An Analysis of Visual Field Inspection Data of 900 Pipe-Arch Structures

GERALD H. DEGLER, DAVID C. COWHERD, AND JOHN O. HURD

Approximately 50 percent of the structural plate corrugated metal pipe structures under the jurisidiction of the Ohio Department of Transportation are of the pipe-arch configuration. Because these structures have experienced numerous problems, the Ohio Department of Transportation established a research project to identify and determine the causes of these problems. The initial phase of this project involved a field inspection of 890 pipe-arch structures. The inspection was conducted by each of the 12 Ohio Department of Transportation district offices. The inspection consisted of a visual examination plus limited dimensional measurements. Specific areas that received a rating included (a) the amount of structure distortion, (b) the occurrence and severity of multiplate and bolt erosion and seepage, (c) the occurrence and extent of cracking of the multiplates, (d) the condition of the pavement over the structure, and (e) the condition of the channel bottom. A statistical analysis of the field data was performed to determine the dominant modes of structure failure and interrelationships between the structural failures and such variables as age, depth of cover, gauge of the multiplate, and geographic location. Attempts were also made to determine whether one failure mode influenced another (e.g., distortion of the structure causing cracking, or vice versa). Results of the statistical analysis show that the dominant modes of failure or deterioration are (a) fairly heavy corrosion of the multiplates and fasteners (27 percent), (b) significant distortion or flatness of the structure's crown (12 percent), and (c) cracking of the multiplate at the corner radius bolt line (3 percent). Interrelationships were demonstrated with correlation coefficients of 0.9 or greater for (a) age versus durability, (b) durability versus geographic location, and (c) shape problems contributing to cracking problems, and so on.

The Ohio Department of Transportation (ODOT) requires that all bridges with spans of 10 ft or more be inspected annually in accordance with the Federal Bridge Inspection Program. Because corrugated metal pipes (CMP) are commonly used as drainage structures under Ohio roads, these structures must be inspected annually under this program if their spans are in excess of 10 ft.

CMP come in a variety of shapes including circular, elliptical, pear, and arched. The most popular and widely used structural plat CMP shape is the pipe arch (see Figure 1). It should be noted that these structures are flexible and that the soil backfill surrounding the structure is an integral part of this structure. If the backfill is soft and compressible, the sides of the pipes move out and the top of the pipe becomes flat. When the top radius of the pipe reaches a critical value, the pipe collapses.

In order to establish a general overview of the condition of CMP in Ohio, ODOT requested each of their district offices to conduct field inspections of all pipe-arch corrugated metal structures. The pipe-arch shape was selected because this type of structure has been demonstrated to have more structural problems than any other CMP configuration. It also represents approximately 50 percent of Ohio's CMP population.

During February and March 1987, the 12 districts of ODOT conducted visual and limited dimensional inspections of 962 corrugated metal pipe-arch structures. A copy of the field inspection report used during this evaluation is shown on Table 1. These inspections required measurement of the rise and span at two different locations (preferably at locations where obvious structure deformation had occurred), noting the pavement type and condition immediately above the structure (whether settling had occurred), the type of channel bottom and its condition, and quantifying on a scale from 0 to 9 such factors as structure shape, corrosion of the metal pipe, corrosion of the seams and bolts within the structure, and the presence of cracking along the bolt joints. A rating of 9 was given when the factor under consideration was in perfect condition. On review of this field data, it was observed that, of the 962 structures investigated, 890 structures were fully evaluated, partial data were available on 31 structures, and no data were available for 41 structures. The reasons that data were unavailable for the 41 structures included

1. Inability to locate the structure;
2. The structure was too full of water, or silt, or both, to permit inspection; and
3. The structure was removed some time in the past.

The remaining 890 field inspection reports were then subjected to a statistical analysis in an attempt to identify potential interrelationships between structure failures and such factors as structure age, size, depth of cover, gauge, and so on. The purpose of this paper is, therefore, to present the results of the analysis of the 890 pipe-arch structures located within the state of Ohio. A distribution of the pipe-arch structures by district is presented in Figure 2.

DESCRIPTION OF PIPE-ARCH STRUCTURES

The multiplate pipe-arch structures are made of steel sections with corrugations 6 in. wide by 2 in. deep running at right

G. H. Degler and D. C. Cowherd, Bowser-Morner Associates, Inc., 420 Davis Avenue, P.O. Box 51, Dayton, Ohio 45401. J. O. Hurd, Ohio Department of Transportation, 25 South Front Street, P.O. Box 899, Columbus, Ohio 43216.

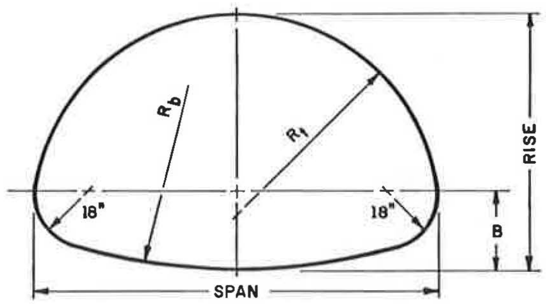

FIGURE 1 Structural plate steel pipe arch.

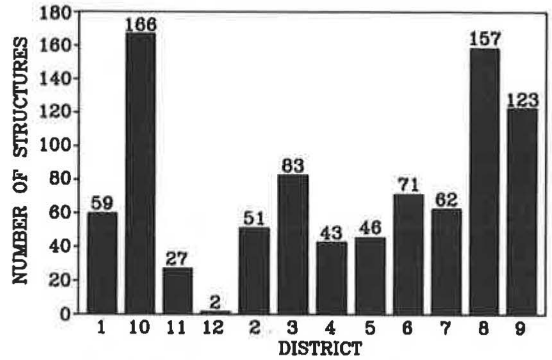

FIGURE 2 Number of pipe-arch structures by district.

angles to the length of the section. Sections vary in thickness from approximately 0.280 in. for No. 1 gauge to 0.109 in. for No. 12 gauge. A typical cross section of the pipe-arch structure would be eight separate sections in 10- to 12-ft lengths bolted together with ¾-in. diam bolts. All of the structures installed in Ohio have an 18-in. corner radius with 6 by 2-in. corrugations. Typically, the crown of the structure is constructed of a lighter gauge material than the bottom or invert. A commonly used configuration is a 10-gauge thickness for the crown and an 8-gauge thickness for the bottom. A tabulation of the number of structures as a function of the top gauge thickness is presented in a frequency histogram in Figure 3. A review of this data reveals that the majority of the structures have a crown gauge thickness of between 7 and 10. The structures ranged in size from a span and rise of 6 ft 1 in. by 4 ft 7 in. to 16 ft 7 in. by 10 ft 1 in.

