79-25

ZCFT-79-39-TJS/RJH
NOVEMBER 1, 1979

PERFORMANCE OF ALUMINUM RIVETED CULVERT IN CALIFORNIA

A report prepared for
CALTRANS' Consideration

by

T. J. Summerson and R. J. Hogan
of
KAISER ALUMINUM & CHEMICAL
CORPORATION

Center for Technology
Pleasanton, California

ClibPDF - www.fastio.com

ZCFT-79-39-TJS/RJH
11/1/79

PERFORMANCE OF ALUMINUM RIVETED CULVERT IN CALIFORNIA
1978 COOPERATIVE CALTRANS-KAISER ALUMINUM SURVEY

by

T. J. Summerson and R. J. Hogan
Applications Research

This report was prepared by KACC from laboratory analyses of samples (metal and soil) collected during field trips made by an inspection team consisting of members of the technical staffs of both CALTRANS and KACC.

The conclusions and recommendations provided in this report are solely those of KACC. The data are submitted as a suggestion for consideration by Caltrans. Kaiser can assume no responsibility or liability for use of these data. No warranties by Kaiser accompany these data and information.

UNRESTRICTED. This report and the information disclosed in it may be distributed to any interested party, including parties not employed by Kaiser Aluminum.

KAISER ALUMINUM & CHEMICAL CORPORATION
CENTER FOR TECHNOLOGY
PLEASANTON, CALIFORNIA

ClibPDF - www.fastio.com

ZCFT-79-39-TJS/RJH

COPIES TO:

R. J. Hogan	CFT 26
J. M. Holzer	Sacramento
M. Karimi	Vancouver
T. M. O'Neill	Sacramento
T. J. Summerson	CFT 26
D. C. Thomas (25)	774 KB
E. J. Westerman	CFT 11
J. R. Young	CFT 10
CALTRANS (125)	Sacramento
Corrosion Section(10)	CFT 26
TIC (2)	CFT 12

ClibPDF - www.fastio.com

CONTENTS

INTRODUCTION ---------- 2

Field Inspections ---------- 3

CFT Laboratory Procedure ---------- 4

RESULTS---------- 5

pH and Resistivities ---------- 5

Pipe to Soil Potentials ---------- 6

Chemical Analysis - Soils ---------- 6

Depth and Extent of Corrosion - Metal Samples----- 7

DISCUSSION---------- 10

Normal Performance---------- 10

Abnormal Performance---------- 10

CONCLUSION---------- 14

RECOMMENDATIONS---------- 15

ACKNOWLEDGMENTS---------- 15

FIGURES 1 THROUGH 4---------- 16-19

TABLES

I Performance of Aluminum Riveted Culvert - 1978 Caltrans-Kaiser Survey ---------- 20-21

II Semi-Quantitative Spectrographic Analysis of Soils, Weight Percent ---------- 22-23

III Atomic Absorption Analysis of Boiling Water Leach of Soil ---------- 24-25

IV Distribution of Maximum Pit Depth of Pipe Gauge, 1978-1979 (11 to 18 Years)---------- 26

V Distribution of Maximum Pit Rate for Culverts Sampled Three Times ---------- 27

VI Single Surface vs. Lap Joint ---------- 28

APPENDICES

A-1 Field Inspection Procedure ---------- 29

A-2 Culvert Inspection Report ---------- 30

A-3 Culvert Inspection Report ---------- 31

APPENDIX F - photos ---------- F-1 through F-94

ZCFT-79-39-TJS/RJH

ClibPDF - www.fastio.com

ZCFT-79-39-TJS/RJH

PERFORMANCE OF ALUMINUM RIVETED CULVERT IN CALIFORNIA
1978 COOPERATIVE CALTRANS-KAISER ALUMINUM SURVEY

by

T. J. Summerson and R. J. Hogan
Center for Technology
Kaiser Aluminum & Chemical Corporation
Pleasanton, CA 94566

SYNOPSIS

Performance of aluminum riveted drainage pipe has been updated from the 1970-71 survey. After 14 to 18 years' service, Alclad 3004 riveted drainage pipe continues to demonstrate good resistance to most soils throughout the State of California.

