Culvert Durability Rating Systems

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The culvert condition rating systems used in durability studies conducted by various private, state, and federal agencies are reviewed in this paper. The rating scales used in these studies were analyzed and compared. A new material durability rating system for both metal and concrete pipe is proposed based on these comparisons. The rating scale corresponds to the one used by the National Bridge Inventory and Inspection Program. The new system will ensure that all types of culvert materials are uniformly rated in every study and will promote the development of a comprehensive data base on the durability of each product material.

The durability of culverts has been studied at great length over the past four decades. Many states at one time or another have conducted at least one study of metal or concrete culverts. Unfortunately, most results have been inconclusive or controversial. Site conditions have an significant effect on how long a facility will last. Product materials react differently in various environments because of inherent strengths and weaknesses. Pipe manufacturers, federal, state, and local government agencies, and consultants all have different opinions on the expected service life of culvert materials and the effects of site conditions.

Durability studies conducted to date have not used a common rating system, instead most have developed their own. This does not present any particular problem to the agency conducting the study but does create problems of correlating information from various studies into a comprehensive assessment of a particular product's qualities and durability in different environments.

Information and ratings from one study seldom correspond directly with those of another, resulting in conflicting data and possible misinterpretation of the information. The answer to these problems is a standard rating system for inspecting and evaluating the condition of the various types of culvert products. A standard rating system would ensure that all culverts were rated identically, end the guess work of correlating studies, eliminate the time and effort of developing rating systems, and eventually provide a comprehensive data basc on the durability of each product material. With a standard rating system, various studies could be analyzed to provide guidance on product service lives.

Evaluated in this paper are current state and federal culvert durability rating systems and clarifications are developed to facilitate the use of the Federal Highway Administration (FHWA) *Culvert Inspection Manual* (*1*).

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FHWA *CULVERT INSPECTION MANUAL*

The Federal Highway Administration presents standard guidelines in their *Culvert Inspection Manual* (*1*). This publication is a stand-alone supplement to the *Bridge Inspector's Training Manual 70* (*2*). The manual is a unique and valuable tool in that it is the first publication to interrelate reporting procedures, rating systems, and component evaluations. The primary objective of the manual is to provide information that will enable users to do the following tasks:

1. Properly inspect an existing culvert,
2. Evaluate structural adequacy,
3. Evaluate hydraulic adequacy and recognize potential flood hazards,
4. Rate the condition of the culvert,
5. Document the findings of a culvert inspection,
6. Recognize and document traffic safety conditions, and
7. Recommend corrective actions.

To meet these objectives, recommendations are made in the manual for procedures for conducting, reporting, and documenting a culvert inspection, and guidelines for inspecting and rating specific hydraulic and structural culvert components are also provided. Major culvert components, such as shape, joints, seams, footings, and material conditions for metal pipe, and alignment, joint, material, and footing conditions for concrete pipe are described and evaluated to assist the inspector in identifying common types of culvert distress and recognizing their significance. Detailed provisions and guidelines are provided for each type of metal and concrete pipe configuration (Tables 1 and 2).

Recommended in this paper are changes in the assessment and rating of material durability conditions for metal and concrete pipe to improve inspection procedures and evaluation of data. Although distress conditions of both materials are presented in the manual in a systematic and well-structured way, a greater degree of detail is necessary in the condition descriptions to ensure that unique characteristics and features are associated with each rating number in order to eliminate subjective interpretation by an inspector.

Slight modifications to the culvert rating system will be based on the information contained in the durability studies from the various states analyzed. The proposed rating of material evaluations, based on the system used in the *Bridge Inspectors Training Manual 70* (*2*), is as follows:

Rating	*Description*
9	New condition.
8	Good condition–no repairs necessary.
7	Generally good condition–potential exists for maintenance
6	Fair condition–potential exists for major maintenance.
5	Generally fair condition–potential exists for minor rehabilitation.
4	Marginal condition–potential exists for major rehabilitation.
3	Poor condition–repair or rehabilitation required immediately.
2	Critical condition–the need for repair or rehabilitation is urgent. Facility should be closed until the indicated repair is complete.
1	Critical condition–facility is closed. Study should determine the feasibility for repair.
0	Critical condition–facility is closed and is beyond repair.