The structures were installed from 1933 through 1986. The frequency of distribution of the various gauge installations is presented in Figure 4. As can be seen from reviewing this information, the majority of the pipe-arch structures in Ohio

TABLE 1 BRIDGE INSPECTION REPORT

District ______

A. BACKGROUND INFORMATION
1. Structure no. ______
2. Structure file no. ______ 3. Structure location ______
4. Year installed ______ 5. Corrugation ______
6. Depth of cover (ft) ______ 7. Metal gauge: Top ___ Bottom: ___
8. Design rise × span (ft) ______ 9. Plate configuration ______
10. Original foundation/backfill information available: Yes ___ No ___

B. MEASUREMENT
1a. Measured rise × span (ft) ___ Location ______
1b. Measured rise × span (ft) ___ Location ______
2. Pavement type and condition ______
3. Channel bottom type and condition ______

4. Structure Shape	Rating	Condition
a. Symmetrical throughout	9	
b. Slight nonsymmetrical sections, minor sag	7–8	
c. Significant distortion and flatness (one section)	6	
d. Significant distortion and flatness (throughout)	4–5	
e. Extreme distortion (one section)	3	
f. Extreme distortion (throughout)	2–1	
g. Partial collapse; reverse curvature	0	
h. Other observations ______		
5. Metal Plate		
a. No defects or corrosion	9	
b. Minor defects and superficial corrosion	7–8	
c. Fairly heavy corrosion, light pitting	6	
d. Fairly heavy corrosion, moderate pitting	4–5	
e. Severe local corrosion and pitting	3	
f. Severe corrosion (throughout)	2–1	
g. Widespread corrosion and pitting	0	
h. Other observations ______		
6. Metal Seams/Bolts		
a. No defects or corrosion	9	
b. Slight water seepage and superficial corrosion	7–8	
c. Water seepage with fairly heavy local corrosion	5–6	
d. Water seepage with fairly heavy local corrosion throughout	3–4	
e. Water seepage with severe local corrosion	0–2	
7. Seams—Cracking		
a. Properly assembled	9	
b. Minor metal cracking and/or seam openings	7–8	
c. Major cracking (one location) and infiltration	6	
d. Major seam cracking throughout and infiltration	4–5	
e. Severe cracking (>3 in.) throughout	3	
f. Severe cracks continuous from bolt hole to bolt hole with significant infiltration	2–1	
g. Major cracks continuing from bolt hole to bolt hole with backfill pushing into structure	0	
h. Other observations (percent of length experiencing cracks) ______		

C. INSPECTOR
1. Name ______ Date ______

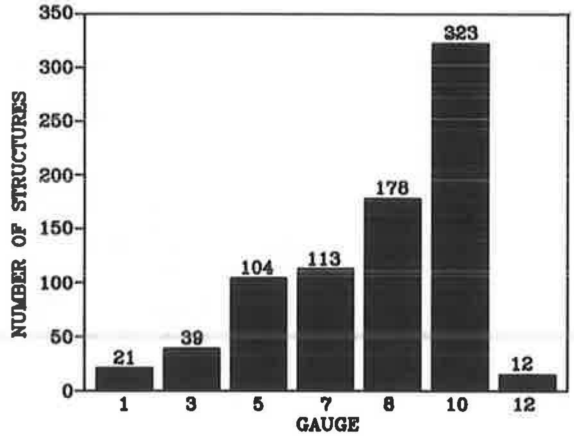

FIGURE 3 Distribution of number of structures by top gauge thickness.

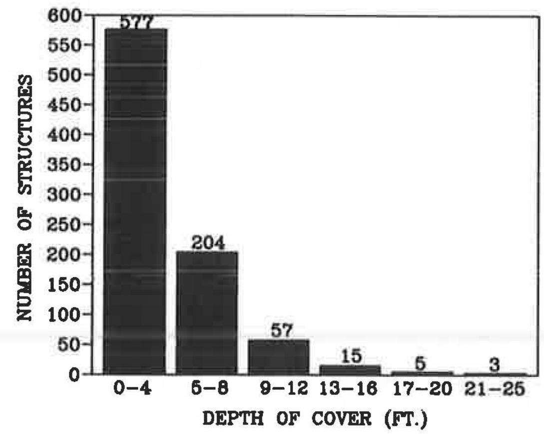

FIGURE 5 Number of structures installed at various cover depths.

were installed during the years 1951 through 1965. The average age of the structures is 25 yr. A total of 365 structures or 41 percent of the total structures installed are 30-yr old and older. This information becomes significant when observing the durability of the structures as a function of age (presented later in this paper).

The depth of cover over the pipe-arch structures ranged between 1 and 25 ft. The distribution of the number of structures at the various depths of cover is illustrated in Figure 5. A review of these data shows that 46 percent of all the structures have a cover of 4 ft or less and 70 percent of the structures have a cover of 6 ft or less. The significance of these data relates to the effect of live and dead load on the structure as a function of the depth of cover (see Table 2).

Because durability of the pipe-arch structures could be a function of the geographic location within the state, the number of structures located at each ODOT district was tabulated. This tabulation will provide a basis for attempting to show a correlation between structure durability and those areas of the state with high abrasive stream loads or acid mine drainage, or both.