There is no evidence of any serious corrosion in lap joints. Corrosion is still confined to the thin protective cladding layer at most locations. Although a few instances of culvert perforations have been reported, most have occurred under conditions outside the recommended pH and resistivity limits. In no instance has there been a structural failure, actual or impending.

The recommendation is made that Alclad 3004 pipe be accepted by the State of California within the proposed pH and resistivity guidelines.

ClibPDF - www.fastio.com

INTRODUCTION

Aluminum drainage pipe was introduced in the United States about 1959. During the next 10 years, a number of field surveys were begun by various State Highway Departments, including some cooperative studies with the aluminum pipe suppliers. Several reports were published. Most showed that aluminum pipe was performing satisfactorily in soil-water conditions where pH was within a range of 4 to 9 and the minimum resistivity of the soil was greater than 500 ohm-cm. Acceptance of these values was not universal, however, and field surveys were continued.

In California, a survey of aluminum drainage pipe was made in 1970-71. The survey team was composed of technical personnel from Materials Laboratory, State of California Department of Highways and from Kaiser Aluminum & Chemical Corporation. Soil, water and metal samples were taken from more than 70 locations (mainly in California) where the pipe had been in use for 6 to 10 years. pH and resistivity of the soil and water samples were determined. Metallographic cross sections were prepared from the metal samples and the maximum depth of pitting measured. These data were examined by statistical analysis in an attempt to determine whether there was interaction between pH, resistivity, metal thickness and corrosion resistance--as determined by maximum depth of pitting. The probability of perforation within a 50-year service span was also determined.

The results of the statistical analysis and all of the supported experimental data were provided to the State of California Department of Highways Materials Laboratory by Kaiser Aluminum's Center for Technology in a report written by Dr. Jack Karush, September 16, 1971. This report concluded that the probability of a perforation within 50 years was

ClibPDF - www.fastio.com

quite small (i.e. less than 2%), and that, within acceptable soil pH range of 4 to 9 and minimum resistivity of 500 ohm-cm, the pitting rate was not dependent upon pH or resistivity. In addition, it was reported that corrosion in the lap joints was no problem.

For the next six years, California Department of Highways felt that existing experiences with aluminum were still too limited for them to approve use of aluminum pipe for applications requiring 25 or 50-year life within the pH and resistivities ranges proposed by Kaiser Aluminum (pH 4 to 9 and resistivity greater than 500 ohm-cm).

In 1978, Caltrans (State of California, Department of Transportation) agreed to a Kaiser Aluminum proposal to update the 1970-71 field survey report. Aluminum drainage pipes had now been in service for 14 to 18 years. Hopefully, the update would provide sufficient assurance to allow acceptance of aluminum under the previously proposed parameters.

Field Inspections

Some 40 of the original test sites were mutually selected, representing different soil/water conditions in California. In addition, at Caltrans' request, some 14 sites at the Rancho California development in Riverside County were inspected. (Corrosion of the aluminum pipe at Rancho California had been reported by Caltrans in late 1976.)

A standard inspection procedure was established in which an inspection team of Caltrans and Kaiser Aluminum personnel visited each test site (54), visually inspected the aluminum pipe, and collected soil, water and metal samples (71) for laboratory analyses at Kaiser Aluminum's Center for Technology (CFT) in Pleasanton, California. In metal sample selection, every attempt was made to sample the worst condition observed. Past experiences have shown that soil side corrosion in the crown area, in from the shoulder of the road, is the most severe.

ClibPDF - www.fastio.com

As a result, most of the samples were taken from that area.

Because of Caltrans' continued concern about crevice corrosion in lap joints, an additional metal sample was taken of a lap joint on every third site inspected in each geographic location.

