CORROSION PERFORMANCE OF ALUMINUM CULVERTS

Final Report

J. T. Ellis

Research Laboratory Section
Testing and Research Division
Research Project 60 NM-26
Research Report No. R-976

Lansing, November 1975

INTRODUCTION

This is the third and final report of a series which were filed after inspections of aluminum culvert installations in the Upper Peninsula. This report presents information obtained from two inspections conducted during September 1970 and August 1974.

Progress Report No. 1 (MDSHT R-569, March 1966) reports the history, background, and physical characteristics of certain aluminum culvert installations in Michigan. The first report briefly discusses corrosion theory, selection of the test culverts, and preliminary appraisal of the corrosion performance of the test culverts based on data from the first inspection. Progress Report No. 2 (MDSHT R-679, December 1968) reports on a detailed study designed to define the environmental site conditions of the test culverts so that their corrosion performance could be more thoroughly evaluated. A brief summary of the first two reports follows.

The installation of 27 aluminum culverts on relocated US 2 in Gogebic County was completed during the summer of 1965. Six of the 27 culverts were selected during the first inspection (October 1965) to serve as test samples. Four galvanized steel culverts from the same construction project and an adjacent project were selected as comparison references within the same environment. In addition to the State culverts, four county road installations of aluminum culverts in Gogebic and Ontonagon Counties were chosen to obtain information on the corrosion performance of aluminum culverts in various other environments with similar climatic conditions. The 14 test culverts were visually inspected and the natural soils, backfill, and waters were checked for pH during the first inspection. The results from the inspection and pH data revealed no serious corrosion or apparent corrosive environment for either type of culvert.

Inspection No. 2, conducted during the week of August 14, 1967, consisted of the following operations:

1) A careful visual inspection of the culvert inverts

2) Sampling the soils and water for laboratory pH measurements and chemical analysis for substances known to influence the corrosion of aluminum

3) Polarization voltage measurements as a possible method for predicting corrosion rates

4) Soil resistivity measurements as a possible method for indicating soil corrosivity

5) Cutting samples from the test culverts for laboratory metallurgical analysis.

The resulting data from Inspection No. 2 revealed evidence of minor corrosion or mild corrosive conditions, or both, at nearly all culvert sites. Corrosion was largely confined to small amounts of white corrosion product or superficial pitting. Only small amounts of corrosion-inducing chemicals were found in the soils and water surrounding most culverts. Four culverts showed slightly more serious corrosion and/or corrosive conditions than the others. Conclusions drawn from this second inspection were: 1) none of the test culverts display severe corrosion and/or corrosive conditions; and, 2) aluminum appears to be performing satisfactorily as a culvert material with respect to corrosion. Progress Report No. 2 recommended that: 1) a visual inspection of the culvert inverts be performed every three years; 2) a visual inspection of the culvert exverts (soil side) be performed every six years; and, 3) a second soil resistivity survey and a resampling of the soils and water and of the culverts for chemical analysis be considered if subsequent visual inspections indicate a change in corrosion rate or corrosion conditions.

In view of the findings of Inspection No. 2, and further research on underground corrosion, the following testing program was proposed for future inspections.

1) Inspect the culvert inverts as thoroughly as prevailing site conditions permit, noting the types of corrosion and estimating the frequency of corrosion sites.

2) Excavate and inspect an area of the culvert exverts and again describe the types and frequency of corrosion sites.

3) Sample the soils and waters of the test culverts for pH and chemical analysis to determine if significant changes in soil and water chemistry have occurred since the previous inspection.

4) Prepare a photographic record of the test culverts' environmental site conditions and invert and exvert conditions.

Polarization voltage measurements, soil resistivity measurements, and culvert sampling were not specifically proposed since these tests had been performed previously and it was believed that the information obtained would not justify the additional time and cost involved.

INSPECTION NO. 3

The third inspection, conducted during the week of September 14, 1970, included all of the tests proposed above. The procedures used, results, and a discussion of the results from the third inspection are as follows.

Visual Examination

The location, properties, and environmental site conditions of each test culvert are given in Table 1 of the Appendix. As stated previously, the US 2 culvert sites generally have poor drainage conditions and most culverts contained ponded water. High water levels, increasing amounts of sand and silt in the inverts, and overgrowth of vegetation hampered the inspection (Fig. 1). Examination of the invert (water side) surface was generally limited to the area above the existing water level and to the area near the ends. When water levels were low enough to permit cleaning the bottom of the invert, a more thorough inspection was conducted. Examination of the exvert (soil side) surface was limited to about 1 sq ft of excavated area near one end of the culvert. Corrosion conditions at each culvert site are described in the following notes.

Galvanized Steel Culverts, US 2

Station 96+00

Invert: The visible area of the culvert continues to be in excellent condition. Previously noted white and red corrosion on rivet heads has not significantly increased in severity. A small amount of white and red corrosion is beginning to show at horizontal plate joints.

Exvert: The culvert exvert is in excellent condition, with no evidence of corrosion attack.

