ROBERT HUMPHREYS
COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

March 12, 1957

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

D.2.1.
D.1.7.

MEMO TO: D. V. Terrell
Director of Research

One of the more-or-less continuing projects in the field of drainage which have been delegated to the Research Division is the determination of the performance characteristics of coated and uncoated corrugated metal pipe, pipe arches, and field-assembled arches. The attached report by E. M. West, dealing with condition surveys of unpaved arches, presents the results of our most recent work along these lines.

The report covers observations of 86 unpaved structures located mostly in the central and eastern part of the state, but representing 30 counties. Regions of both acid and non-acid bearing waters are included, and the point of greatest concern is rusting in the invert or on the sides at the low water elevation. Although the evidence indicated that as many as 60 percent of these arches inspected had rusted or corroded to a considerable degree, the problem was not found serious enough to warrant paving of all arches before or at the time they are installed. On the other hand, paving the invert, or applying a suitable protective coating at the first evidence of rapid corrosion would seem highly desirable.

In many cases an effective bituminous coating or something similar should correct the condition. On the other hand, a few arches have corroded so extensively they are becoming structurally unsound. Those may require complete concrete paving, such as that applied to an arch on Ky. 267 in Perry County, as illustrated in Fig. 3 of the report.

As you know, the Research Division has made several studies of treatments on piers, abutments, and other parts of structures severely damaged by acid waters, and has assisted the Division of

Maintenance in the selection, application and subsequent observations of the treatment. After this report has been studied by the Division of Maintenance, possibly a few of the metal arches most seriously corroded could be selected for treatment and study in the same general way.

Respectfully submitted,

L. E. Gregg
Assistant Director of Research

LEG:dl
Enc.
Copies to: Research Committee
J. C. Cobb (3)

Commonwealth of Kentucky
Department of Highways

A SURVEY INSPECTION OF PLAIN CORRUGATED METAL PIPE ARCHES AND MULTI-PLATE METAL PIPE ARCHES IN KENTUCKY

by

Eugene M. West
Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky

March, 1957

INTRODUCTION

Past observations have indicated that rusting has been rather prevalent in the large, un-paved metal drainage structures most of which have been installed since the opening of the Kentucky Rural Secondary Program in 1949. Since all of these structures are relatively new, and since rusting in any form can be considered a threat to the life of a structure, the Chief Engineer's Office, in 1954, requested that a study be made to determine the over-all frequency, possible causes, and individual seriousness of this condition.

Altogether, a total of 86 of these un-paved structures were inspected. Although it would have been virtually impossible to inspect every one in the state, a pattern was followed which was believed to provide a representative and sufficiently large sampling. This pattern, by counties and by number of structures inspected per county, is shown in Fig. 1. Structures were located for inspection by use of the R. S. Final Estimate Forms.

Almost all of the structures inspected showed evidence of rusting in one form or another. Moverover, the condition was found in areas where testing for acidity, using methyl red and methyl orange pH indicators , indicated no serious acidity of the water, sometimes heretofore thought to be prerequisite to rusting.

A number of arches were found to be in need of immediate attention, and it was noted that the life of many others could undoubtedly be extended by a protective treatment of the inverts.