Details of the inspection procedure are provided in Appendix A-1, A-2, and A-3.

Some 20 days were spent by the inspection team on these inspections, over a 10-month period. Members of the field inspection team included:

CALTRANS: Ken Mori, representing W. R. Green, Chief, Office of Planning & Design, and Forrest Myhres, representing the Chief, Materials Laboratory.

KACC: CFT - R. J. Hogan, Kirby Lee, Andy Quan, and T. J. Summerson

Highway Products - Jim Holzer, Mike Karimi, and Dan Larsen

OTHERS: Dan Rasp, Riverside County District Engineer's Office, Rancho California

CFT Laboratory Procedure

pH and minimum resistivities of soils and waters were determined as soon as possible. The methods used are similar to those described in California Department of Highways Method 643B. The elements present in soils and waters from the various geographic locations were determined by spectrographic analysis. In addition, for several soils, including those few soils where perforations or deep pitting were found, a boiling water leach of the soil was analyzed in order to determine the concentration of soluble ions (compounds) present in the soil. (Specific tests were made for chlorides, sulfates, phosphates, nitrates, iron, copper and mercury or lead.)

The metal samples were cleaned of soil and corrosion products by first scrubbing in water-detergent solution and then

ClibPDF - www.fastio.com

by chemical cleaning by ASTM Method G.1 (hot phosphoric-chromic acid solution.) Each sample was photographed on soil and water sides at 1 to 2X magnification in order to show the extent or lack of corrosion. Then, the samples were examined at low magnification. Areas with the deepest appearing corrosion were selected for metallographic examination. The metallographic samples were photographed in cross section at 5X in order to show the deepest attack on soil or water sides, in lap, etc. An etchant was used to delineate the 7072 alloy cladding layer and to make easy the determination of whether pitting had advanced beyond the depth of the thin cladding layer.

RESULTS

pH and Resistivities

Specific pH and minimum resistivity values of each soil sample are tabulated in Table I. Graphic presentation of soil pH and resistivity (Figure 1) for 53 soil samples show only nine soils have either the pH or resistivity outside the proposed pH 4 to 9; Rmin 500 ohm-cm limits. (These are sites 5, 24, 25, 33, 34, 35, 42, 44, and 47.) Five of these are low resistivities, salt water soils (24, 25, 33, 34, and 44). The other four soils have a pH outside the limits.

Only seven water samples were taken for evaluation. The pH and resistivity of these are given below:

Site	Location	pH	Resistivity ohm-cm
3 (71-025)	Sacramento County - 32nd Street	9.8	2,800
4 (71-027A)	" " - W. 2nd Street	8.5	8,600
16 (67-122)	Nevada County - Alta Sierra	7.0	20,000
18 (71-135)	" " - " "	5.9	25,830
32 (78-23)	Riverside County - Rancho City	7.7	1,200
33,34 (70-016)	Imperial County - Salton Sea	8.1	24
44 (67-024-78)	Solano County - Main Prairie	7.9	2,500
46 (67-038-78)	" " - " "	7.6	3,100

One pH (71-025) is above 9. All others are within the preferred limits pH 4 to 9.

ClibPDF - www.fastio.com

Pipe to Soil Potentials

Pipe to soil potentials are also shown in Table I. Values ranged from -0.50 to -1.0 volts ($Cu/CuSO_4$) with no apparent relationship between potential and corrosion resistance, soil resistivity, pH or composition. We have found in other tests that the potential of aluminum in soils will vary with differences in composition and moisture content of the soil, thickness and uniformity of the oxide film, and contact with dissimilar metals. In most instances, in this study we suspect the observed potential variations are related to surface film and soil conditions. (However, at one location, 78-12, it has been suggested that dissimilar metal coupling was at least partially responsible for the low potential of aluminum. This resulted from the steel reinforcement mesh in the concrete head wall having been directly bonded to the aluminum pipe).