RATING SYSTEMS

Culvert rating systems included in available state durability reports and federal agency publications, as well as pertinent Transportation Research Board papers, were examined. A list of the 151 references resulting from the literature search is available from the author. Discussion in this paper is limited to those studies that reflect current practices in each region of the country (Figure 1).

There are a number of methods used for analyzing culvert durability. Studies based on percent of metal or concrete loss provide documentation on the actual pipe wall thickness and the rate of deterioration, but may not present an accurate assessment of the culvert's overall condition. Concrete and metal loss cannot be rated in a linear fashion. Once abrasion and corrosion forces start to pit the surface of the metal, the area exposed to corrosion is increased and the rate of metal loss accelerates. Ratings of 20 to 30 percent metal loss do not portray the actual severity of the installation's condition (Table 3). A culvert with its zinc coating lost, metal heavily corroded and pitted, and a quarter of its thickness gone was not considered indicative of a facility in good condition by any of the other studies examined. Similarly, if 50 percent of a concrete pipe wall had deteriorated, it could represent a much more serious problem than a linear rating would indicate. A rating system should take these effects into consideration.

TABLE 1 FEDERAL HIGHWAY ADMINISTRATION'S CULVERT INSPECTION RATING GUIDELINES FOR CORRUGATED METAL CULVERT BARRELS (*1*)

Rating Guidelines for Round or Vertical Elongated Corrugated Metal Pipe Barrels

Rating	Condition
9	• New Condition
8	• *Shape*: good, smooth curvature in barrel - *Horizontal*: within 10 percent of design • *Seams and Joints*: tight, no openings • *Metal*: - *Aluminum*: superficial corrosion, slight pitting - *Steel*: superficial rust, no pitting
7	• *Shape*: generally good, top half of pipe smooth but minor flattening of bottom - *Horizontal Diameter*: within 10 percent of design • *Seams or Joints*: minor cracking at a few bolt holes, minor joint or seam openings, potential for backfill infiltration • *Metal*: - *Aluminum*: moderate corrosion, no attack of core alloy - *Steel*: moderate rust, slight pitting
6	• *Shape*: fair, top half has smooth curvature but bottom half has flattened significantly - *Horizontal Diameter*: within 10 percent of design. • *Seams or Joints*: minor cracking at bolts is prevalent in one seam in lower half of pipe. Evidence of backfill infiltration through seams or joints. • *Metal*: - *Aluminum*: significant corrosion, minor attack of core alloy - *Steel*: fairly heavy rust, moderate pitting
5	• *Shape*: generally fair, significant distortion at isolated locations in top half and extreme flattening of invert - *Horizontal Diameter*: 10 percent to 15 percent greater than design • *Seams or Joints*: moderate cracking at bolt holes along one seam near bottom of pipe, deflection of pipe caused by backfill infiltration through seams or joints. • *Metal*: - *Aluminum*: significant corrosion, moderate attack of core alloy - *Steel*: scattered heavy rust, deep pitting
4	• *Shape*: marginal significant distortion throughout length of pipe, lower third may be kinked - *Horizontal Diameter*: 10 percent to 15 percent greater than design • *Seams or Joints*: Moderate cracking at bolt holes on one seam near top of pipe, deflection caused by loss of backfill through open joints • *Metal*: - *Aluminum*: extensive corrosion, significant attack of core alloy - *Steel*: extensive heavy rust, deep pitting
3	• *Shape*: poor with extreme deflection at isolated locations, flattening of crown, crown radius 20 to 30 feet - *Horizontal Diameter*: in excess if 15 percent greater than design • 3 in. long cracks at bolt holes on one seam • *Metal*: - *Aluminum*: extensive corrosion, attack of core alloy, scattered perforations - *Steel*: extensive heavy rust, deep pitting, scattered perforations
2	• *Shape*: critical, extreme distortion and deflection throughout pipe, flattening of crown, crown radius over 30 feet - *Horizontal Diameter*: More than 20 percent greater than design • *Seams*: plate cracked from bolt to bolt on one seam • *Metal*: - *Aluminum*: extensive perforations due to corrosion - *Steel*: extensive perforations due to rust
1	• *Shape*: partially collapsed with crown in reverse curve • Seams: failed • *Road*: closed to traffic
0	• *Pipe*: totally failed • *Road*: closed to traffic

NOTE: See Coding Guide for description of Rating Scale. As a starting point, select the lowest rating that matches actual conditions.