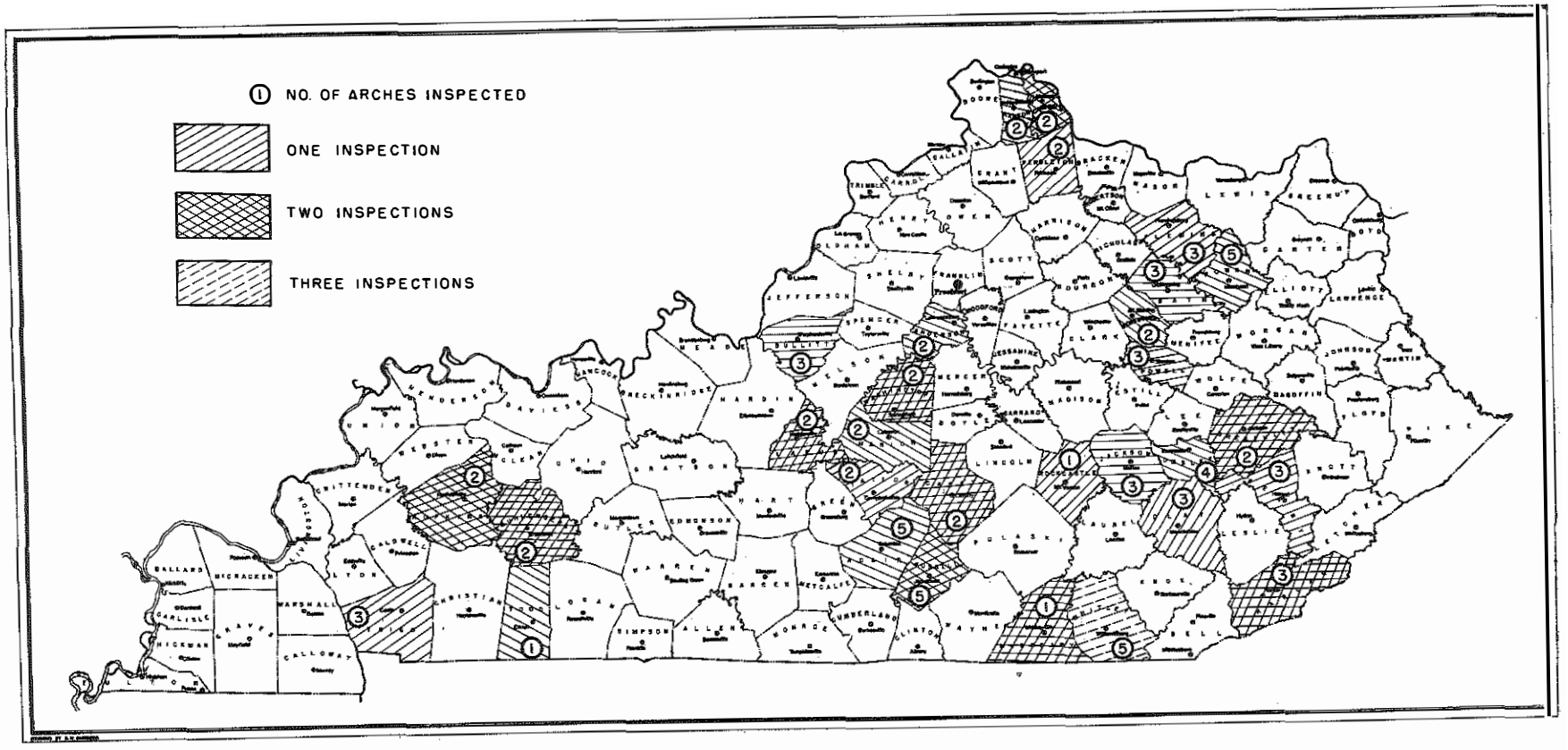

Fig. 1 - Pattern of Metal Arch Inspections by County and by Number of Inspections per County.

Inspection Procedure

For each structure the following data were recorded on printed forms:

1. Date installed
2. Type and size of structure
3. Approximate grade
4. Channel conditions (especially with regard to possible scour and abrasion)
5. Condition of the spelter
6. Type and extent of any observed rusting
7. Presence and extent of acidity
8. Any special features of the culvert or its site

In most cases the water's acidity was tested with pH indicators. However, when there was no water present it was possible to determine probable acidity by searching for stains on the metal of the structure itself or on the gravel in the channel. In all locations a general description of the drainage area was recorded, and when acid water was suspected a more thorough study of the area was made for verification.

FINDINGS

The data from the inspection forms were assembled and arranged to provide Table 1 of this report. From the table it is evident that 52, or 60 percent, of the structures showed some form of rust.

Extreme rusting conditions were found on three of the roads inspected in Perry, Harlan and Hopkins Counties, all of which are in mining areas. The condition of the structures inspected in these areas was invariably serious, evidently because of the presence of highly corrosive mine water.