Chemical Analysis - Soils

Spectrographic analyses of the soil samples are presented in Table II. (Not all elements were tested.) Due to the heterogeneity of the soils, these results are considered to be semi-quantitative in nature. As expected, the major elements present are aluminum and silicon. The "heavy metals" such as iron, copper, nickel, chromium, manganese, vanadium, lead and mercury varied in concentration, when present. The concentration of alkali and alkaline earth elements (Na, K, Mg, Ca, Ba) relate to their presences in complex compounds with aluminum and silicon such as mica, felspar, etc. No attempt was made, however, to identify and classify those minerals present in these soils.

The concentration and identity of "water soluble elements" or ions present in these soils are of interest in relationship to corrosion resistance. Table III presents the results of analyses to determine the amount of soluble chlorides, sulfates nitrates, phosphates, copper, iron and mercury present at some

ClibPDF - www.fastio.com

31 pipe locations. By comparison with Table II, the soluble iron and copper are shown to be only a small percent of the total concentrations of iron and copper present in the soil. (Note that soluble iron and copper in Table III are expressed in mg/ℓ while total iron and copper contents in Table II are expressed in weight percent. For example, 1 weight percent of iron would be equivalent of 10,000 mg/ℓ.)

Comparing minimum soil resistivity (Figure 1) with concentration of soluble chlorides, sulfates and nitrates, an inverse relationship is observed. The obvious examples are the low resistivity Salton Sea (70-016) and National City (67-180) soils, containing high concentrations of chloride. Sulfates and nitrates show a similar effect; but less dramatic because the concentrations of these ions species are less than that of the chloride.

As for the soluble "heavy metals", there is only one soil which showed copper to be above the minimum detectable amount of 0.4 mg/ℓ. This is one of the two San Diego - Sweetwater Creek soils (70-180-78A) where 0.7 mg/ℓ of copper ion was reported. There were several soils with soluble iron concentrations of 10 mg/ℓ or greater. This occurred mainly in low resistivity - low chloride-containing soils. (For example, Site 67-034 in Solano County - Maine Prairie has 20 mg/ℓ soluble iron and a resistivity of 830 ohm-cm with only 80 mg/ℓ chloride but 320 mg/ℓ sulfate.) Soluble mercury is difficult to detect because of the low concentrations present. It appears, however, that trace amounts of mercury may be present in two soils where perforations have occurred, (Rancho California sites 78-13 and 78-17).

Depth and Extent of Corrosion - Metal Samples

The cleaned surfaces of every metal sample (71) and the area of deepest corrosion observed in metallographic cross section of each sample are shown on pages F2 through F93. For easy reference, each figure contains the date of installation, metal thickness (gage), pH and resistivity of the soil and/or

ClibPDF - www.fastio.com

water, as well as the maximum measured depth of corrosion found on each surface of the metallographic specimens.

The distribution of the maximum measured pit depths is tabulated in Table IV by pipe gage and surface (soil or water side). In most instances (40), the deepest attack was confined to the thickness of the protective 7072 cladding alloy layer. Since the 7072 cladding layer on Alclad 3004 sheet represents 5% per side of the total thickness, as the pipe gage increases in thickness, so does the cladding thickness and, naturally, the measured depth of corrosion--when reported as confined to the cladding thickness.

Table IV shows eight instances where the maximum measured depth of corrosion penetrated the thin protective 7072 cladding layer. In seven of the eight instances, this resulted in some perforations. In all seven instances, perforations were the result of soil side corrosion, usually in the crown area. With the exception of the pipes at Santa Cruz - Scotts Crossing (78-28) and Sweetwater Creek (70-180-78) Caltrans test sites, pipes at the other six locations with perforations are still structurally sound.