TABLE 2 FEDERAL HIGHWAY ADMINISTRATION'S CULVERT INSPECTION RATING GUIDELINES FOR CONCRETE CULVERT BARRELS (*1*)

Rating Guidelines for Precast Concrete Pipe Culvert Barrels			
Rating	Condition	Rating	Condition
9	• New condition		
8	• *Alignment*: good, no settlement or misalignment • *Joints*: tight with no defects apparent • *Concrete*: no cracking, spalling, or scaling present; surface in good condition	4	• *Alignment*: marginal; significant settlement and misalignment of pipe; evidence of piping; end sections dislocated about to drop off • *Joints*: differential movement and separation of joints, significant infiltration or exfiltration at joints • *Concrete*: cracks open more than 0.12 in. with efflorescence and spalling at numerous locations; spalls have exposed rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in.
7	• *Alignment*: generally good; minor misalignment at joints; no settlement • *Joints*: minor openings, possible infiltration/exfiltration • *Concrete*: minor hairline cracking at isolated locations; slight spalling or scaling present on invert		
6	• *Alignment*: fair, minor misalignment and settlement at isolated locations • *Joints*: minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration • *Concrete*: extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. deep or small spalls present.	3	• *Alignment*: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • *Joints*: significant openings, dislocated joints in several locations exposing fill materials; infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway. • *Concrete*: extensive cracking, spalling, and minor slabbing; invert scaling has exposed reinforcing steel
5	• *Alignment*: generally fair; minor misalignment or settlement throughout pipe; possible piping • *Joints*: open and allowing backfill to infiltrate; significant cracking or joint spalling • *Concrete*: cracking open greater than 0.12 in. with moderate delamination and moderate spalling exposing reinforcing steel at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. deep	2	• *Alignment*: critical; culvert not functioning due to alignment problems throughout • *Concrete*: severe slabbing has occurrerd in culvert wall, invert concrete completely deteriorated in isolated locations
		1	• *Culvert*: partially collapsed • *Road*: closed to traffic
		0	• *Culvert*: total failure of culvert and fill • *Road*: closed to traffic

NOTE: See Coding Guide for description of Rating Scale. As a starting point, select the lowest rating that matches actual conditions.

FIGURE 1 Location of study reports, indicated by shaded areas.

TABLE 3 CALIFORNIA STATE RATING SYSTEM (*3*)

Rating	Metal Loss (%)	Water	Air Splash	I (inside)	O (outside)	Soil	Abrasion
0	0						
1	10						
2	20						
3	30						
4	40						
5	50	Designates metal loss in the culvert due to the various corrosion components.					
6	60						
7	70						
8	80						
9	90						
10	100						

In some studies, sample coupons from field installations were used to determine the metal thickness and were the main basis on which the condition of the facility was rated (Table 4). A major problem with ratings systems based on coupons is the lack of correlation between coupons and field ratings. Coupons may not include perforations, or coating blisters, or thickness loss that may otherwise be observed in field inspections.

Rating systems based on visual observations are more subjective than the precise techniques used for measuring the pipe wall thickness, however they are more indicative of a culvert's overall performance. Visual condition ratings should be based on the worst area observed in the culvert because this will be the most likely point of failure. A uniform rating system should, therefore, be based on visual ratings with detailed descriptions of the culvert's conditions and should include measurements where appropriate.

