shape should be inspected for. Deflection becomes critical when the pipe deforms completely under its load, causing severe, sharp bends at the peak of the structure. Multiple types of buckling (bends, warps, or crumpling) should be inspected for as well, caused by hinging, wall crushing, or dimpling. All these deformations are indicators of the culvert's failing condition and functionality.

## Joints/Seams

Refer to *Joints* section

## Blockage

Refer to *Blockage* section

## Scour

Refer to *Scour* section

# MASONRY

## Structural Deterioration

Much like concrete culverts, cracking and spalling can have a large impact on the structural performance of masonry culverts. When this damage is widespread, the culvert condition is more critical. Inspectors should note significant cracking, and spalling of the masonry blocks as well as their locations.

Displacement of individual masonry units can have an effect on the overall structure performance as well. This is most true when the displaced masonry units are at the bottom of the structural sidings; if these units become dislodged, the units they support above are prone to collapse as well. The inspector should note significantly displaced masonry units, especially if there are multiple in close proximity to each other.

## Invert Deterioration

See *Invert Deterioration – Footings* section

Masonry structures also commonly have concrete inverts. If the structure under inspection has a concrete invert, rate the invert based on the *Concrete Closed Bottom Structure* rating.

## Structural Deformation

Not Applicable

## Joints/Seams

Refer to *Joints* section

Joints in masonry culverts are rated in a slightly different manner; the joints in a masonry structure are not aligned between specific segments, but rather they are present between masonry blocks. These joints are inspected for mortar cracks, water exfiltration, backfill infiltration, vegetation in the cracks, and misalignment due to lack of mortar. All of these problems can indicate a failing masonry culvert structure.

## Blockage

Refer to *Blockage* section

## Scour

Refer to *Scour* section

# SLAB AND ABUTMENT

## Structural Deterioration

The slab is the primary load-carrying member and should be inspected top and bottom for evidence of leakage, deterioration and structural adequacy. The edge of the slab, approximately the first 12 inches, will not govern the condition rating.

Visually inspect the concrete deck for cracks, spalls, and other defects. Hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid “pinging” type sound.

Documentation should be placed on the form stating if the reinforcing steel bars are exposed on all surfaces. Note length, number of bars exposed, and location.

Common concrete deck defects may include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Corrosion of reinforcing bars

## Invert Deterioration

See *Invert Deterioration – Footings* section

## Concrete / Masonry Abutment

An abutment is a substructure unit located at the ends of a bridge or slab culvert. Its function is to provide end support for the bridge and to retain the approach embankment. Wingwalls are also located at the ends of a bridge or culvert. Their function is only to retain the approach embankment and not to provide end support for the bridge. Wingwalls are considered part of the abutment component only if they are integral with the abutment. When there is an expansion joint or construction joint between the abutment and the wingwall, that wingwall is defined as an independent wingwall and not considered in the evaluation of the abutment component.

Inspection procedures for abutments involve examining material deterioration and settlement. However, because stability is a paramount concern, checking for various forms of movement are required.

The most common problems observed during the inspection of abutments are:

- Vertical movement
- Lateral movement
- Rotational movement
- Material defects
- Drainage system malfunction

## Blockage

Refer to *Blockage* section

## Scour

Refer to *Scour* section

# TIMBER

## Structural Deterioration

Crushing due to rot, insect or rodent damage, and abrasion or wear are the largest threats to timber culvert structures. Insects or rodents can penetrate the structure and eat away at the wood members while leaving holes, creating section loss of the member's cross section, and lessening the member's structural capacity. Inspectors should look for evidence of infiltration by searching for the small holes on the surface of wood members. Minor insect or rodent damage can have little effect on structural capacity, but when significant damage has occurred, the structural capacity will be reduced.

Rotting members, particularly those near the bottom of the structure, will threaten the structural capacity of the member as well. When a wood member is significantly rotted, it is prone to crushing from the weight it supports. Inspectors should note any significant areas of rot, especially on primary structural members.

Abrasion is another factor causing section loss of structural members in timber structures. Abrasion due to soils and debris will wear down and chip away the wood surface over time, reducing the durability of the invert. Typical abrasion damage in wood inverts appears as chips and reduced thicknesses. Inspectors should note any significant abrasion resulting in significant member section loss.

Checks and cracking of key structural members, particularly stringers, is a sign of imminent collapse and is of critical importance. Heavy loading or consistent fatigue loading on these members will increase the stress on these members, causing the cracks and checks to extend, and may lead to failure of the members. Inspectors should note any visible structural cracks on structural members. It should be noted that standard drying cracks in wood are normal and expected, and do not constitute structural problems.