In Table V, corrosion rates for those aluminum culverts examined in 1967 and 1970-71 are compared with those re-examined in the 1978 survey. The corrosion rates, in mpy (mils/year), were calculated from the maximum measured pit depths divided by the actual time of service at the time the pit depths were measured. (The 1967 and 1970-71 values were taken from Dr. Karush's 1971 report, Table III.) Table V shows the 1978 corrosion rates are lower than those calculated in 1967 and 1970-71. The main reason for this is the fact that, by and large, the depth of pitting is still confined to the protective cladding layer. As a result, the rate of corrosion diminished with an increase in service time. And there was no increase in maximum pit depth. (A decrease in corrosion rate with time is also characteristic of other aluminum alloys

ClibPDF - www.fastio.com

such as 3003, 3004, and 5052. (See H. P. Godard, "Corrosion of Light Metals", pp 98-99, and W. Ailor, "Handbook for Corrosion Testing & Evaluation", pp 557.)

The incidence of perforation, shown in Table V for culverts which have been part of the survey since 1967, has increased from one to three in 1978. (A fourth culvert, 67-178, shows a corrosion rate of 3.3 mpy.) Of the three culverts, however, only the San Diego County - National City pipe (67-180) shows extensive perforations. It is a test pipe, placed in a salt water, low resistivity, poor draining soil. The soluble copper, in non-native backfill over the crown, provided an acceleration of corrosion. The other two culverts were found to possess only a few perforations. The Sacramento County - Florin Road pipe (71-021) has a few pinhole perforations, limited to a few panels in one of three pipes at that location. The Contra Costa County - Orinda pipe (67-023-70) first found with a perforation in 1970-71, has had the only remaining perforation removed in 1978--in order to provide the metal test sample.

Table VI provides information on the corrosion rates for aluminum pipe in lap joints. For comparison, the maximum measured depth of pitting for the soil and water surfaces of the lap samples is provided. There is a good mix of samples in this group which represents crown, honch and invert locations for various pipe thicknesses in the different geographic locations. In all 13 examples, the maximum corrosion depth is confined to the thin 7072 cladding layer. As is to be expected, the measured maximum pit depths increase in depth with increase in pipe thickness--because the cladding layer is thicker. Moreover, in no instance was the depth of attack in the faying surfaces (crevice) of the lap joint deeper than the attack found on the soil or water sides of the pipe. As for the extent of corrosion of the cladding, lap versus single surface, the photographs in the Appendix show that there is no significantly greater area of cladding corroded in the laps than on the soil or water side surfaces.

ClibPDF - www.fastio.com

DISCUSSION

Normal Performance

In this latest survey, aluminum drainage pipe continues to possess good resistance to corrosion after 14 to 18 years' service throughout the State of California. Corrosion ratings, based on the maximum measured depth of pitting, are declining with time. This is attributed to the protective quality of the 7072 cladding alloy,* and to the fact that, in most cases, the maximum pitting depth is still limited to this relatively thin cladding layer. (The actual maximum depth of pitting, when found to be confined to the cladding layer, will increase with an increase in pipe thickness since the 7072 cladding layer in Alclad 3004 sheet represents 5% per side of the total thickness.)

Moreover, corrosion in the laps (crevice) is found to be no more severe than that on a single surface in terms of either depth of pitting or the relative amount of cladding surface consumed.

Finally, in the majority of examples, pH, minimum resistivity, chemical compositions of soils and their hot water soluble leaches of the soil showed no adverse effect on performance.

Abnormal Performance

Now consider the isolated instances of abnormal behavior where corrosion has extended beyond the cladding layer into the 3004 core, sometimes causing one or more perforations. Can the reason(s) for this uncommon behavior be pinpointed? There were eight locations where deep pitting or perforations have been reported. Three of the eight are in soil/water conditions

---

*The 7072 cladding alloy establishes a galvanic cell with the 3004 core alloy. The 7072 cladding is anodic (about 150 mv) to the 3004 core alloy. Most of the 7072 cladding layer has to be corroded away before there is any significant pitting attack in the 3004 core alloy. (The actual extent of lateral corrosion within the 7072 cladding before pitting of the 3004 core begins will depend upon many factors, including pH, resistivity, and chemical content of the soil and water.) This is one form of cathodic protection.