TABLE 1: DATA FROM INSPECTION OF UNPAVED METAL PIPE ARCHES — ARRANGED ALPHABETICALLY BY COUNTIES

County	Date of Inspection	Location of Structure	Date Installed	Size in Inches	Condition of Spelter	Remarks
Adair	6-15-56	BS-1-270-1. Ky. 551. 0.8 mi. from Cc. line.	1949	twin 107 x 72	PP rust *	Invert completely covered with pp rust. One outlet silted; other free of silt.
Adair	6-15-56	BS-1-270-1. Ky. 551. 1.3 mi. from Co. line.	1949	twin 93 x 64	Heavy pitting; T. B. rust **	High abrasive action, entire invert rusted; high, scouring stream.
Adair	6-15-56	BS-1-270-1. Ky. 551. 2.1 mi. from Co. line.	1949	twin 93 x 64	T. B. rust	T. B. rust over entire invert flow line, 1 ft. of gravel in one; none in other. Highly abrasive, scouring stream.
Adair	6-15-56	Ky. 76 - between Knifely and Eunice.	1949	twin 76 x 44	T. B. rust	T. B. rust throughout both inverts. High erosive and abrasive action.
Adair	6-15-56	Ky. 76 - at Neatsville, between Knifely and Eunice.	1949	159 x 96	T. B. rust	T. B. rust throughout invert. High erosive and abrasive action.
Anderson	5-12-54	BS 3-211-2	1949	58 x 36	Like new	No loss of spelter; no rust or evidence of abrasion.
Anderson	5-12-54	BS 3-231-2	1949		Dull	No evidence of ruet, acid, or abrasive action.
Bath	9-14-56	BS 6-204-1. Ky. 1106. Bethel - Reynoldsville Rd. 4.5 mi. from Bethel.	1951	77 x 57	Dull	Good condition.
Beth	9-14-56	BS 6-204-1. 5.3 mi. from Bethel at Jct. Ky. 1106 and Ky. 1324.	1951	77 x 57	Dull	Good condition.
Bath	9-14-56	BS 6-204-1. Ky. 1106. Bethel-Reynoldsville Rd. 5.4 mi. from Bethel.	1951	77 x 57	Dull	Good condition.
Breathitt	8-3-54 (1) 7-19-55 (2)	BS 13-427-1. Mt. Carmel Rd. 3.2 mi. from intersection of Ky. 541.	1949	twin 142 x 90	(1) T.B. ruet; pp rust. (2) T.B. rust; pp rust.	One arch completely rusted in invert; other silted 1/3 full. One arch completely rueted in invert; other silted 1/2 full.
Breathitt	8-3-54	BS 13-407-1.	1949	77 x 57	T.B. rust	Advanced stage T.B. rust along entire flow line. No acid.
Bullitt	5-12-54		1950	77 x 57	Dull	No evidence of rust. Impossible to inspect spelter at invert because of silt.
Bullitt	5-12-54			159 x 96	Dull	No evidence of rust.
Bullitt	5-12-54		1950		Dull	Some evidence of abrasion; slight pitting and pp ruet.
Campbell	5-19-54 (1) 6-13-55 (2)	BS 19-491-1. at 2.1 mi.	1949	93 x 64	(1) Dull; pp rust; spelter gone; pitting (2) No change.	Poor alignment; skew cut off wrong; large rocks in pipe. High abrasive action. No change.
Campbell	5-19-54 6-13-55	BS 19-491-1. at 0.0 mi.	1949	123 x 77	Dull Dull	No evidence of rust. No change.
Casey	6-2-54 (1) 6-15-56 (2)	BS 23-261-1. Ky. 551. 1.0 mi. from Clementsville	1949	159 x 96	(1) T.B. ruet (2) Scaly ruet	(1) Gravel and scaly ruet completely cover invert. (2) No change. No acid.
Casey	10-16-56	Jct. Attereon Rd. and Ky. 70.	1955	72 x 44	PP rust; loose scely rust.	Inlet and outlet of invert covered with red rust.
Clay	7-18-55	BS 26-145-3. Little Sexton Creek Rd. 300 ft. from intersection of Ky. 577 and Ky. 421.	1949	77 x 57	Like new	Inspection made after heavy shower. Unable to see flow line.
Clay	7-18-55	BS 26-505-1. Fogertown - Langnau Rd. 6.5 mi. from Burning Springs.	1949	twin 123 x 77	Heavy pitting; spelter gone.	Heavy pitting end silted outlet in one arch. Spelter gone, pp rust and heavy silting in other.
Clay	7-18-55	BS 26-505-1. Fogertown - Langnau Rd. 12.5 mi. from Burning Springs.	1949	72 x 107	Heavy pitting, loose scaly rust.	Spelter gone and heavy pitting over 5-in. width of flow line.
Fleming	9-19-56	BS 35-610-1. Ky. 681. 1.4 mi. from Cowan.	1952	123 x 77	Dull	Large rocks throughout. No rust.
Fleming	9-19-56	BS 35-610-1. Ky. 681. 1.5 mi. from Cowan.	1952	123 x 77	Dull	
Fleming	9-19-56	BS 35-610-1. Ky. 681. 1.7 mi. from Cowan.	1952	189 x 115	Dull	Slight pp rust. No acid.
Harlan	7-20-55 (1) 6-5-56 (2)	BS 48-408-1. Cranks Creek Rd. 0.25 mi. from U.S. 421	1949	123 x 77	Heavy pitting; loose scaly ruet. Heavy pitting; perforated	(1) Loose scaly rust covers 6-in. width of entire flow line. No acid. (2) Heavy etching; corrugations perforated; inlet silted. Acid test 4.4 to 6.0 ph. Stream yellow-orange.

* Pinpoint rust
** Tubercular rust.