Station 549+50

Invert: Minor white and red corrosion at horizontal and vertical plate joints and on rivet heads was again observed. The previously noted spots of white corrosion on the first ten corrugations from the south end were still visible with no significant increase in maximum density (8 to 10 per sq in.). Other minor random corrosion spots were also observed. Moderate soil staining was prevalent throughout the bottom of the invert.

Exvert: The galvanizing was soil stained and dark but showed only superficial attack.

North end, Sta. 181+10

North end, Bruce Crossing

South end, Sta. 96+00

Figure 1. Typical culvert site conditions during Inspection No. 3.

Station 622+00

Invert: The 5-in. arc of white corrosion spots up to about 1/4 in. diameter noted before near the north end was still visible at about the same degree of severity (8 to 10 per sq in.). A similar type arc of smaller (up to about 1/8 in. in diameter) but more dense (12 to 15 per sq in.) white corrosion spots was observed near the south end (Fig. 2). Many other random white spots up to about 1/4 in. in diameter were noted throughout the entire invert. Soil staining of the bottom, and white and red corrosion on rivet heads and at horizontal plate joints were slightly more prevalent than before.

Exvert: Minor soil stain was visible, but no significant corrosion attack was present on the excavated area.

Station 643+00

Invert: A moderate amount of white and red corrosion on rivet heads and at horizontal plate joints was observed. Random white corrosion spots up to about 1/4 in. in diameter with a maximum frequency of 6 to 8 per sq in. were prevalent throughout the upper invert. The invert bottom was badly soil stained.

Exvert: Many spots of superficial white corrosion up to about 1 in. in diameter were prevalent over the excavated area (Fig. 3). A small amount of red rust, along with soil stain, was noted but no serious penetration of the galvanizing was observed.

Aluminum Culverts, US 2

Station 114+50

Invert: A small number of randomly dispersed superficial corrosion spots up to about 1/4 in. in diameter were again noted near the west end. Moderate soil stain covered about a 1-ft arc in the invert bottom.

Exvert: Only a few random spots of incipient corrosion were present.

Station 121+75

Invert: A small number of incipient white corrosion spots up to about 1/4 in. in diameter with a maximum density of 4 to 5 per sq in. were observed. Previously noted white stain or etch at several plate joints and brown soil stain in the invert bottom were still visible but with no significant increase in severity.

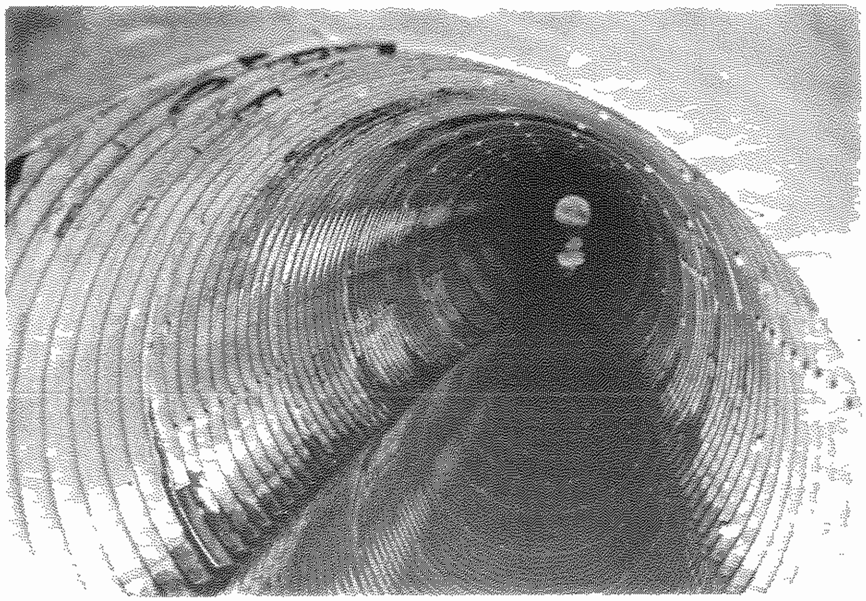

Figure 2. Galvanized steel culvert, Sta. 622+00. Middle left portion shows an arc of white corrosion.