The first step in developing a comprehensive durability rating system is to examine available studies, analyze the rating systems, and prepare a rating table that most closely reflects the conditions considered by the majority. On the surface this may appear to be a straightforward task, but most studies have a unique goal that is reflected in the rating table. Rating tables also vary in evaluation of condition ratings. What one study considers a poor rating may be a fair or critical rating for another. The range of ratings may also be restricted by the numbering system used. More broad numbering systems provide more latitude in rating a structure but they may, however, prove to be cumbersome if too large. A 0 to 100 scale, although allowing the rater more room for assessment than a 1 to 5 scale, is meaningless to the rater and reviewer if evaluations are other than increments of 10. A scale of 1 to 10 seems to provide the best compromise between maximum flexibility in rating and maintenance of a distinct significance in each number.

Although a scale based on 10 allows easy conversion of many studies and direct correlation to percentages, it does not correspond to the most widely used and accepted rating scale based on 9, which is used in the National Bridge Inspection Program. By using the bridge program's 0 to 9 scale, culvert inspections will follow a national program already in force. The use of an established rating system would make adoption and use of culvert guidelines easier, because no changes to the current bridge system would be necessary and inspectors would already be familiar with the rating scale. A common system would help promote more culvert reviews and result in larger data bases on pipe products.

METAL CONDITION RATING SYSTEMS

The condition rating scales for corrugated metal pipe from the various state studies are presented in Table 5. There is no distinction made between steel and aluminum in the tables because, regardless of actual durability characteristics, the distress conditions are essentially identical. All state rating scales have been adjusted to conform to the 0 to 9 scale. For comparison purposes, the studies were arranged on the scale according to their original condition guidelines. State condition ratings for metal culverts were similar in the top values of 9 and 8. Once a metal culvert had deteriorated past superficial rust, there was little agreement on the rating, and most studies did not show a uniform systematic progression of deterioration. Rating conditions jumped dramatically from "pinpoint rust" to "heavy pitting rust," with very little, if any, guidance given to evaluate conditions between these extremes. Rating descriptions were also not quantitative. Describing a condition as simply "moderate signs of deterioration" does not adequately explain the condition. Specific degrees of deterioration should be listed such as depth of rust, degree of pitting, and amount of thinning of the metal.

The severity placed on the first sign of perforation was somewhat uniform and represented a critical rating: 1 or 0,

TABLE 4 COUPON RATINGS SYSTEMS

Rating Scale	Idaho (*4*)[a] Metal	Colorado (*5*)[b] Metal	Concrete
5	Like new	No visible corrosion	No apparent change except slight staining
4	Dull: age weathered to the point all zinc luster gone	Light salt deposit or rusting, blistering near edges	Light pitting and/or salt deposits
3	Pinpoint rust: evidence of rust in very small areas	Mild salt deposit or rusting, blistering near edges	Moderate loss of surface mortar and salt accumulation
2	Scale rust: large areas of rust wherein scale can be seen	Extensive rusting and formation of blisters	Moderate loss of aggregate
1	Pitting: rusted to the extent base metal is pitted	Severe corrosion or rusting	Extensive aggregate loss, swelling and/or warping of coupon
0		Very severe rusting or loss of adhesion of protective coating	Total failure of coupon

[a] From field installations, used reverse scale in report.
[b] Based on coupons exposed to environmental conditions.