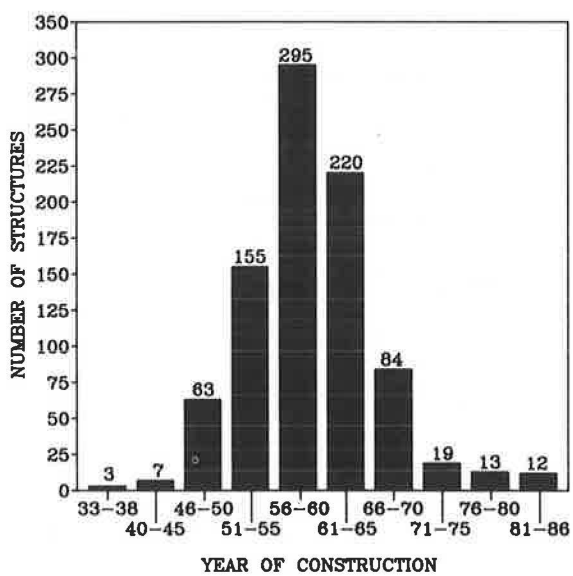

FIGURE 4 Number of structures installed by year of installation.

ANALYSIS OF FIELD DATA

Areas of Analysis

All of the field data shown on the bridge inspection report were entered into a computer program to permit a statistical evaluation of all parameters for determining any potential interrelationships. More specifically, this evaluation sought to determine the answers to the following questions:

1. Does the durability of the structure (susceptibility to corrosion and abrasion) have any relationship to its age?
2. Does the durability of the structure have any relationship to its geographic location (i.e., pH and abrasion effects)?
3. Does the durability of the structure have any relationship to such problems as distortion or cracking of the structure, or both?
4. Does the gauge of the multiplate sections have any relationship to the structure's distortion or cracking problems, or both?
5. Does the depth of cover over the structure have any relationship to the structure's distortion or cracking problems, or both?

TABLE 2 RELATIONSHIP OF DEPTH OF COVER TO STRUCTURE LOADING

Depth of Cover (ft)	[a]Live Load (lb/ft²)	[b]Dead Load (lb/ft²)	[c]Design Load (lb/ft²)
1	1,800	120	1,651
2	800	240	894
3	600	360	826
4	400	480	757
5	250	600	731
6	200	720	791
7	175	840	873
8	100	960	912

[a] Highway H20 loading.
[b] Weight of soil = 120 lb/ft³.
[c] Assumes an 85 percent compaction of the backfill.

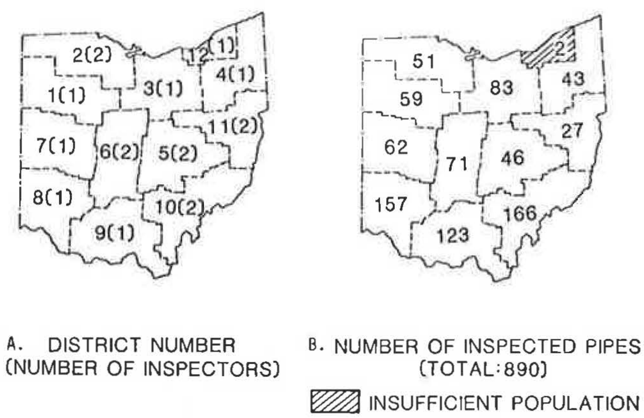

FIGURE 6 Number of inspectors and pipe structures by district.

6. Does distortion of the structure's shape have any relationship to the occurrence of the cracking problem?
7. What are the dominant modes of failures and the causes of these failures?
8. What is the frequency of distribution of the number of structures and their rating (by total and by category)?
9. What is the geographic location of those structures receiving perfect or poor scores, or both (by total and by category)?
10. Is there any noticeable difference in the subjective ratings established by the inspectors in each of the 12 ODOT districts?

Subjectiveness of the Field Inspector's Evaluation

Presented in Figure 6*A* are the number of inspectors in each ODOT district and in Figure 6*B* the number of pipe arches inspected in each district. Because there were 18 different inspectors involved in the evaluation of the pipe-arch structures, it was necessary to conduct a comparison of the rating scores between each of the inspectors to determine whether any of the inspectors' scores needed to be normalized to account for differences in establishing the rating of 0 to 9 for each of the four categories evaluated. Because a maximum of 9 could be given for each of the four categories, a perfect score would be 36. A listing of the individual inspectors, the number of structures, and the average score given by that inspector is presented in Table 3. The weighted average for scores given by all of the inspectors was 30.3. The standard deviation was 2.54. A close review of the scoring by the various inspectors shows that the majority of the readings were comparable, with the exception of inspectors *M*, *O*, and *P*, all of District 10. Because this district is known for its high abrasive stream loads with low pH values, the low scores could possibily be attributed to structure durability problems. However, because inspector *N* in District 10 posted high scores, any attempt to offer a conclusive explanation of the District 10 score variations would be inappropriate without cross checking inspectors. Because all other district scores compared favorably, it was decided to proceed with the statistical evaluations using the field data exactly as presented in the field inspector reports.

TABLE 3 AVERAGE STRUCTURE SCORE BY EACH INSPECTOR

Inspector	District No.	No. Inspected	Score
A	1	59	29.5
B	2	50	30.2
C	3	83	31.5
D	4	42	32.5
E	5	28	31.9
F	5	16	30.8
G	6	10	30.3
H	6	61	29.9
I	7	58	30.1
J	7	3	34.7
K	8	154	30.0
L	9	119	29.9
M	10	64	26.1
N	10	92	32.2
O	10	3	23.3
P	10	7	25.6
Q	11	25	30.8
R[a]	12	2	30.0
Unknown		13	31.0
Total		890	30.3
Weighted average = 30.3			

[a] Included with District 3 during the evaluation.