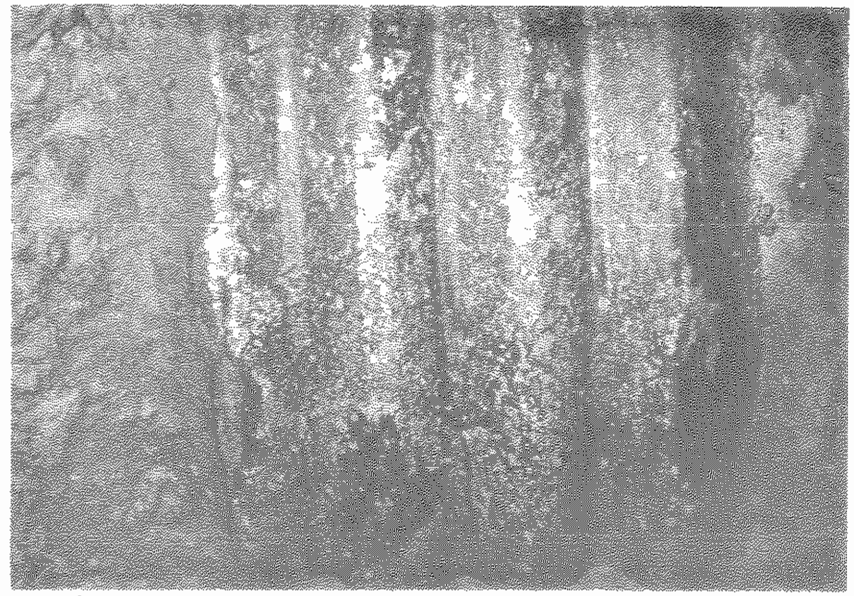

Figure 3. Galvanized steel culvert, Sta. 643+00 (exvert). The light areas in the center are spots of superficial corrosion.

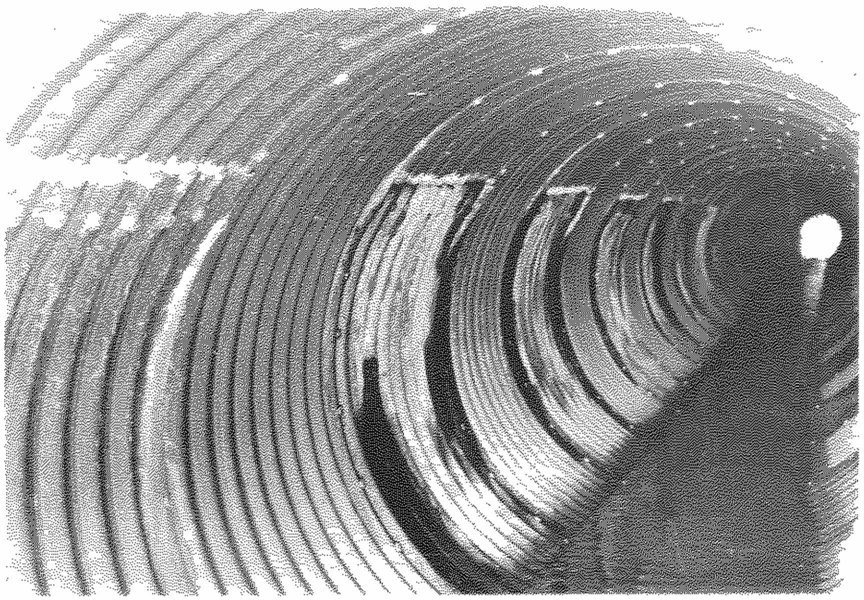

Figure 4. Aluminum culvert, Sta. 181+10. Second horizontal plate joint shows a white crusty material which formerly was gelatinous.

Exvert: Several pitted areas where the cladding was perforated exposing the core alloy were observed. Most pits were in the 1/8 by 1/4-in. range, but a few ranged up to 1/4 by 1/2 in. No penetration of the core alloy was noted.

Station 181+10

Invert: The previously observed white staining or etching and soil staining at horizontal and vertical plate joints appears to have increased somewhat in the number of joints attacked and in severity of attack. The gelatinous corrosion product previously noted on the fourth joint from the south end seemed to have dried into a white crusty material (Fig. 4). When the white material was removed, the type of corrosion appears similar to the white staining or etching at the other joints. No perforation of the cladding was apparent at any of the plate joints. Additional soil nodules, with accompanying pits under each, were observed in the bottom of the south end invert. These pits, as with the previous ones, perforated the cladding to the core alloy, but did not appear to have proceeded further. The invert bottom appears to be becoming increasingly more soil stained.

Exvert: A considerable number of pits were present on the excavated surface. Most of the pits were under nodules of soil similar to the ones in the invert. The pits ranged in size up to about 1/2 in. in diameter, but most were smaller. As in the invert, most of the pits had perforated the cladding to the core alloy, but had not proceeded further.

Station 330+00

Invert: Many small stains or spots of superficial corrosion were prevalent throughout the visible invert. Most of the spots were in the 1/16 to 1/8 in. diameter range with a maximum density of 8 to 10 per sq in. White corrosion was present at horizontal plate joints and in the invert bottom.

Exvert: Several relatively large pits under nodules of soil were observed. The largest pit was about 3/4 in. in diameter and several others were 1/2 in. or more in diameter. Most pits penetrated the cladding to the core alloy, but none had proceeded further.

Station 420+35

Invert: Numerous minute stains or corrosion spots are present throughout the entire invert. The majority of the spots are in the 1/16 to 1/8-in. diameter range, with a maximum density of 12 to 14 per sq in. Moderate soil staining was visible at several horizontal plate joints on the invert bottom.

Figure 5. Aluminum culvert, Wood Spur (exvert). Elongated dark areas in the center and to the left of the joint are areas of corrosion attack where the cladding has been removed, exposing the core alloy.

Figure 6. Aluminum culvert, Bruce Crossing (exvert). The dark areas in the center represent areas of corrosion attack where the cladding has been perforated, exposing the core alloy.