The connecting fasteners should also be inspected for rusting, loosening, or any other damage that will threaten the integrity of the connection. The severity of the fastener conditions on the structural deterioration will depend on the extent and severity of damage.

## Invert Deterioration

See *Invert Deterioration – Footings* section

Timber structures also commonly have concrete inverts. If the structure under inspection has a concrete invert, rate the invert based on the *Concrete Closed Bottom Structure* rating.

## Structural Deformation

Not Applicable

## Joints/Seams

Refer to *Joints* section

## Blockage

Refer to *Blockage* section

## Scour

Refer to *Scour* section

## INVERT DETERIORATION – FOOTINGS

For structures supported by footings, such as CMP arches, three-sided box culverts, and slab and abutment structures, the “invert” considered in rating is the footings. These footings are assumed to be made of concrete and suffer from the same deterioration problems as concrete structures, such as spalling, scaling, and cracking. For more specifics on these deterioration problems, refer to the Concrete Structural Deterioration section.

Erosion of the streambed over time can expose the footings to water flow and lead to damage of the footings. Additionally, if the erosion is severe enough, differential settlement of the structure can occur due to the footings unequal movement from their original positions resulting from loss of soil support. Damage in the structure is often apparent if differential settlement has occurred; distress in the walls will occur resulting in an unusual cross section.

Inspectors should note the severity of erosion around the culvert’s footings based on the depth of the footing that is exposed to water flow, and any damages or settlement that has occurred as a result of this erosion.

## JOINTS

Key factors to look for in the inspection of joints is if there are openings, the severity of any openings, misalignment between segments, and indications of soil infiltration and water exfiltration due to seepage through open joints. Inspectors should record joint defects with their locations and severity indicated. If the structure is one continuous structure (i.e. not segmented or bolted at joints), this rating can be skipped. If the joints are held together by seams, the condition of the seams should be rated in addition to any joint openings.

Joint defects may include:

1. Open joints
2. Seepage at the joints
3. Misalignment of joints
4. Surface sinkholes over the culvert

Movement of the structural segments from their original position due to settlement and erosion can lead to openings to form at the joints between segments, known as open joints. The vertical offset between pipe segments should be examined to determine severity. Open joints can seepage to occur through the joints and lead to misalignment between structural segments if the separation is severe. Excessive seepage through an open joint can lead to soil infiltration or erosion of the surrounding backfill soil material, reducing lateral support. The larger the joint opening, the more severely that this is likely that this is to occur. Open joints may be probed with a small rod or flat rule to check for voids. Misalignment of joints should be apparent when looking down the culvert from the end. If there are open joints and the structure appears to be running irregularly, there is likely some misalignment.

Seepage along the outside of the culvert barrel may also remove supporting material. This process is referred to as “piping”, since a hollow cavity similar to a pipe is often formed. Piping can also occur through open joints. Piping is controlled by reducing the amount and velocity of water seeping along the outside of the culvert barrel. Piping at open joints should be considered in the joint rating as well.

## BLOCKAGE

Scour and upstream streambed degradation can be increased due to inadequate waterway area caused by blockage. The geometry of the culvert barrel, the amount of debris carried by the channel during high water periods, and the adequacy of freeboard should be considered in determining waterway adequacy. Check for the formation of sandbars or debris which could change the direction of flow or other obstructions which could influence the adequacy of the waterway opening. Accumulation of drift and debris at the orifice of the culvert should be noted on the inspection form and included in the condition rating.

Some culverts installed in recent years were intentionally placed below the normal streambed elevation. This is done to promote the formation of a natural stream bottom through the culvert barrel and is required in some streams for migratory fish species. The burial of the invert should be noted in the construction plans on the culvert detail sheets. When inspecting such culverts, the Culvert Waterway Blockage rating should not be down rated if the culvert was originally designed with a buried invert.

## SCOUR

The removal of a streambed or bank area by stream flow is called scour. If not addressed, scour can lead to the undermining of footings, headwalls, and culvert end sections through the continual removal of supporting material. Eventually, serious structural problems such as piping and the rotation of footings can take place as additional supporting material is removed. Additionally, scour can affect the culvert's water conveyance and its ability for aquatic organisms to pass. The depth of any scouring should be measured with a probing rod by the inspector. In low flow conditions, scour holes have a tendency to fill up with debris or sediment. The inspector should also indicate the location and extent of any undercutting around footings, headwalls, wingwalls, and the end sections of the culvert. Scour holes can eventually cause cantilevered pipe end sections to detach and collapse or bend down, restricting stream flow.