Statistical Evaluation

Method of Approach

A statistical evaluation was conducted to determine whether an interrelationship existed between such problem areas as (a) distortion or sag of the structure, (b) cracking of the multiplates, (c) corrosion of the multiplates, and (d) corrosion of the seams and bolts and such independent variables as age, depth of cover, gauge of the multiplate, and geographic location. This analysis also attempted to determine the influence that one problem category might have on another (e.g., distortion of the crown on cracking of the multiplate structure). The evaluation also addressed the frequency of occurrence of various modes of failure or deterioration. For purposes of simplifying the presentation of the data, the following abbreviated definitions have been established:

Problem Categories

1. Shape: Refers to a rating of 0 to 9 based on the amount of distortion or sag in the structure.
2. Seams: Refers to a rating of 0 to 9 based on the amount of cracking of the multiplate within the structure.
3. Plate: Refers to a rating of 0 to 9 based on the severity of corrosion occurring on the multiplate.
4. Metal: Refers to a rating of 0 to 9 based on the amount of corrosion and seepage occurring on the bolt and seam joints.

Independent Variables

1. Age: Years since installed.
2. Cover: The amount of cover (in ft) over the structure.

3. Top gauge: The thickness of the multiplate structure (crown).
4. Geographic location: Categorized by ODOT district.

The ratings for the four problem categories were averaged according to year and ODOT district. These average values were then grouped in 5-yr increments beginning in 1940 and average values were established for each subsequent 5-yr grouping. This resulted in 9 data points (the years 1933 to 1939 were eliminated because only 2 data points were accumulated during this time period). These data were then processed using the least-square method of regression for the following relationships:

1. Age as a function of shape, plate, metal, seams, plate and metal (durability) and total score.
2. Depth of cover as a function of shape, plate, metal, seams, and total score.
3. Gauge of pipe-arch crown as a function of shape, plate, metal, seams, and total score.

Attempts were made to fit the data to three different types of regression curves: for example, linear, exponential, and power. Coefficients of determination (r^2) were established for each of these regression curves.

Results of Analysis

1. Age versus shape, plate, metal, seams, durability, and total score.

The results of attempting to fit the various types of regression curves to the data are shown in Table 4. The quality of fit was found to be greater than 0.9. As might be expected, the age of the structure showed good correlation with those variables that directly relate to structure durability factors (e.g., corrosion or seepage, or both); of plate and metal seams and bolts, the combination of these two scores, and the total score for each of the four variables evaluated. Distortion of the structure and the occurrence of cracking along the seams had

TABLE 4 RESULTS OF REGRESSION CURVE ANALYSIS

VARIABLE x	VARIABLE y	TYPE OF REGRESSION	EQUATION	COEFFICIENT OF DETERMINATION
Age	Shape	linear	-	0.75
		exponential	-	0.74
		power	-	0.56
Age	Plate	linear	-	0.89
		exponential	$y=9.0-0.45\,e^{0.05x}$	0.91
		power	-	0.89
Age	Metal	linear	-	0.87
		exponential	-	0.89
		power	$y=9.0-0.06x^{1.04}$	0.95
Age	Seams	linear	-	0.69
		exponential	-	0.44
		power	-	0.71
Age	Plate & Metal (Durability)	linear	$y=18.0-0.19x$	0.89
		exponential	$y=18.0-0.75e^{0.06x}$	0.93
		power	$y=18.0-0.20x^{0.92}$	0.94
Age	Total Score	linear	$y=35.3-0.21x$	0.94
		exponential	$y=36.0-1.85e^{0.04x}$	0.95
		power	$y=36.0-0.74x^{0.65}$	0.91
Cover	Shape	linear	-	0.29
Cover	Plate	linear	-	0.19
Cover	Metal	linear	-	0.05
Cover	Seams	linear	-	0.34
Cover	Total Score	linear	-	0.77
Top Gage	Shape	linear	-	0.13
Top Gage	Plate	linear	-	0.06
Top Gage	Metal	linear	-	0.74
		exponential	-	0.75
		power	-	0.56
Top Gage	Seams	linear	$y=8.25+0.25x$	0.93
Top Gage	Total Score	linear	-	0.67

no correlation with the age of the structure. The relationship between age and plate, as well as between age and total score, were best described by an exponential curve fitting. A linear relationship for total score and age gives about the same good result as an exponential curve. A power curve provides the best method for describing the relationship between age and the occurrence of corrosion and seepage along the seams and fasteners.

Because the ratings for plate and metal represent the durability of the pipe-arch structure, these two categories were combined in an attempt to improve on the coefficient of determination. However, this combination produced a coefficient that was slightly lower than the age versus metal power relation (0.95 to 0.94).

Illustrated in Figures 7, 8, and 9 are the relationships of age to metal, plate, and total composite score. It should be noted that although an exponential curve fit was used to describe the relationships in Figures 8 and 9, a linear curve could also have been used because the coefficient of determination for a linear relationship was only slightly lower. It is interesting to note that the decrease in the total composite score with age (see Figure 9) indicates that a newly installed structure has, on the average, a score of 34 (a decrease of 2). This could possibly be explained by the experience of some structures with shape problems during installation.

The overall deterioration (total composite score of the 890 structures) as a function of time is shown in Figure 10. This curve generally describes a linear deterioration of the structure with approximately a 30 percent reduction in the total composite score over a 50-yr period.

2. Depth of cover versus shape, plate, metal, seams and total score.

Because much of the corrosion of corrugated metal structures can be attributed to salt water seepage into the structure that has originated from the road surface, it was hypothesized that those structures with very little depth of cover would show more extensive corrosion and seepage problems than those

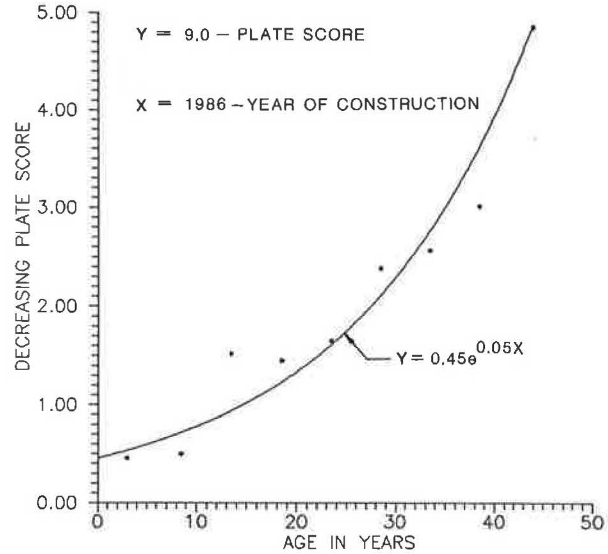

FIGURE 8 Decrease in plate score with age of structure.

structures with a considerable amount of coverage. Further, because the corrugated metal pipe structures are more susceptible to live loads with shallow cover and dead loads with excessive amounts of cover, it was thought that there might be a relationship of depth of cover to shape or distortion problems. However, as can be seen from Table 4, no correlation was established with any of the test variables.