TABLE 5 STUDIES ON METAL CONDITION RATINGS

RATING	FLORIDA (6)	KANSAS (7)	CALIFORNIA (LA COUNTY) (8)	LOUISIANA (9)	MAINE (10)	MICHIGAN (11)	MINNESOTA (12)	MISSISSIPPI (13)
9		No corrosion - Galvanizing intact.	No corrosion.	No signs of deterioration.	Approaching Original Condition (Galvanizing intact)			
8	Galvanizing intact.		Superficial corrosion. Discoloration of surface, red or black scale lightly adhering to surface.			Galvanizing intact.	Spelter entirely intact.	Spelter entirely intact.
7		Superficial rust (edges and bolt heads) - No pitting; weathered to point all zinc luster gone.	Slight corrosion. Some loss of zinc coating, thin flaking and shallow pitting of surface.	Very slight signs of deterioration and pitting.	Superficial Rust (no pitting).			
6	(+) Galvanizing partly gone, some surface rust.					(+) Galvanizing partly gone, some rust.	(+) General pinpoint rust.	(+) Spelter just gone and thin rust beginning to form in places, no abrasion and no pitting.
5		Moderate rust - Rust flakes light, minor pitting.	Moderate corrosion. Deep pitting of surface.	Moderate signs of deterioration and pitting.	Moderate Rust (minor pitting).			
4	(+) Galvanizing gone. Significant metal loss (about 25%).					Galvanizing gone, significant metal loss.	Heavy pitting rust.	Complete loss of spelter and considerable loss of metal in invert. Pitting and some abrasion.
3		(+) Fairly heaving rusting - Rust flakes light, moderate pitting, but metal is sound.	Heavy corrosion. Build-up of laminations of rust scale.		(+) Fairly Heavy Rust (moderate pitting, metal sound).			
2	Deep pitting, heavy metal loss, first perforation visual or under blows of spike (at least 50% metal loss).			Extreme signs of deterioration and pitting.		Deep pitting, heavy metal loss, metal can be perforated with a sharp metal probe.	Heavy pitting rust and loss of metal in invert.	Decided pitting and abrasion. Heavy loss of metal in invert.
1	Complete metal loss in about 1/2 area of maximum corrosion in invert.	(+) Heavy rusting - Rust flakes easily removed - Deep pitting into base metal.	Heavy corrosion. Beginning to perforate.		(+) Heavy Rust (deep pitting and some perforation).		Start of perforations.	Metal corroded and abraded through invert in small spots. Very heavy rust and deep pitting in general over invert.
0	Metal gone, full width of area of maximum corrosion.	Heavy rust - Deep pitting and unsound or perforated areas. Unsound areas easily perforated with pick end of geologist hammer.	Perforated.	Signs of complete deterioration, and the pipe is no longer useful as a drainage tool.	Unsound Areas (extensive perforation to bottom completely deteriorated).	Metal perforated.	Entire invert gone.	Entire invert gone.

(+) Indicates intermediate rating - condition may also correspond to the next highest rating.
* National Corrugated Steel Pipe Association.

in all cases. The exact uniform and represented a critical rating: 1 or 0, in all cases. The exact point of failure, however, varied for each study. Some considered this point to be the first perforation, others considered it the deterioration of the entire invert or the collapse of the facility.

Each study concentrated on a unique durability feature, with most increasing the number of rating descriptions as the facility neared failure. One notable exception was the Ohio report. The upper half of the ratings are very distinct and clear for conditions representing "excellent" to "fair" facilities. The "poor" rating, however, constitutes one condition description and dominates the entire lower half of its rating system. There is a great deal of deterioration that must take place for a facility to go from a "fair" condition, which constitutes heavy rust and scale with no penetration, to a "poor" condition, which has the invert gone. The poor rating in this case is too large to be of benefit to an evaluator interested in the lower range of conditions approaching failure. The Ohio report, however, recognized the limitations of the rating system used. The predictive equations developed were based solely on measured metal loss.

The use of the broad "poor" category was reasonable in this case because they were not concentrating on predicting failure by means of evaluating metal ratings but only on identifying those installations that were considered in poor condition. The Ohio report is noteworthy because it illustrates the importance of understanding the concentration and scope of the study before reviewing its data.

The Ohio study also highlights another problem with ratings systems that are skewed heavily in one direction. Reviewers of a rating scale may assume that there is a linear relationship for each of the rated conditions. In the case of the Ohio report and many other studies, this observation would lead to estimation of deterioration to failure sooner than it would actually occur. Care must be taken to review the rating scale and conditions before using and comparing data from a particular study.