Exvert: Several quite large pits up to about 1 in. in diameter, along with others up to 1/4 by 1 in., were present on the exposed outer surface. Most of the pits appeared to have penetrated the cladding to the core alloy, but corrosion did not appear to have progressed beyond the cladding.

Station 458+20

Invert: The previously noted white corrosion spots along the former high water line were still present at about the same maximum size (1/4 in. in diameter). Several plate joints and about a 2-ft arc in the invert bottom were moderately soil stained.

Exvert: Several corrosion spots up to about 1/2 in. in diameter were present under nodules of soil. Corrosion was limited, however, to superficial attack with no significant penetration of the cladding at any of the spots.

Aluminum Culverts, County Installations

Bessemer

Invert: The previously noted spots of white stain or etch covering the entire invert are still present in about the same maximum size and density (1/4 in. in diameter and 4 to 5 per sq in.). The invert bottom was moderately soil stained.

Exvert: The white blotchy condition observed during previous inspections remains prevalent over the entire visible exvert (about 3 or 4 ft on each end exposed). The blotches appear to be increasing slightly in size and frequency (maximum size about 1-1/2 in. in diameter and maximum frequency about 15 to 20 per sq ft).

Wood Spur

Invert: The white stain or etch spots previously observed continue to be prevalent over the upper half of the invert. The maximum spot size remained at about 1/4 in. in diameter with a maximum frequency of 4 to 5 per sq in. The invert bottom continues to be badly soil stained.

Exvert: Several relatively large pitted areas up to 1 by 2 in. were present on the excavated exvert. Some of the pits were long and narrow (about 1/2 by 2 in.). The cladding was perforated and removed in most of the pitted areas (Fig. 5). No significant further penetration beyond the cladding into the core alloy was observed.

Bruce Crossing

Invert: The superficial white stain or etch noted previously over about 50 percent of the invert area was still present in about the same size (maximum of about 1/4 in. in diameter) and frequency (maximum of about 10 per sq in.). An area of larger white spots up to about 1/2 in. in diameter was observed in the upper invert near the south end. These spots also appeared to be quite superficial.

Exvert: Quite severe attack of the cladding was observed in several areas up to 1 by 2 in. in size. The cladding had been removed in these areas, but no deeper penetration beyond the cladding was noted (Fig. 6).

Ewen

Invert: The random surface stain spots noted previously remain about the same size (about 1/8 to 1/4 in. in diameter) but slightly more prevalent (4 to 5 per sq in. maximum). Moderate superficial white stain or etch was noted on the second and fourth corrugations from the north end.

Exvert: Moderate soil stain along with several random white blotches were noted on the exposed surface. The white blotches appeared to be quite superficial with no significant penetration of the cladding.

The visual inspections of the test culverts revealed, in general, no corrosion attack of immediate seriousness to either the galvanized steel or aluminum culverts. Corrosion of the galvanized steel culverts' inverts was largely confined to minor white and red corrosion at horizontal and vertical plate joints, rivet heads, and numerous random spots of incipient white corrosion dispersed throughout the inner surface. Of the galvanized steel culverts, Sta. 622+00 had the most severe invert condition with two arcs of closely spaced white corrosion spots. Only Sta. 643+00 had any significant corrosion attack of the exvert, and this attack was generally limited to many spots of superficial white corrosion and a small amount of red rust and brown soil stain.

Corrosion of the aluminum culvert inverts was again generally confined to small spots of corrosion at or near former water-air interfaces and to random spots or blotches of white stain or etch. The white stain or etch was often seen at horizontal and vertical plate joints. All aluminum test culverts were moderately to severely soil stained in the invert bottom. Sta. 181+10 again exhibited the most severe invert corrosion condition with additional pits under hard soil nodules in the bottom. The new pits ranged up to about 1/2 in. in diameter and perforated the cladding to the core alloy. A more serious corrosion condition prevailed on several of the aluminum culvert exverts (soil side). Quite large areas where the cladding had been removed exposing the core alloy were observed on seven of the ten aluminum test culverts. The pitted areas were often, but not always, under hard nodules of soil. Three culverts (Sta. 420+35, Wood Spur, and Bruce Crossing) were the most severely attacked with pits up to 2 sq in. visible (Figs. 5 and 6). All corrosion attack appeared to be largely confined to the cladding. Of those culverts where quite large areas of cladding had been removed, no significant further penetration into the core alloy was observed.

Chemical Analysis

The waters traversing the test culverts and the natural soils and backfill at each culvert site were again sampled for chemical analysis in the laboratory. This series of samples was taken to determine if the soil and water chemistry of the culvert environmental site conditions had changed from the previous inspections, and to see if correlation between soil and water chemistry and corrosion was possible. The moisture content of the soils was determined by the Standard Method of Laboratory Determination of Moisture Content of Soil, ASTM D-2216. Using this method, the moisture content of soil is expressed as the ratio of the weight of water in a given sample mass to the weight of the solid particles. The weight of water is determined by measuring the weight loss of a soil sample after drying to constant weight at 110±5 C. Moisture content of the soil (W) is calculated as follows:

$$W = \frac{\text{weight of moisture x 100}}{\text{weight of oven dry soil}}$$

The dried soil samples were extracted with distilled water for chemical analysis of the water soluble fraction. The chemical data, pH data, and soil moisture content are presented in Table 2 in the Appendix.