3. Top gauge versus shape, plate, metal, seams and total score.

Typically, the multiplate pipe-arch structures are constructed with a 10-gauge material for the crown and an 8-gauge material for the bottom invert. The bottom invert is typically 1 to 2 gauge numbers heavier than the crown. Because data on the bottom gauge numbers were missing for many of the

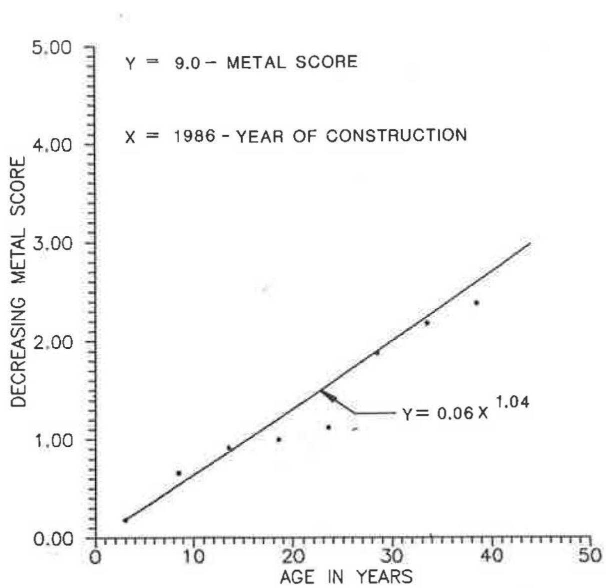

FIGURE 7 Decrease in metal score with age of structure.

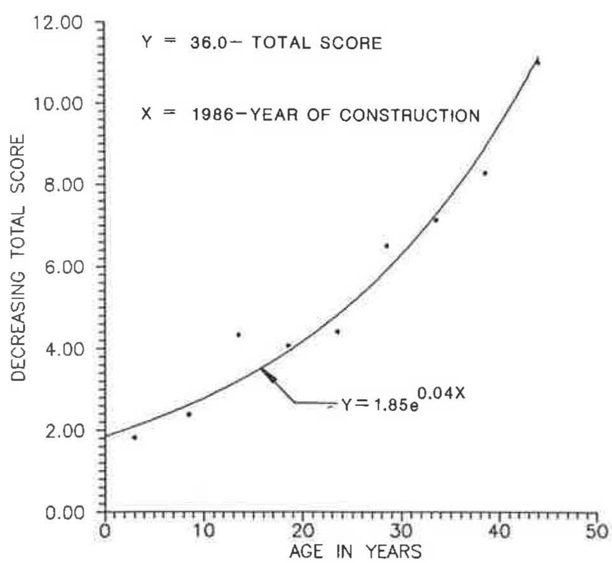

FIGURE 9 Decrease in total composite score with structure age.

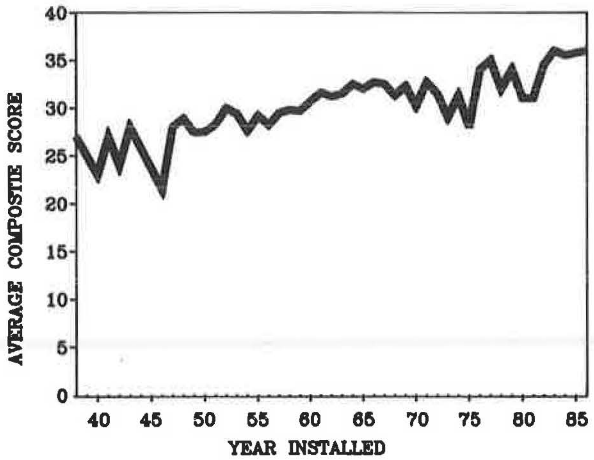

FIGURE 10 Average composite score of structures based on year of installation.

structures, it was decided to perform this analysis using the top gauge numbers. It was hypothesized that some relationship could exist between gauge thickness and structure durability or seam cracking, or both. Because movement or distortion of the structure is totally dependent on the type of backfill and its compaction, no relationship was anticipated between the gauge number and shape score. Results of the regression curve fitting for each of the test variables indicated that the only relationship that existed was between the top gauge and seams or cracking, or both. However, further analysis of this relationship revealed that the significance of this correlation is questionable because the seam rating score decreases only 0.25 when the top gauge increases by 10.