TABLE I: CONTINUED

County	Date of Inspection	Location of Structure	Date Installed	Size in Inches	Condition of Spelter	Remarks
Harlan	7-20-55 (1) 6-5-56 (2)	RS 48-401-1. Cranks Creek Rd. 1.5 mi. from U. S. 421.	1949	twin 77 x 57	(1) Heavy pitting (2) T. B. rust	(1) Heavy pitting along 3 ft. width of flow line. (2) Mine water, but no discoloration.
Harlan	7-20-55 (1) 6-5-56 (2)	RS 48-401-1. Cranks Creek Rd. 2.8 mi. from U. S. 421.	1949	107 x 72	(1) Spelter gone - heavy pitting (2) Heavy pitting	(1) Heavy pitting along 3 ft. width of flow line. Bank eroded into inlet. No acid. (2) Little change. Water now black from coal washing upstream.
Hopkins	7-8-54 (1) 9-24-55 (2)	RS 54-640-1. 1.2 mi. from Jct. Ky. 254 and Ky. 892	1949	77 x 57	(1) Dull (2) Doll	(1) No rust; some silt in outlet. Culvert laid too low. (2) No change.
Hopkins	8-24-55	RS 54-640-1.	1949	77 x 57	Dull	Spelter partially gone at bottoms of corrugations. End eroded at outlet.
Jackson	7-18-55	RS 55-169-1. Ky. 578. 500 ft. from Jct. Ky. 1350.	1949	77 x 57	Like new	Spelter protected by 6" of silting along entire flow line.
Jackson	7-18-55	RS 55-169-1. Ky. 578. 0.5 mi. from Laurel Co.	1949	77 x 57	Like new	Arch half full of silt, sand, gravel; impossible to inspect invert.
Jackson	7-18-55	RS 55-169-1. Ky. 578. 2.5 mi. from Annville.	1949	93 x 64	T. B. rust; spelter gone.	Spelter gone and pitted at invert. T. B. rust to 5 ft. back of outlet.
Kenton	10-11-56	RS 59-335-1. Turkeyfoot Rd. 0.6 mi. from Richardson. Rd.	1952	77 x 57	Dull	
Kenton	10-11-56	RS 59-335-1. Turkeyfoot Rd. 1.2 mi. from Richardson Rd.	1952	93 x 64	Like new	
Larue	6 -54 (1) 5-31-56 (2)	RS 62-341-1. 4.7 mi. from Jct. Ky. 52 & Ky. 583.	1949	123 x 77	(1) T. B. rust; spelter gone. (2) T. B. rust; spelter gone; loose scaly rust.	(1) Concrete structure nearby shows no evidence of abrasive or acid action. (2) Rust over entire low water line flow.
Lewis	11-13-56	Vanceburg	1940	4 barrel 120	Loose scaly rust; heavy pitting.	2 barrels experimentally paved with concrete; other 2 pitted and rusted.
Marion	6-2-54	RS 78-362-1. at 0.2 mi.	1949	93 x 64	Dull, pp rust.	Considerable abrasive wear in flow line. No acid.
Marion	6-2-54	RS 78-362-1. at 0.5 mi.	1949	107 x 72	Dull, pp rust.	Considerable abrasive action possible.