Comparison of these data with data from previous inspections shows no significant changes in chemical content or pH levels. Other causative factors of corrosion attack, such as differentials in oxygen or aeration (oxygen concentration cells) and moisture along the structure surface, also contributed to the observed corrosion. Some correlation between soil and water chemistry and corrosion was evident, since in most instances where significant corrosion did occur, evidence of corrosion-inducing chemicals was present. For example, the most severely attacked culverts (Sta. 181+10, Sta. 330+00, Sta. 420+35, Wood Spur, and Bruce Crossing) all had low pH values and/or relatively high amounts of chemicals present somewhere in their environments. Overall, the chemical data indicate no serious corrosive conditions exist at any of the test culvert sites.

North end, Sta. 96+00

South end, Sta. 420+35

Figure 7. Typical site conditions during the final inspection.

Figure 8. Galvanized steel culvert, Sta. 549+50 (exvert). Light spots are pitted areas where the galvanizing has been penetrated.

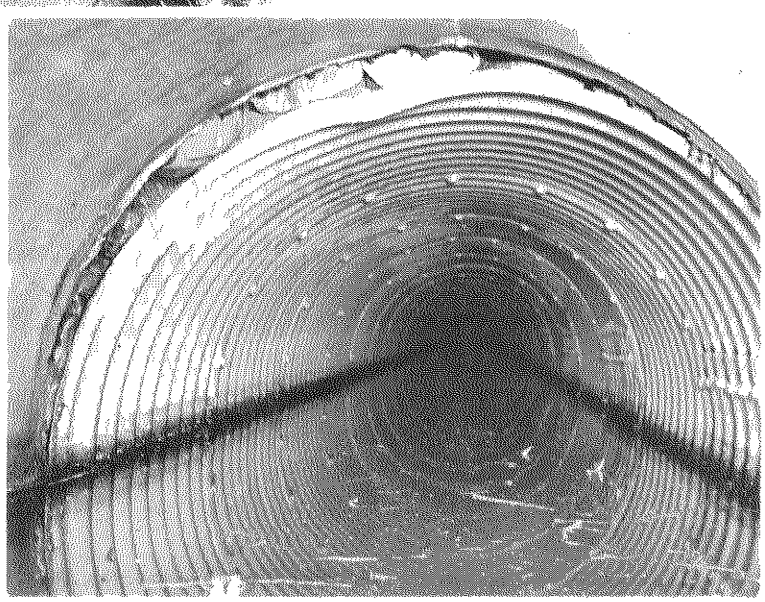

Figure 9. Aluminum culvert, Sta. 330+00. Upper portion shows separation of headwall from culvert and large stones in the backfill.

INSPECTION NO. 4

Since the data from Inspection No. 3, and previous inspections, had shown only moderate corrosion attack and little indication of corrosive environmental conditions, only one further inspection was proposed to finalize the formal evaluation program of the test culverts. That final inspection was conducted during the week of August 19, 1974 with the same testing program as in Inspection No. 3, except that chemical analysis of the soils and waters was limited to pH measurements.

Visual Examination

The same environmental conditions prevailed at most culvert sites as during previous inspections (i.e., poor drainage, high water levels, and dense overgrowth of vegetation, as shown in Figure 7). Again, the visual examination of the invert was generally limited to the area above the existing water level and the exvert to about 1 sq ft of excavated area. The following notes describe the observed corrosion condition of the test culverts.

Galvanized Steel Culverts, US 2

Station 96+00

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Station 549+50

Invert: No significant increase in corrosion since the previous inspection. The north end is partially blocked with sticks and brush--possibly a beaver dam. The north headwall was separated from the culvert about 3 in.

Exvert: The galvanizing is slightly more soil stained and darker than on the previous inspection. Several pits under soil nodules have penetrated the galvanizing (Fig. 8).

Station 622+00

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Station 643+00

Invert: A moderate increase in the amount of red rust at plate joints and on rivet heads was noted. The north headwall was separated from the culvert about 2 in.

Exvert: The entire excavated area was covered with red rust and tightly adhering soil. Beneath the soil were pitted areas, some of which appeared to have perforated the galvanizing to the steel base metal. No deep penetration beyond the galvanizing was noted, and the culvert was still solid.

Aluminum Culverts, US 2

Station 114+50

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Station 121+75

Invert: No significant change since the previous inspection.

Exvert: Not inspected because of hard rain.

Station 181+10

Invert: Little significant change since the previous inspection. The north headwall was separated about 4 in. from the culvert, exposing 2 to 4-in. diameter stones in the backfill. A few additional soil nodules with accompanying pits were noted. The red and white staining and etching at plate joints noted previously appears stable.

Exvert: No significant change since the previous inspection.

Station 330+00

Invert: No significant change except that both the north and south headwalls have separated from the culvert about 2 in., exposing 2 to 4-in. diameter stones in the backfill (Fig. 9).

Exvert: No significant change since the previous inspection.