Culverts supported by footings, such as three-sided box culverts and arches without an invert slab are considered to be scour critical structures. The inspector should check such structures for evidence of scour and undermining of the footings. The inspector should also look for any indication of footing rotation.

# REFERENCES

Arnoult, JD. 1986. Culvert Inspection Manual. Federal Highway Administration (FHWA). IP-86-2. [Available from: https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=31&id=57]

Hunt JH, Zerges SM, Roberts BC, Bergendahl B. 2010. Culvert Assessment and Decision-Making Procedures Manual For Federal Lands Highway, First Edition. Federal Highway Administration (FHWA). CFL/TD-10-005. p. B.1-B.74. [Available from: https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=208&id=166]

MDOT. 2016. Asset Collection & Condition Assessment Guide for 1’ - <10’ Span Culverts. Michigan Department of Transportation (MDOT). [Available from: https://www.michigan.gov/documents/mdot/MDOT_RFP_SS_REQ2435_Tams_Culvert_Colection_616748_7.pdf]

MDOT. 2017. Michigan Structure Inspection Manual (MiSIM). Michigan Department of Transportation (MDOT). [Available from: https://www.michigan.gov/mdot/0,4616,7-151-9625_24768_24773-326737--,00.html]

ODOT. 2017. Culvert Inspection Manual. Ohio Department of Transportation (ODOT). p. 29-67. [Available from: http://www.dot.state.oh.us/Divisions/Engineering/Hydraulics/Culvert%20Management/Pages/Culvert-Management.aspx]

WisDOT. 2018. Bridge Inspection Field Manual. Wisconsin Department of Transportation (WisDOT). p. 48-57. [Available from: http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/inspection-manual.aspx]

# APPENDIX E: INVENTORY ITEMS

| | MDOT Pilot | Roadsoft | Michigan Geographic Framework (MGF) Database | TAMC Culvert Pilot (per 2-22-18 meeting) |
|---|---|---|---|---|
| **Inventory** | | | | |
| City/Township | | x | | |
| Reference Intersection | x | x | | |
| Reference Distance | | x | | |
| Beneath | x | | | |
| Milepoint | | x | | |
| Inventory ID | x | x | x | x |
| Waterway | | x | | |
| GPS Coordinates | | x | | x |
| Description | | x | | |
| Material Type | x | x | x | x |
| Asset Collection Date | x | x | x | x |
| Date Installed | x | x | x | |
| Number of Culverts | | x | | |
| Shape | x | x | x | x |
| Entrance Structure | x | x | | |
| Exit Structure | x | x | | |
| Skew Angle | | x | | x |
| Length | | x | x | x |
| Span | | x | x | x |
| Rise | | x | x | x |
| Depth of Cover | x | x | | x |
| Height/Diameter | x | x | x | x |
| Width | x | x | x | x |
| Liner | x | | | |
| Liner Material | x | | | |
| Liner Diameter | x | | | |
| Spatial Quality Index | x | | | |
| Road Surface Elevation Upstream | | x | | |
| Road Surface Elevation Downstream | | x | | |

| | | | | |
|---|---|---|---|---|
| Invert Elevation Upstream | | x | | |
| Invert Elevation Downstream | | x | | |
| Invert Above Channel Bottom | x | | | |
| Riprap (Y/N) | x | | | |
| Safety Grate (Y/N) | x | | | |
| End Extension (Y/N) | x | | | |
| Extension Material Same as Original (Y/N) | x | | | |
| Extension Shape Same as Original (Y/N) | x | | | |
| Extension Dimensions Same as Original (Y/N) | x | | | |
| Wetland Protection Act | | x | | |
| Inland Lakes Act | | x | | |
| Memo | | x | | |
| Scheduled Maintenance/Inspection Activity | | x | | |
| Surface Type | | x | x | x |
| Collection Type | | | x | |
| | | | | |
| **Condition Evaluation** | | | | |
| Culvert Rating | x | x | x | x |
| invert deterioration | | x | | x |
| joints/seams | | x | | x |
| section deformation | | x | | x |
| corrosion | | x | | x |
| scour | | x | | x |
| blockage | | x | | x |
| Channel Rating | | x | | |
| Waterway Rating | | x | | |
| Maintenance | | x | | |
| Work Order | | x | | |
| Stream Crossing Survey | | x | | |
| Photos/other attachments | | x | | |