McCreary	6-25-54 (1) 7-20-55 (2)	RS 74-213-1. U. S. 27 - Holly Hill at 1.6 mi. from Jct. Ky. 592 and Ky. 92.	1949	twin 142 x 90	(1) PP rust; T. B. rust (2) PP rust; spelter gone	One barrel 35% silted with pure sand. Other barrel invert advanced T. B. rust. One barrel 35% silted. Other barrel has spelter gone along flow line.
Menifee	1-2-57	RS 83-96-1. 1 mi. east of Miraba	1950	77 x 55	T. B. rust	Water stained red.
Montgomery	9-14-56	RS 87-377-1. Cecil Rd. 0.4 mi. from Ky. 11.	1951	77 x 57	PP rust	Slight pp rust. No acid.
Montgomery	9-14-56	RS 87-377-1. Cecil Rd. 2.6 mi. from Ky. 11.	1951	77 x 57	PP rust	PP rust throughout invert.
Muhlenberg	7-8-54 (1) 8-25-55 (2)	RS 89-543-1. at Jct. Ky. 171 and Ky. 600.	1949	77 x 57	(1) T. B. rust (2) T. B. rust; spelter gone; heavy pitting	(1) Complete rust in trickle line. Evidence of scouring. No acid. (2) Heavy pitting and rust in trickle line. Evidence of scouring and acid.
Muhlenberg	8-25-55	Ky. 601. 1.0 mi. west of Greenville.	1936	- -	Dull, pp rust; spelter gone.	First multi-plate in Ky. Only loss of spelter is within 3-in. of concrete base.
Owsley	7-19-55	RS 95-136-1. Travellers Rest - Scoville Rd. in front of Post Office.	1950	123 x 77	PP rust; spelter gone; heavy pitting.	Spelter gone along flow line.
Owsley	7-19-55	RS 95-136-1. Travellers Rest - Scoville Rd. 0.8 mi. from Travellers Rest.	1950	twin 93 x 64	Spelter gone; heavy pitting.	One barrel heavily silted.
Owsley	7-19-55	RS 95-136-1. Travellers Rest - Scoville Rd. 1.7 mi. from Travellers Rest.	1950	twin 77 x 57	Spelter gone; heavy pitting.	Heavy pitting along flow line.
Owsley	7-19-55	RS 95-156-1. Ky. 486. 2.5 mi. from Jct. Ky. 30 and Ky. 486.	1950	107 x 72	Spelter gone; heavy pitting.	Spelter gone, heavy pitting for 5 ft. width along flow line.
Pendleton	9-26-56	Concord - Butler Rd.	1950	120 x 72	Dull	Some discoloration. No acid.
Pendleton	9-26-56	Ky. 609	1950	96 x 48	Dull	
Perry	3-5-56	RS 97-722-1.	1949	107 x 72	Loose scaly rust	Bolts missing at top of projecting end.
Perry	3-5-56	RS 97-722-1.	1949	97 x 57	Dull	Silted 1/3 full. No acid.
Perry	3-5-56	RS 97-722-1.	1949	93 x 64	Dull	Silted 1/2 full. Invert too low. Spelter dull in flow line.
Powell	9-14-56	RS 99-180-3. Hardwick Creek Rd. Ky. 1057. 7.8 mi. from Clay City.	1952	107 x 72	T. B. rust	T. B. rust along flow line. Rest like new.
Perry	3-5-56	RS 97-722-1	1949	159 x 76	Loose scaly rust. Spelter gone in invert.	Invert completely gone. Arch deformed by loss of strength. Extreme rust.