Station 420+35

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Station 458+20

Invert: No significant change since the previous inspection. The north headwall was separated from the culvert about 2 in.

Exvert: No significant change since the previous inspection.

Aluminum Culverts, County Installations

Bessemer

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Wood Spur

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Bruce Crossing

Invert: No significant change since the previous inspection.

Exvert: No significant change since the previous inspection.

Ewen

The aluminum culvert formerly at this site had been washed out and replaced with a galvanized steel culvert in the spring of 1971. The aluminum culvert was found at the Ontonagon County garage in Bruce Crossing. The following describes the condition of both culverts -- the damaged aluminum culvert at the garage and the galvanized steel replacement culvert.

Aluminum - The culvert was in two sections; one section was partially collapsed and badly damaged during the washout (Fig. 10). The other section was intact and in generally good condition. The bottom of the invert

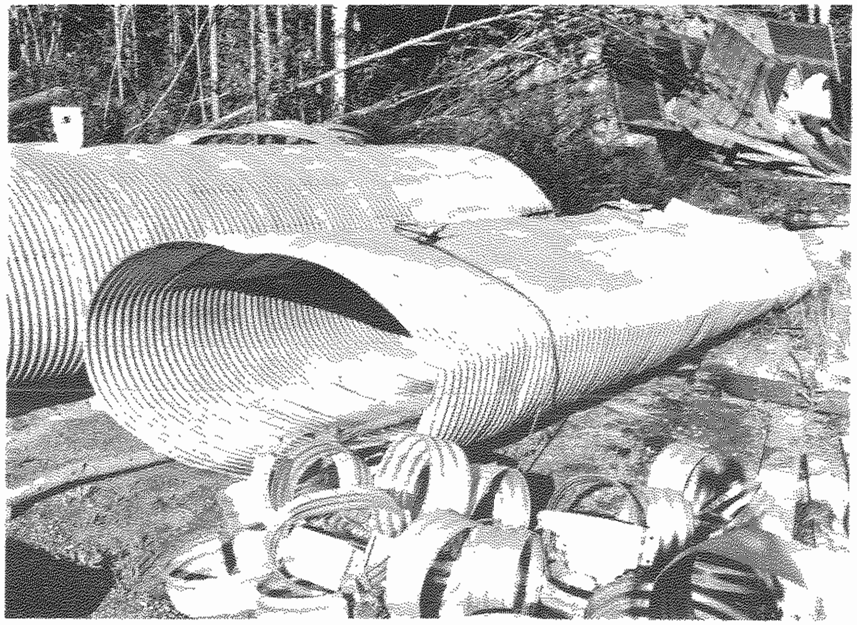

Figure 10. Aluminum culvert formerly at Ewen, now at Ontonagon County garage at Bruce Crossing.

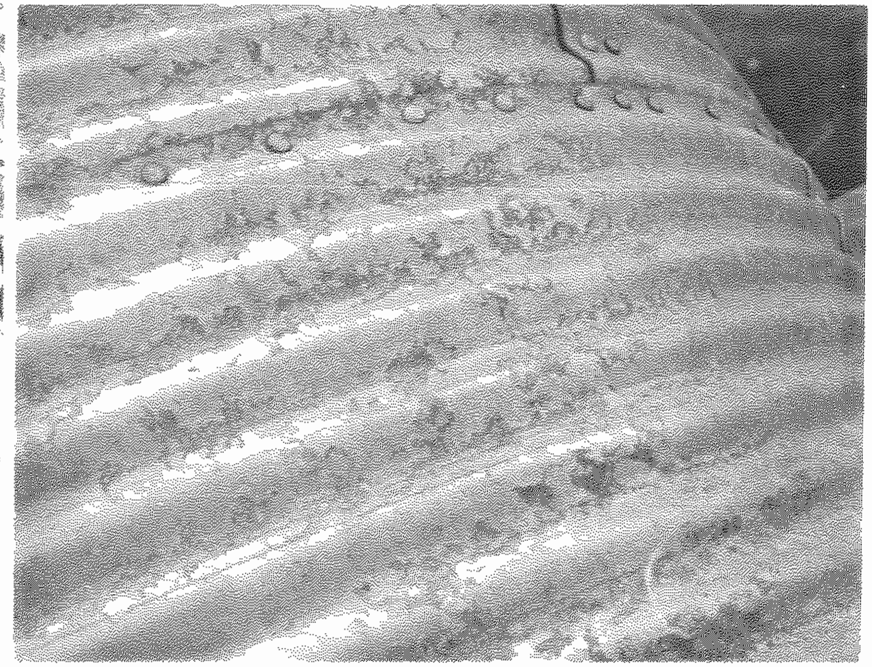

Figure 11. Close-up of aluminum culvert in Figure 10, showing the corrosion attack on the exvert (dark areas).