4. Geographic effects.

Because the eastern and southeastern sections of Ohio typically have streams with low pH values (5.1 to 7.1) and high

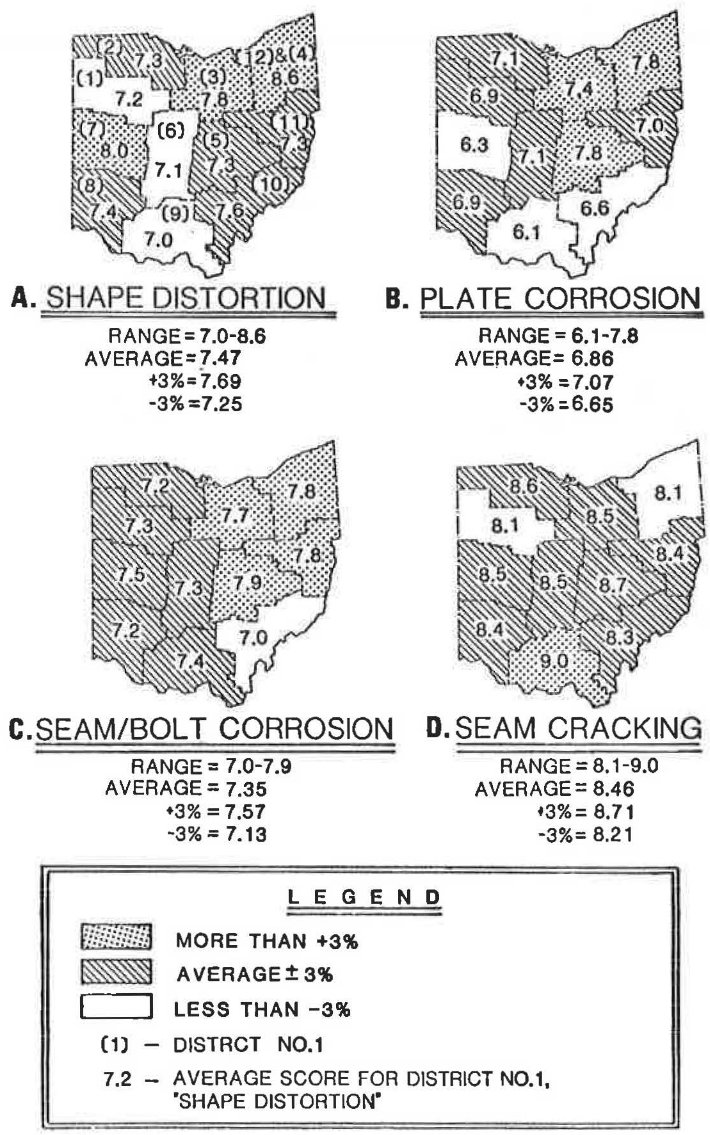

FIGURE 11 Geographic influence of pipe-arch problem area.

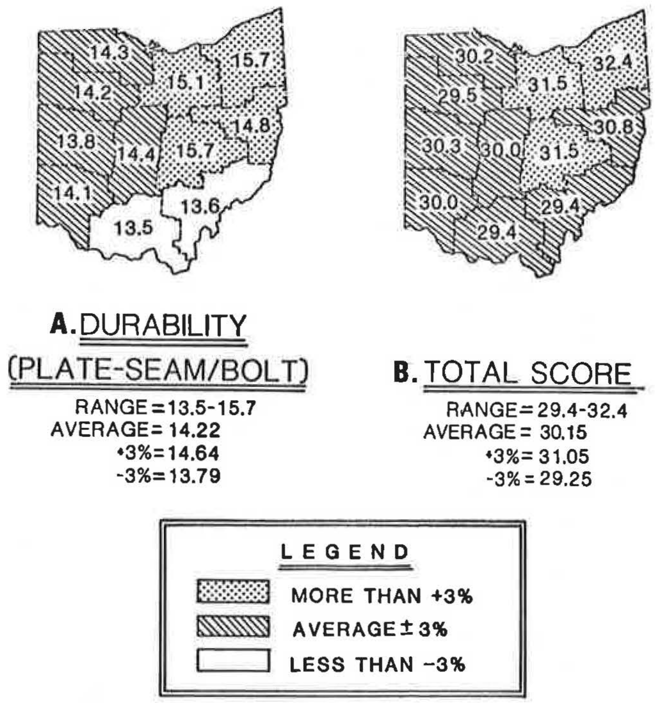

FIGURE 12 Geographic effects on structure durability and total composite score.

abrasive bed loads, an attempt was made to establish a correlation of shape, seam, plate, and metal (seam or bolt) corrosion with the geographic areas of the state. Presented in Figures 11*A*, 11*B*, 11*C*, and 11*D* are the average scores (by district) for each of the four categories evaluated. These scores represent an average of the scores for all structures within a district. Note that the dotted areas of the state represent districts where the scores were greater than 3 percent of the state average. Conversely, areas with no shading represent districts where the scores were less than 3 percent of the state average. Areas with shading represent districts that had scores within ±3 percent of the state average. A score of 9 represents no deterioration.

An evaluation of this data indicates that pipe arches in the northeastern area of the state are in better shape than those in the south or southeast. The low plate corrosion scores in southeastern Ohio were expected in view of the low pH values of the streams in this area. A low seam or bolt corrosion score also occurred in District 10. Because both the plate and metal seam or bolt scores provide a measure of the effects of corrosion and seepage on the structure, these two scores were combined (see Figure 12*A*). As expected, the southeastern portion of the state had the lowest durability scores whereas the northeastern area had the highest scores.

TABLE 5 COEFFICIENT OF DETERMINATION FOR DURABILITY VERSUS AGE REGRESSION CURVES

Regression Curve	9 and 10	1, 2, 6, 7, 8	3, 4, 5, 11, 12
Linear	0.85	0.90[a]	0.89
Exponential	0.78	0.85	0.86
Power	0.52	0.65	0.65

[a] Durability score = 18.54 − 0.19 age (see Figure 7).

Seam cracking does not appear to be a problem in the south whereas the northeastern and northwestern portion of the state have a significant occurrence of seam cracking. The offsetting effects of the corrosion problems in southeastern Ohio and the seam cracking problem in the northern portion of the state resulted in a more uniform total score for the state, as evidenced by a majority of the scores falling within the range of ±3 percent of the average score (see Figure 12*B*). This canceling effect suggests that better regressions may be obtained between various parameters if data were separately processed in groups of two or three districts. This grouping and regression analysis was done for durability (plate and metal) versus age, with the results shown in Table 5 and in Figure 13.

Comparing the coefficients of determination shown in Table 5 with the data in Table 4 fails to demonstrate any improvement by this grouping of data. It can, therefore, be concluded that it is more appropriate to conduct the analyses on a statewide basis than by separate groupings of districts. Nevertheless, separate regressions for small groups of districts show different regression curves. For example, in Figure 13 it can be seen that the decrease in the durability scores is slower in Districts 3, 4, 5, 11, and 12 than in all the other districts.