The proposed metal rating system in Table 6 provides a detailed and unique description for each rating from new to failure. Incorporated in this table are all changes and additions to the metal rating descriptions in the FHWA *Culvert Inspection Manual* (*1*). The intent was to provide a rating system that is easy to understand and has logical increments of deterioration. Major conditional features identified include galvanizing, level of rust, depth of pitting, metal thinning, and degree of perforations. The ratings in the state studies were adjusted to reflect the facility condition ratings described in the bridge rating scale. The effect was the consolidation of

TABLE 5 *continued*

RATING	OHIO (14)	OKLAHOMA (15)	OREGON (16)	TENNESSEE (17)	WASHINGTON (18)	NCSPA (19)
9	Condition as constructed, no apparent loss of galvanizing (Excellent).	Culvert shows absence of only minor amounts of thin rust coatings present as spots or patches of less than one inch diameters. Spelter intact, even in the invert area. Geology Hammer: hard blows will not penetrate (Excellent).	Zinc like new.		Spelter like new	
8	Discoloration but no scaling or corrosion (Very Good).		Zinc dull to very dull.	Spelter entirely intact	Spelter dull to very dull	Spelter intact - spangles visible
7	Slight to and scale, pitting just started, isolated spots of moderate corrosion (Good).	Thin continuous coatings of rust in invert area. Spelter absent in invert area. Some small blisters (scale) occasionally present. Geology Hammer Hard blow will not penetrate (Good)	Pinpoint rust spots, zinc entirely gone		Pinpoint rust spots spelter entirely gone	
6	Moderate to heavy scale and rust, no geologist's hammer penetration, no perforation (Fair).		Light rust film, shallow pitting	(+) General pinpoint rust	Light rust film, shallow pitting	(+) General pinpoint rust
5		Thick and scaling rust coatings, pitting of culvert surface noticeable. Geology Hammer Penetrates with 2-3 hard blows in same area (Fair)	Rust or pits not halfway through core metal.		Rust or pits not halfway through core metal.	
4				Heavy pitting rust.		(+) Heavy pitting rust.
3		Scaling pronounced, pitting of metal surface obvious and widespread. Geology Hammer Perforates with one moderate blow (Poor).	Rust or pits halfway through core metal.		Rust or pits halfway through core metal.	
2	Penetration with geologist's hammer, perforation, loss of invert (Poor).		Rust or pits over halfway through core metal.	Heavy pitting rust and loss of metal in invert.	Rust or pits three-quarters through core metal.	Rust scaling loose.
1		(+) Severe scaling, pitting progresses to perforation. Holes may be any size. The rating of (Pf) will be used until such deterioration has taken place in order to cause failure (Perforation).	Few holes through metal.	Start of perforation.	Few holes through metal.	First small perforation.
0		Culvert is bent, warped, sagged, broken, etc., to such an extent as to cause the culvert not to function as intended (Failure).	Large area of metal gone.	Entire invert gone.	Large areas of metal gone.	Perforations large or beginning to connect so small strip removed.

(+) Indicates intermediate rating - condition may also correspond to the next highest rating.
* National Corrugated Steel Pipe Association.

TABLE 6 METAL CONDITION RATINGS

Rating	Condition	Description
9	Excellent	New condition, galvanizing intact, no corrosion.
8	Very good	Discoloration of surface, galvanizing partially gone.
7	Good	Superficial or pinpoint rust spots, no pitting.
6	Fair	Moderate rust, rust flakes tight, shallow pitting of surface galvanizing gone.
5	Fair—marginal	Heavy rust and scale, moderate pitting and slight thinning of core metal.
4	Marginal	Extensive heavy rust, thick and scaling rust coatings, deep pitting and significant metal loss (approximately 25 percent).
3	Poor	Rust and pitting halfway through core metal (some deflection or penetration when struck with pick or geology hammer).
2	Very poor	Extreme deterioration and pitting, three quarters of core metal gone, first perforations.
1	Critical	Extensive or large perforations.
0	Failure	Invert completely deteriorated, culvert beginning to bend, warp or sag, collapse of the culvert is imminent.

some of the less significant upper ratings and an expansion of the ratings of the more critical factors. The degree of perforations now span over three ratings instead of one or two, as was the case in many of the state scales. They are still considered poor or critical items, but now correspond closer to the depth of rust and pitting, and thinning of the metal.