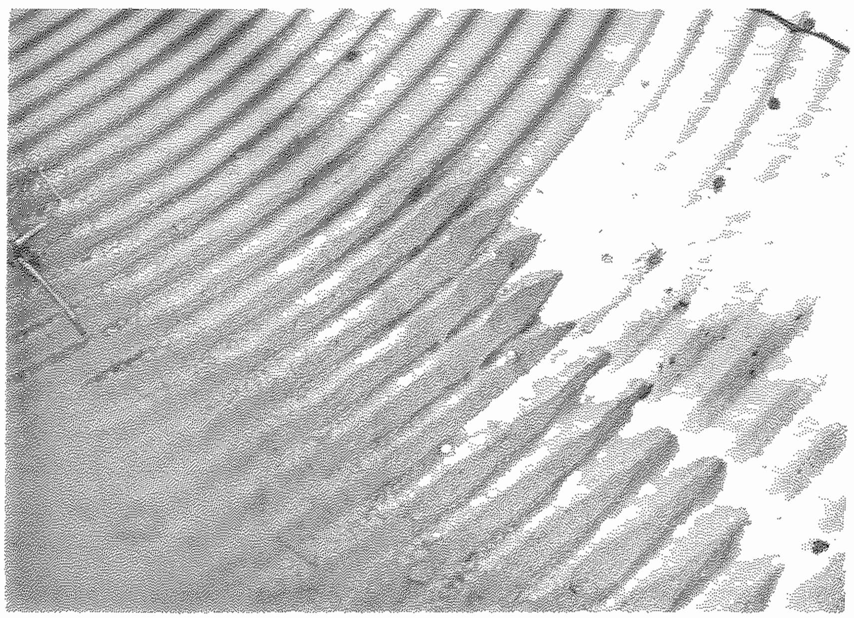

Figure 12. Close-up of galvanized steel replacement culvert at Ewen. Cleaned area at middle right shows part of the 5-ft arc of red rust on the invert bottom.

had many small pits up to about 1/2 in. in diameter which had perforated the cladding, but did not appear to have proceeded further. About 1/3 to 1/2 of the exvert was covered with pitted areas where the cladding had been removed (Fig. 11). In no instance did it appear that the corrosion had gone significantly beyond the cladding. The culvert, in general, was solid and in good condition with respect to corrosion attack.

Galvanized Steel - An approximate 5-ft arc in the bottom of the invert was quite badly attacked and showed much red rust (Fig. 12). Abrasion had contributed to the attack as indicated by more severe rusting on the upstream side of the corrugations and the presence of many rocks inside. The culvert was solid with no observed deep penetration into the steel base metal. The culvert has been in service for about three years.

The fourth visual inspection revealed, in most cases, only minor changes in corrosion attack as compared with the previous inspection. One galvanized culvert (Sta. 643+00) showed a significant increase in corrosion on its exvert, with the galvanizing perforated and showing much red rust. The galvanized replacement culvert at Ewen, after three years of service, also showed significant attack, with red rust showing in the bottom of the invert. The corrosion condition of the aluminum culverts appears to have stabilized. Even the culverts which showed the most severe attack during early inspections (Sta. 181+10, Wood Spur, Bruce Crossing) have reached a near stable condition.

The pH measurements of soils and waters, given in Table 2 of the Appendix, show little change from previous measurements; ranging, as before, from near neutral to slightly alkaline for the waters and backfill, and from near neutral to quite acidic for the natural soils.

CONCLUSIONS

1) The corrosion attack on the aluminum test culverts after slowly progressing during the first few years of service, most seriously from the soil side, appears to have stabilized to the point where little additional corrosion is occurring.

2) The corrosion attack on two of the four galvanized steel reference culverts, while not yet serious, continues to progress.

3) A slight correlation between soil and water chemistry and corrosion attack was found. The most seriously attacked test culverts all had low pH values and/or relatively high amounts of corrosion-inducing chemicals present in their environment.

4) Aluminum is performing satisfactorily as a corrosion resistant culvert material in the Upper Peninsula environments to which it has been exposed.

RECOMMENDATIONS

1) Retain the present specification which permits corrugated aluminum alloy pipe as an alternate material for Class A culverts (1973 Standard Specifications for Highway Construction, Section 5.11, page 339).

2) Since the most severe corrosion attack occurred on the exvert (soil side) of the test culverts, and non-uniform backfill was evident, it is recommended that the Design Standard for Bedding and Filling Around Pipe Culverts IV-82B, which states: "Minimum limits for granular materials Class III are shown in details 1, 2, and 3, except that for corrugated steel pipe, a minimum of six inches of granular material Class III, or better, shall be placed completely around the pipe for the full length of bedding and fill along the pipe." be revised so that it also applies to aluminum alloy pipe. This will prevent corrosion cells from forming due to different environments at various points on the soil side of the culvert pipe.