It is also shown in Figure 13 that a two-slope line (similar to an exponential curve) would better describe the durability relationship to age than does a straight line. The slope of the curves corresponding to the decrease of durability with time experiences a significant increase after the age of about 35 yr.

5. Frequency of occurrence evaluation.

Various computer sorts of the field inspection data for the 890 structures were performed in an attempt to reveal major

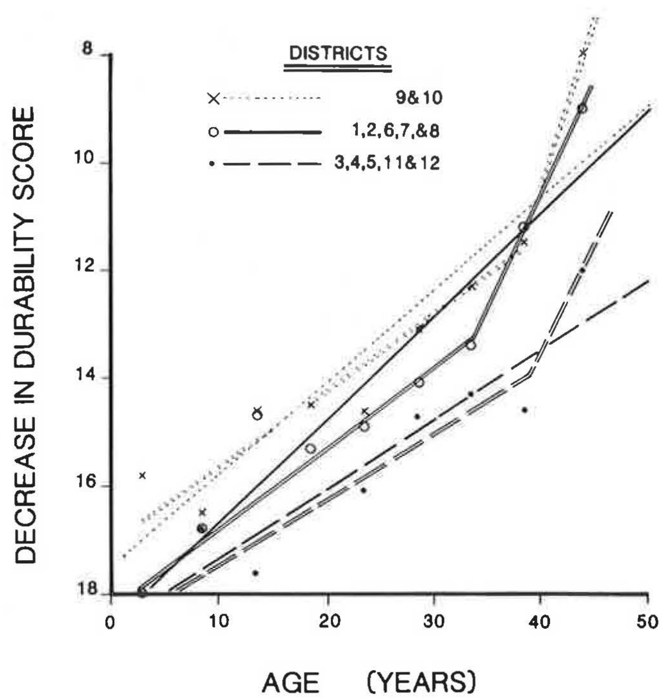

FIGURE 13 Decrease in durability score with increasing age of structure.

TABLE 6 STRUCTURE SCORE VERSUS FREQUENCY OF OCCURRENCE

	Metal			
Score	Seams/Bolts	Plate	Seams	Shape
0	8	1	0	2
1	2	4	0	1
2	4	11	0	6
3	7	48	2	7
4	6	41	2	17
5	74	49	5	21
6	47	82	11	50
7	276	314	144	343
8	256	181	101	217
9	191	140	596	208
No data	19	19	29	18
Total	890	890	890	890

problem areas and the causes of problems. Presented in Table 6 are a frequency of occurrence for the structure score for metal durability (seams or bolts and plate), seams (cracking), and shape. The number of structures receiving the score rating from 0 to 9 are shown in this table. A review of these data reveals that 20 structures (2.2 percent) experienced major cracking (score of 6 or less) at either one location or throughout the structure. A total of 104 structures (11.7 percent) experienced significant flatness or distortion (score of 6 or less) at least one section within the structure. An additional 343 structures (27.3 percent) experienced slight nonsymmetrical distortion or minor sagging (score of 7) at one or more locations throughout the structure.

With regard to durability, a total of 64 (7.2 percent) of structures experienced severe corrosion and pitting (score of 3 or less), either locally or throughout the structure. An additional 172 (19.3 percent) of structures experienced fairly heavy corrosion with either light or moderate pitting (score of 4 to 6) throughout the structure. A total of 148 (16.2 percent) structures experienced significant water seepage with fairly heavy corrosion (score of 6 or less) occurring at the seam or bolt joints.

Because information on whether significant distortion or sagging of the structure influenced the occurrence of seam cracking was required, a frequency of occurrence of seam versus shape scores was prepared (see Table 7). As a review of this table indicates, the number of structures with a low score (6 or less) is very small. Therefore, a grouping of the structures (shown in Table 8) was prepared and used for the linear regression analysis. The results of this analysis indicated a linear regression curve fit of the data with an excellent coefficient of determination ($r^2 = 0.99$). This relationship may be expressed as seam score = 7.06 + 0.19 × shape score. This relationship should only hold for shape scores of 5 or greater because there are insufficient data points below this rating to establish any degree of confidence for the equation holding true.

An evaluation of shape scores as a function of span or rise dimensions failed to show any correlation. This evaluation was based on a total population of 715 pipe-arch structures.

Presented in Table 9 is a listing by district of the number of structures that received a perfect rating (a score of 36). A total of 48 structures received a perfect score. This represents 5.4 percent of the total number of structures in the field. The structures were built during the period 1947 to 1986, with the average age being 24 yr. An interesting observation from this table is the unusually high percentage (24 percent) of the 83 structures installed in north central Ohio receiving a perfect score. The average age of these structures is 37 yr. This area of the state has a very low stream abrasion, with stream pH values ranging from 7.9 to 8.3.

A listing of the number of structures receiving the lowest scores is presented in Table 10. This listing represents a range of scores between 7 and 24. A review of these data shows that District 10 has the highest percentage of structures with low scores. This was expected because the stream loads in this area are highly abrasive and the pH values range from 5.1 to 6.5. An unusual observation from this table is the relatively high number of structures receiving a low score in District 3. This is the same district that had the highest percentage of structures receiving a perfect score. The frequency of occurrence of these low scores is presented in Table 11.

Presented in Figure 14 is a histogram of the frequency of occurrence of the scores ranging from 14 to 36. The total composite score ranged from 7 to 36. The average of the total composite score was 30.15, with a standard deviation of 4.0 and a variance of 15.6. Presented in the following table are the average score, standard deviation, and variance for each of the four problem area categories evaluated: shape, plate, metal, and seams.