CONCRETE COALITION RATING SYSTEMS

The concrete condition rating scales from the state studies are illustrated in Table 7. One observation immediately apparent upon reviewing the table is the lack of reports. There have been very few studies on the durability of concrete pipe. Durability problems are rare with highway concrete culverts, and normally the only problem encountered is concrete loss in the invert resulting from acidic effluents such as those in mine drainage areas. The state of Ohio has conducted the most studies on concrete culverts, with concentration on the effects of acid environments on the pipe.

The conditional rating scales for concrete pipe were similar, considering the small data base available for analysis. Deterioration concentrated on the degree of scaling and softness of the concrete. In all but one case, deterioration was described in a distinct and systematic progression. Failure was uniformly

TABLE 7 STUDIES ON CONCRETE CONDITION RATINGS

RATING	KANSAS (7)	MAINE (10)	MISSISSIPPI (13)	OHIO (I) (14)	OHIO (II) (20)
9	Intact - no deterioration.	Approaching original condition.		Condition of concrete as constructed (Excellent)	As manufactured.
8			No weathering or disintegration and no softening from acid or alkali or other causes	Discoloration but no loss corrosion, or softening (Very Good)	Slight loss of mortar, aggregate not exposed.
7	Light scaling - 0-1/8" in depth.	Discoloration, slight (scaling) of mortar, no softening of concrete.		Slight loss of mortar leaving aggregate exposed (Good)	Moderate loss of mortar, aggregate exposed.
6			(+) Some weathering or (scaling) and disintegration. Slight erosion of invert.	Moderate loss of mortar and aggregate, slight softening of concrete (Fair).	Significant loss of mortar around aggregate.
5	Medium scaling - 1/8"-1/4" depth.	Slight scaling of smaller aggregate, no softening.			Significant loss of mortar, slight aggregte loss.
4			(+) Decided disintegration or erosion in invert. General weathering and (scaling). Softening due to alkali or acid.		Moderate aggregate loss (part of first layer).
3	(+) Heavy scaling - Scaling over 1/4" depth.	(+) Moderate (scaling) (loss of mortar and aggregate minor amounts of softening).			Aggregate loss (all of first layer into second layer).
2			(+) Decided disintegration throughout the pipe. Considerable weathering and (scaling). Softening due to alkali or acid.	Significant loss of mortar and aggregates, complete loss of invert, concrete in softened condition (Poor).	Reinforcing exposed at a few places.
1	(+) Heavy scaling - Exposed mesh or rust showing on surface.	(+) Extensive (scaling) of mortar and aggregate plus softening of concrete.	Extreme disintegration and (scaling). Material very soft due to acid or alkali.		Reinforcing exposed throughout pipe.
0	Heavy scaling - Total thickness of pipe deteriorated.	Invert completely deteriorated.	Disintegration through pipe. Reinforcing exposed.		Reinforcing gone.

(+) Indicates intermediate rating - condition may also correspond to the next highest rating.

considered to be complete disintegration of the invert at a rating of 0.

Table 7 contains two Ohio studies and is a good example of the differences between rating systems. The first, Ohio (I), was developed from the same study as the metal rating system. The rating systems were consistent for both metal and concrete in that there was a strong concentration on the conditional ratings for the upper range of the scale and only one for the lower half. A follow-up study, Ohio (II), conducted 3 years later, provided a much more detailed rating system for concrete pipe. Unfortunately, this study did not cover metal pipe and, therefore, no comparable rating scale is available. This scale proved to be one of the most comprehensive rating systems found for concrete pipe.

The proposed concrete rating system in Table 8 provides a detailed and unique description for each rating from new to failure. Changes and additions to the concrete rating descriptions in the FHWA *Culvert Inspection Manual* (*1*) are shown in bold type. The rating system provides logical and progressive increments of deterioration for mortar and aggregate scaling, concrete hardness, and reinforcement condition. As in the case of the metal rating scale, the conditional ratings in the state studies had to be modified and consolidated to conform to the facility condition rating system used in the bridge inspection program.