TABLE I: CONTINUED

County	Date of Inspection	Location of Structure	Date Installed	Size in Inches	Condition of Spelter	Remarks
Powell	9-14-56	RS 99-180-3. Hardwick Creek Rd. Ky. 1057. 8.7 mi. from Ky. 15.	1952	twin 159 x 96	P. P. rust	Silted 3 ft. throughout both barrels.
Powell	9-14-56	RS 99-180-3. Ky. 1057. 8.8 mi. from Ky. 15.	1952	77 x 57	P. P. rust	Silted throughout. Slight pp rust along invert.
Rockcastle	6-23-54	RS 102-337-2.	1949	66 x 38	Like New	Silted at outlet.
Rowan	9-19-56	RS 103-322-1. Ky. 1157. at 1.9 mi. east of Clearfield.	1952	77 x 57	T. B. rust	T. B. rust throughout invert. No acid water.
Rowan	11-13.56	RS 103-262-1.	1949	twin 94 x 66	Like new; dull.	Excellent condition.
Rowan	11-13-56		1949	twin 94 x 66	Dull; pp rust; spelter gone; loose scaly rust.	One barrel silted 1/2 full. Highly abrasive stream.
Rowan	11-13-56		1949	twin 94 x 66	Dull.	Both barrels silted 1/5 to 1/3 full.
Rowan	11-13.56		1949	77 x 57	P. P. rust; T. B. rust; spelter gone.	Invert covered with rust.
Russell	6-15-54	RS 104-238-1.	1949	170 x 104	T. B. rust	Some rust. Gravel deposit 6" deep.
Russell	6-15-54	RS 104-238-1.	1949	77 x 57	T. B. rust, spelter gone.	Spelter gone in invert. Light T. B. rust. No acid. Abrasive force light.
Russell	7-21-55	RS 104-238-1.	1949	77 x 57	Like new.	Spelter very good. Sand and gravel in outlet.
Russell	6-15-54 (1) 7-21-55 (2)	RS 104-238-2. 3.4 mi. from Jct. Ky. 379.	1949	twin 93 x 77	(1) P. P. rust. (2) P. P. rust.	Rust in flow line - no acid.
Russell	6-15-54 (1) 7-21-55 (2)	RS 104-218-1. 2.0 mi. from Ky. 379.	1949	93 x 64	(1) T. B. rust. (2) T. B. rust; spelter gone.	(1) Invert rusted. Spelter gone. No acid. (2) T. B. rust 2' wide in flow line.
Scott	12-26-56	RS 37-485-1. 0.8 mi. from Wood Lake.		77 x 57	Dull.	Like new.
Scott	12-26-56	RS 37-485-1. 2.4 mi. from Wood Lake.		77 x 57	P. P. rust; spelter gone; loose scaly rust.	
Scott	12-26-56	RS 37-485-1. 2.6 mi. from Wood Lake.		twin 92 x 57.	Dull; P. P. rust	Aluminum paint on bolts and projecting ends. Tree at invert.
Scott	12-26-56	RS 37-485-1.		twin	Dull; P. P. rust	
Taylor	6-16-54	RS 109-348-1.	1950	77 x 57	Dull; T. B. rust.	Outlet silted. Heavy abrasive action.
Taylor	6-16-54	RS 109-288-1.	1949	107 x 72	T. B. rust.	Some gravel, heavy rust in flow line.
Todd	7-7-54	RS 110-426-1.	1949	twin 42 x 28	Dull.	No rust.
Trigg	7-7-54	RS 111-74-1.	1949	93 x 64	Dull; P. P. rust.	
Trigg	7-7-54	RS 111-74-1.	1949	77 x 57	T. B. rust.	Rust in invert. No acid.
Trigg	7-7-54	RS 111-74-1.	1949	77 x 57	Dull.	Half full of silt and mud.
Washington	5-13-54 (1) 8-25-55 (2)	RS 115-269-1.	1949	142 x 90	(1) Dull; P. P. rust. (2) Dull; P. P. rust.	(1) P. P. rust in trickle line. (2) Spelter black along flow line.
Washington	5-13-54 (1) 8-25-55 (2)	RS 115-189-2.	1949	142 x 90	(1) Dull. (2) Dull. P. P. rust.	(1) Slight rusting at bolts. (2) Scattered P. P. and T. B. rust along flow line.
Whitley	6-6-56	RS 118-820-1. Ky. 628, at Mt. Ash, Ky.	1949	156 x 96	T. B. rust; heavy pitting.	Water slightly acid.
Whitley	6-6-56	RS 118-820-1. Ky. 628, at Mt. Ash, Ky.	1949	107 x 72	Loose scaly rust.	9-in. of silt in invert.
Whitley	6-6-56	RS 118-820-1. Ky. 628, at Mt. Ash, Ky.	1949	156 x 96	T. B. rust; scaly rust.	T. B. and scaly rust over entire invert.
Whitley	6-23-54 (1) 7-20-55 (2) 6-6-56 (3)	RS 118-740-1.	1949	twin 107 x 72	(1) P. P. rust. (2) P. P. rust. (3) P. P. rust.	(1) Both arches deformed at centers. 2-in. of sand and gravel in both. (2) No change. (3) No change. Silting heavier.
Whitley	6-23-54 7-20-55 6-6-56	RS 118-740-1.	1949	twin 72 x 44	(1) T. B. rust. (2) T. B. rust. (3) T. B. rust; scaly rust.	(1) One arch silted 1/2 full. T. B. rust entire length of other. No acid. (2) No change. (3) Rusting greater; silting lighter.

On the Harveyton-Stacey Road (Ky. 267) in Perry County, three un-paved structures were found to have their inverts completely cut by rusting for the entire length of the culvert. One of these, a 159 by 96 in. pipe arch, 70 ft. long, had an unusually wide strip of metal from the invert missing, as shown in Fig. 2; and the arch itself had been deformed by the consequent loss of strength. Another structure on this road, shown in Fig. 3, had been paved with concrete at some undetermined earlier date, probably because of rusting in the invert. There were some signs of deterioration in the concrete; but these were slight, and the arch itself was not deformed. This structure had been placed -- as had all of those inspected on this road -- in 1949.

Types of Rusting

The term rusting is used in this report to define that condition where metal is exposed and has become discolored in such a way as to indicate that oxidation has been taking place. Undoubtedly there are differences in the conditions which cause rust to develop in the un-paved structures, as well as differences in the types and severity of the rusting.

Structures in water that is highly acidic usually lose their spelter rather early. The galvanized coating seems to be more vulnerable to the acid than the base metal itself. Once the spelter is gone the oxidation process in the base metal continues to progress even when there is no flow of acid water. This process normally results