Problem Area	*Score*	*Standard Deviation*	*Variance*
Shape	7.5	1.3	1.8
Seam Cracking	8.5	0.9	0.8
Plate Corrosive	6.9	1.7	3.0
Metal (seam or bolt corrosion)	7.4	1.5	2.3

TABLE 7 FREQUENCY OF OCCURRENCE OF SEAM VERSUS SHAPE SCORES

	Shape Score											
Seam Score	0	1	2	3	4	5	6	7	8	9	No Data	Total
3	1	0	0	0	0	0	1	0	0	0	0	2
4	0	0	0	1	1	0	0	0	0	0	0	2
5	0	0	0	0	0	1	2	0	1	0	1	5
6	0	0	0	0	0	1	1	7	1	1	0	11
7	1	0	3	3	4	7	8	88	17	13	0	144
8	0	0	0	0	1	4	5	30	39	21	1	101
9	0	1	3	2	10	8	32	210	159	167	4	596
No data	0	0	0	1	1	0	1	8	0	6	12	29
Total	2	1	6	7	17	21	50	343	217	208	18	890

TABLE 8 CORRELATION OF SHAPE VERSUS SEAM SCORES

Shape Scores		No. of Structure		Average Seam Scores
0		2		
1	1.5	1	16	7.33
2		6		
3		7		
4	4.5	17	38	7.94
5		21		
6		50		8.22
7		343		8.32
8		217		8.63
9		208		8.75

TABLE 9 NUMBER OF STRUCTURES WITH PERFECT SCORES

Number of Structures			
District	Perfect Scores	No. Installed	Percentage
1	0	59	0
2	0	51	0
3	19	83	24.0
4	4	43	9.3
5	1	46	2.2
6	3	71	4.2
7	3	62	4.8
8	12	157	7.6
9	4	123	3.3
10	2	166	1.2
11	1	27	3.7
12	0	2	0
Total	49	890	5.4

CONCLUSIONS

Before the initiation of the analysis of the field inspection data, a number of questions were presented to establish if there was an interrelationship between certain design parameters for pipe arches and the problem areas of shape; distortion or sagging, or both; seam cracking; and durability. Results of the analysis permit the following conclusions:

1. Durability: The durability rating of the structure (susceptibility to corrosion and seepage) has been established as a linear relationship with age until the structure is approximately 35-yr old, at which time the rate of the structure deterioration increases.

2. Durability versus geographic location: The field data clearly indicated that the pipe arches located in southeastern Ohio (which have high abrasive stream loads with a low pH value) result in a higher rate of structure deterioration (decreasing durability scores) than other geographic areas of the state.

3. Durability versus distortion or cracking: There was no apparent relationship indicated between the structure's shape and seam cracking problems and the amount of corrosion or abrasion, or both.

4. Gauge versus distortion or cracking problems: There is no apparent relationship indicated between the gauge of the multiplate sections and the problems of shape distortion, durability, or seam cracking.

5. Depth versus distortion or cracking: There is no correlation indicated between the depth of cover and the shape distortion, durability, or cracking problems.

TABLE 10 NUMBER OF STRUCTURES WITH LOW SCORES (RANGE FROM 7 TO 24)

Number of Structures			
District	Low Scores	No. Installed	Percentages
1	6	59	10.2
2	1	51	2.0
3	10	83	12.1
4	0	43	0
5	3	46	6.5
6	2	71	2.8
7	5	62	8.1
8	11	157	7.0
9	9	123	7.3
10	23	166	13.8
11	2	27	7.4
12	0	2	0
Total	72	890	

TABLE 11 FREQUENCY OF OCCURRENCE OF LOW SCORES

Scores	No. of Occurrences
7	1
14	1
15	3
16	1
17	2
18	2
19	1
20	5
21	10
22	10
23	16
24	20
Total	72

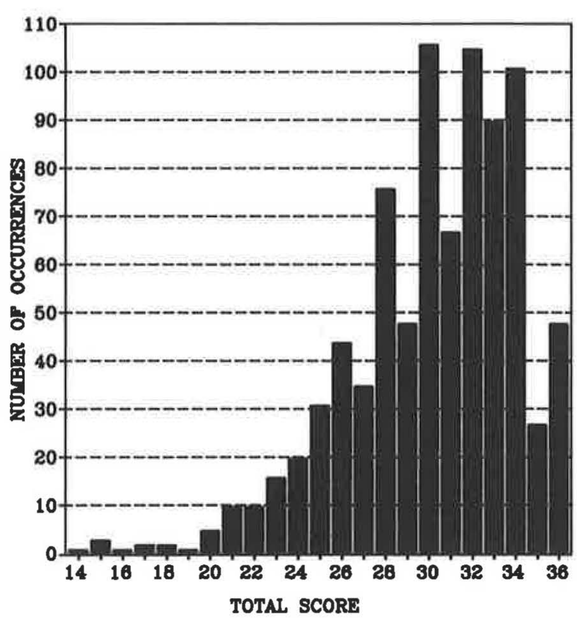

FIGURE 14 Frequency of occurrence of each score (total composite).

6. Shape versus cracking problems: A linear relationship was indicated for these two problem areas for the higher score values (i.e., seam scores of 7 and greater and shape scores greater than 5). Insufficient data were available to establish a relationship at the lower scores.

7. Dominant modes of failure: The most dominant problem area of the pipe-arch structure is the occurrence of corrosion and pitting of the multiplate structure, and seepage and corrosion of the bolted joints. A total of 27 percent of the structures experienced fairly heavy corrosion. Sagging or deflection of these structures was also a problem area with 11.7 percent of the structure showing significant distortion or flatness, or both, in one or more sections throughout the structure.

8. Cracking: Cracking was observed to be only a minor problem, with only 2 to 3 percent of the structures indicating 1- to 1½-in. cracks occurring on either side of the bolt hole along the corner spring-line seam joint.

9. Fidelity of data: Although there were 18 different inspectors involved in the field evaluation of the 890 pipe arch structures, the method of rating generally produced reliable, valid data. When these structures are again inspected by different inspectors, the validity of the field inspection reporting approach will be further verified.

See also "Evaluation of Corrugated Metal Pipe-Arches," Volumes 1 and 2. (*1*, *2*).

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