One major change that was made to the concrete rating scale was the addition of a new intermediate rating condition. Most rating scales reviewed went from first exposure of reinforcing to total deterioration of the invert in one step. This increment is too large for one rating step. Considering concrete pipe's inherent strength from its reinforcing and wall thickness, and that the 1-in. cover of concrete over the reinforcement is protective rather than structural, a condition rating inserted between the two existing evaluations seems appropriate. The intermediate rating condition will be classified as a 2 rating and described as "invert scaling below first layer of reinforcing, 50 percent loss of wall thickness at invert, concrete very soft."

Analytically, the inclusion of an intermediate concrete rating is supported by the rating equations contained in the Ohio (I) and Ohio (II) reports. In both studies, the major variable in the log-linear rating equations was age. The Ohio (I) age function, $age^{0.17}$, was definitely not linear as the rating scale indicated. The updated rating evaluations in the Ohio (II)

TABLE 8 CONCRETE CONDITIONAL RATINGS

Rating	Condition	Description
9	Excellent	New condition.
8	Very good	*Discoloration of concrete*, no cracking, spalling, scaling *or softening of concrete* present, surface in good condition.
7	Good	Minor hairline cracking at isolated locations, slight spalling, *light scaling (0 to ⅛ in. in depth) on invert, slight loss of mortar, aggregate not exposed, no softening of concrete.*
6	Fair	Extensive hairline cracks, some with minor delaminations or spalling, *moderate loss of mortar around aggregate, invert scaling ⅛ to ¼ in. deep.*
5	Fair—marginal	Cracking open greater than 0.12 in. with moderate delamination and moderate spalling exposing reinforcing steel at isolated locations, large areas of invert with spalls greater than 0.25 in. deep, *significant loss of mortar and slight loss of smaller aggregates due to surface scaling (¼ to ½ in. depth).*
4	Marginal	Cracks open more than 0.12 in. with effluence and spalling at numerous locations, spalls have exposed rebars that are heavily corroded, *heavy invert surface scaling greater than ½ in., moderate aggregate loss, concrete softening.*
3	Poor	Extensive cracking, spalling, and minor slabbing, invert scaling has exposed reinforcing steel *at isolated locations, moderate amount of concrete softening.*
2	Very poor	Severe slabbing has occurred in culvert wall, *invert scaling below first layer of reinforcing, 50 percent loss of wall thickness at invert, concrete very soft.*
1	Critical	*Holes through in concrete at isolated locations, 75 percent loss of wall thickness at invert, reinforcing exposed throughout invert.*
0	Failure	*Invert completely deteriorated, reinforcing steel gone, collapse of the culvert is imminent.*

NOTE: Condition descriptions in italic reflect additions to those contained in the FHWA Culvert Inspection Manual (*1*).

report, however, presented a more linear approach using an age function, age$^{0.55}$. An examination of the Ohio data and rating systems indicates that as the length of service life of the concrete pipe in these studies increases, there will be an expansion of ratings within the "marginal" to "poor" range and a consolidation of the "fair" ratings. These conditions would necessitate an increase in the age function of the Ohio equation. The proposed scale broadens the number of "poor" ratings for concrete pipe, increasing the Ohio age exponential to a value closer to 1 or a linear relationship. The incorporation of this condition corresponds to the trend apparent in the Ohio data and allows for an equitable direct comparison between metal and concrete ratings.

SUMMARY

The proposed condition rating systems for metal and concrete pipe provide an orderly progression for determining durability conditions in a culvert. Detailed descriptions of the levels of material distress present unique characteristics and features for each rating number. The development of the systems based on the operational evaluations used under the bridge rating scale permits the two systems to be directly compared. The severity of the conditions in a metal culvert can now be related directly to those for a concrete culvert with the same rating. It also allows for cross comparison with bridge structures, an option that is becoming more important as the number of inspections of bridge length culverts increases.

RECOMMENDATIONS

There should be state and federal programs for inspection of all culverts based on the FHWA *Culvert Inspection Manual* (*1*). The assessment and rating of material durability evaluations for culverts should be revised to eliminate subjective interpretation, thereby creating a uniform evaluation system.

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