APPENDIX

TABLE 1
PHYSICAL CHARACTERISTICS

Project	Corrugated Pipe Type	Location	Dimensions: Length, ft	Dimensions: Diameter, in.	Dimensions: Gage	Embedment Depth, ft	Years of Exposure: Sept. 1970	Years of Exposure: Aug. 1974	Natural Soil Series	Depth[2] Deepest End, in.: Sept. 1970	Depth[2] Deepest End, in.: Aug. 1974	High-Water Line, in.: Sept. 1970	High-Water Line, in.: Aug. 1974	Abrasiveness: Sept. 1970	Abrasiveness: Aug. 1974
F27023 D C4	Steel	Sta. 643+00	140	24	14	14.3	5.8	9.7	Adolph	9	8	16	16	low	low
F27023 D C4	Steel	Sta. 549+50	140	24	14	12.5	5.8	9.7	Adolph	11	8	12	12	low	low
F27023 D C4	Steel	Sta. 622+00	104	24	16	6.5	5.8	9.4	Adolph	6	10	12	12	very low	very low
F27023 B C3	Steel	Sta. 96+00	88	36	14	5.3	5.2	9.1	Peat	22	23	22	23	very low	very low
F27023 B C3	Aluminum	Sta. 114+50 Rt	58	18	16	5.0	5.2	9.1	Skanee	1	1	4	4	low	low
F27023 B C3	Aluminum	Sta. 121+75	72	24	14	5.7	6.4	10.3	Adolph	10	12	10	12	low	low
F27023 B C3	Aluminum	Sta. 181+10	116	36	8	10.8	6.7	10.6	Peat	11	10	15	15	moderate	moderate
F27023 B C3	Aluminum	Sta. 330+00	80	24	14	6.2	6.2	10.1	Peat	10	10	11	15	low	low
F27023 B C3	Aluminum	Sta. 420+35	120	30	14	9.0	6.1	10.0	Peat	16	18	21	18	low	low
F27023 B C3	Aluminum	Sta. 458+50	100	36	8	16.0	6.6	10.5	Skanee	13	11	20	20	very low	very low
County	Aluminum	Bessemer	44	30 84[1]	14	4.0	6.9	10.8	Skanee	1	1	not visible	not visible	moderate	moderate
County	Aluminum	Bruce Crossing	36	60 84[1]	8	4.0	6.9	10.8	Roselawn	18	21	20	21	moderate	moderate
County	Aluminum	Ewen	41	60	8	4.0	6.1	10.0	Ontonagon	34	3	36	36	moderate	moderate
County	Aluminum	Wood Spur	36	24	14	2.5	6.9	10.0	Ontonagon	11	12	11	12	very low	very low

[1] Arched culverts.
[2] Total depth including water, sand, silt, muck, etc.

TABLE 2
CHEMICAL DATA

Sample	Extract From Natural Soil							Extract From Backfill Soil							Water					
	pH		Chloride, ppm	Calcium, ppm	Iron, ppm	Sulfate, ppm	Moisture Content, percent	pH		Chloride, ppm	Calcium, ppm	Iron, ppm	Sulfate, ppm	Moisture Content, percent	pH		Chloride, ppm	Calcium, ppm	Iron, ppm	Sulfate, ppm
	Sept. 1970	Aug. 1974						Sept. 1970	Aug. 1974						Sept. 1970	Aug. 1974				
96+00	6.97	6.54	0	76	0.9	0	30.0	7.80	7.43	0	41	0.5	0	8.9	7.12	7.16	214	127	0	0
114+50 Rt	6.06	6.30	0	12	0.6	0	21.9	7.81	6.92	0	19	0.5	0	4.4	6.98	7.59	53	41	2.1	0
121+75	5.78	6.42	0	32	0.9	12	43.8	8.35	7.38	0	10	0.4	0	7.1	6.51	7.32	4	10	0.1	4
181+10	6.15	6.71	165	363	3.8	19	72.4	7.01	6.95	21	31	0.6	0	20.3	7.56	7.35	14	32	18.0	0
330+00	4.82	3.92	463	219	32.0	37	60.7	7.90	6.55	0	29	0.7	0	6.8	7.02	7.28	32	18	0	14
420+35	5.27	4.95	0	40	1.5	0	20.2	6.13	6.79	15	11	44.9	0	21.3	6.38	7.87	123	36	0.5	0
458+50	4.60	5.47	7	26	0.8	7	16.2	7.73	7.51	0	22	1.2	0	8.8	7.12	7.20	312	139	2.1	0
549+50	3.69	5.93	298	154	27.2	0	32.5	6.17	6.36	10	6	1.7	0	13.0	6.47	6.80	60	29	66.0	0
622+00	4.56	4.95	75	90	39.0	0	59.3	6.75	6.40	0	0	12.0	0	7.3	6.42	5.38	121	24	0.8	0
643+00	4.20	4.46	73	35	29.0	0	44.3	5.94	5.77	5	14	4.1	0	14.0	6.30	6.71	126	40	0.6	0
Bessemer	5.67	6.52	19	55	23.0	0	24.1	6.64	7.67	0	49	1.1	0	14.6	7.31	7.49	53	43	0.1	43
Wood Spur	6.21	6.66	53	43	1.5	12	34.4	6.47	7.04	21	84	6.4	14	17.3	6.78	6.91	119	37	0.3	14
Ewen	7.03	7.08	0	200	3.0	0	36.8	6.05	7.66	6	77	7.4	0	18.6	7.43	7.03	11	31	0.8	0
Bruce Crossing	5.23	7.39	6	7	18.0	53	26.5	7.83	7.86	0	15	4.5	0	5.4	7.22	7.34	0	23	4.1	0