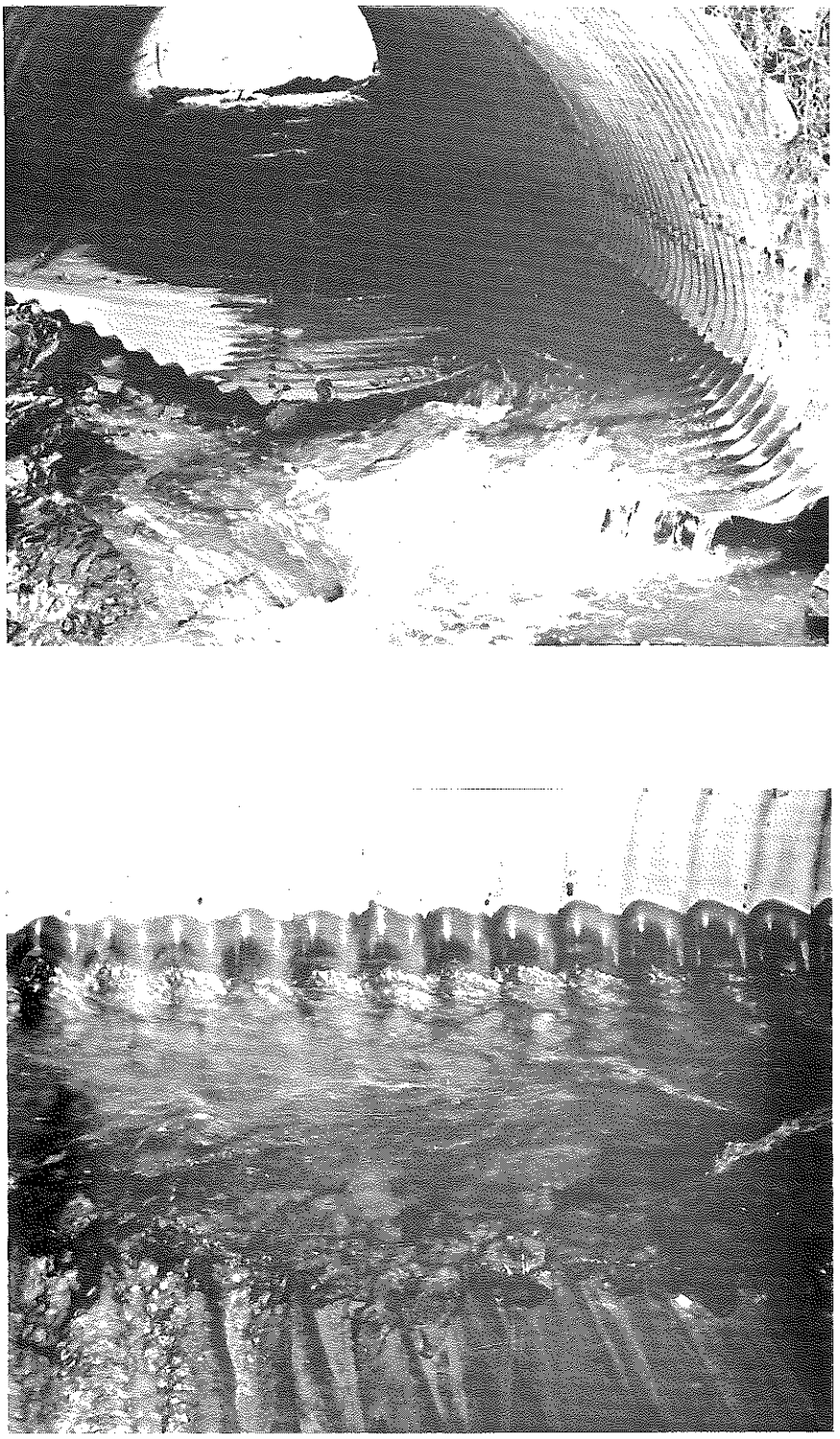

Fig. 2 - Unpaved Pipe Arch on Ky. 267, Showing Effects of Highly Corrosive Water.

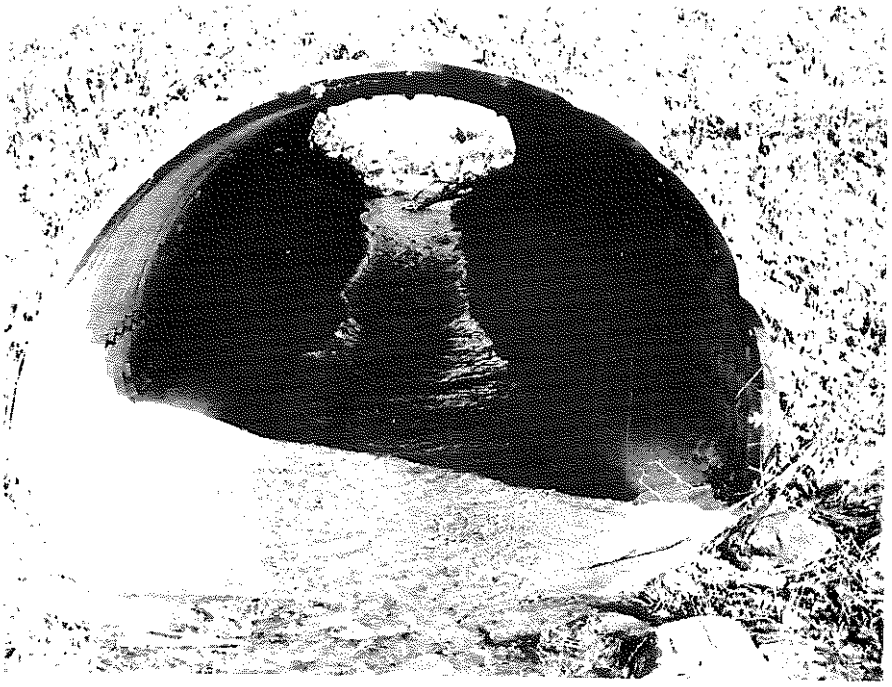

Fig. 3 - Pipe Arch on Ky. 267, Paved with Concrete in Invert.

in scales of rusted material -- described in Table 1 as "loose, scaly rust" -- on the surface of the base metal. Abrasion, together with further acid action, tends to scour these scales free. This leaves exposed a new layer of base metal, subject to the same continuing process.

In some cases the structures undergo a severe change in appearance rather quickly, followed by only slight change after several years of service. It is quite possible in such cases that the initial oxidized layer has formed a protective coating which deters further rusting. However, if this coating becomes subject to abrasive action it may scale away, permitting further oxidation. Consequently, the seriousness of this rusting seems to depend upon the possibilities of abrasive action.

Another type of rusting, found more frequently in areas where it would seem almost impossible to have any severe acid action, appears to start with a roughness of the surface under the flow line. This usually leads to pin point specks of rust, which grow in number and size until they almost completely cover the invert. This usually occurs in the troughs of the corrugations and most heavily at their downstream sides. It is probable that the action is the result of an electroplating process. The water which stands in the corrugations during periods of no flow contains salts of varying concentrations and in volumes which vary according to sand and gravel deposits. This condition can bring about an ionic exchange, resulting in the plating of some of these salts on the underlying base metal. The action tends to separate the spelter from the base metal, and, since it is normally

a continuing process, it gradually covers the entire flow line. Later stages then result in exposed metal, scales and pitting.

Some of the structures inspected gave a deceptive first impression of being in a very advanced stage of rusting. They appeared to be heavily pitted and to have large sections of metal missing. Closer inspection revealed, however, that the extreme roughness and barnacle effect were caused by an accumulation of foreign material; that there was actually little reduction, if any, in the thickness of the base metal.

From study of Table 1 it becomes evident that rusting in one form or another is general for all of the areas inspected; it does not follow any pattern of counties in coal-bearing areas. Acidity tests were made at almost every structure -- prevented only in the few cases where there was no water to test -- and the only indications of serious acidity were found in the Perry, Harlan and Hopkins County inspections.

RECOMMENDATIONS

In extreme cases, where the invert is already scaling away or becoming perforated, virtually immediate maintenance will be needed to preserve the structure. Such structures were found, in this study, on three roads; and it may be assumed that there are more. Unless attention is given to these very soon, either extreme maintenance or replacement may become necessary.

In the case of a number of the structures inspected a protective coating of some sort seems indicated, even though the rusting has not yet progressed sufficiently to threaten the strength of the arch. This seems necessary in view of the amount of rusting that has already taken place during the relatively short lengths of time the structures have been in service. Protective treatment would seem quite feasible economically since it could reasonably be expected to double the service life of the structure at a cost not exceeding twenty percent of the cost of replacement. Conservatively speaking, it is probable that the service life of structures having advanced rust can be readily doubled at an expense of from five to twenty percent of their initial cost. Also, of course, such structures could be inspected and repaved at necessary intervals indefinitely.

However, if immediate attention were not deemed necessary, these structures which have exhibited initial -- but not yet serious -- rusting could be inspected frequently with the intent of making repairs and, eventually, of paving the invert when necessary.

It is not recommended, however, that all of the structures be paved at once. Many in the state will probably never require paving, and in the case of many which already show rust there is a choice of paving now or later. In cases where the present rusting is light, paving may never be necessary.

It is recommended that care be taken to prevent placement of unprotected metal in mine water streams. This has been recommended previously, both by the manufacturers and the Division of Research, and some action has already been taken.

It is not recommended that all metal pipe arches be paved when placed. The observed performance of many un-paved structures has proved completely satisfactory. Also, in those instances where heavy permanent silting exists, paving would be needless.