ClibPDF - www.fastio.com

which are outside the industry recommended guidelines, i.e., pH between 4 and 9 and minimum resistivity greater than 500 ohm-cm. (See items 1, 2, and 3 below.) Of the five remaining locations, three of these are located in one section of Rancho California. (See items 4, 5, and 6 below.)

Description	Age Years	Max. Pit Mils	Soil pH	Soil R_{min} (ohm-cm)	Reference Page
San Diego Co. -Sweetwater Crk., 67-180, 14 gage	17	perf.	8.7	40-130	F90 & 91
Santa Cruz-Scotts Crossing, 78-28, 14 gage	16	perf.	3.7-3.9	5,000	F54 & 55
Contra Costa Co.-Orinda, 67-023, 14 gage	15	perf.	3.9	6,670	F47-49
Riverside Co.-Rancho California,78-12, 12 gage	11-13	perf.	5.7	3,400	F68
" " " " 78-13, 14 gage	"	perf.	7.2	7,220	F69
" " " " 78-17, 12 gage	"	perf.	5.0	2,460	F73 & 74
Sacramento Co.-Florin Rd.,71-021C, 12 gage	15	perf.	6.0	10,700	F20-24
San Diego Co.-Chula Vista, 67-178, 14 gage	16	53 mils	-	-	F92

The aluminum culvert at Sweetwater Creek in San Diego County is part of a test installation, rather than actual drainage, where both galvanized steel and aluminum pipe were tested. (The steel pipe is heavily corroded.) The aluminum showed perforations in the crown area. (See photos on pages F90 and F91.) There is only three inches of soil over the aluminum pipe. This soil has very low resistivity (40 to 150 ohm-cm) and is poor draining. Spectrographic analysis of the soil (Table II) showed a relatively high copper content (0.05 percent). This was confirmed by boiling water leach (Table III) where 0.7 mg/ℓ were reported. Thus, corrosion and perforations appear to be due to the combined effects of poor draining, low resistivity soil containing some soluble copper.

The Scotts Crossing location, off Highway 17 in Santa Cruz County, is believed to be one of the original seven test installations described in the 1965 HRR95 paper entitled, "A Preliminary Study of Aluminum as a Culvert Material" by Nordlin and Stratfull. At that time, perforation was reported

ClibPDF - www.fastio.com

in less than one year. As Figure 3 shows, the pipe is still intact after 16 years, although the invert is completely corroded away. The explanation for corrosion in this instance appears to be related to the low pH (3.7-3.9) reported in 1978, as well as in the original 1965 report.

The few perforations in the small diameter Contra Costa-Orinda pipe (67-023) were the result of the presence of dissimilar metals and the relatively low soil pH (3.9). (The 1970-71 report indicated that remnants of a steel shovel and copper building wire had been found in the backfill, contacting the aluminum pipe where the perforations occurred.) It is interesting to note that the only two perforations found in this pipe have been removed, in 1970-71 and 1978, in order to provide metal samples for laboratory analysis. Now, this pipe contains no perforations!

The other three locations where perforations were reported are in Riverside County at Rancho California (Sites 78-12, 78-13, and 78-17). These were not part of the original survey made in 1970-71. In 1965-67, numerous aluminum culverts were installed throughout the Rancho California development, encompassing some 50,000 acres. The first reports of corrosion at this location occurred ten years later in 1976. Several field inspections have been made separately by Caltrans, FHWA, Kaiser Aluminum, and others. (The Riverside County Engineer's office was represented at most of these inspections.) In addition, Riverside County surveyed the entire development to determine the extent of corrosion. Their final report (1977) revealed possibly three locations out of some 150 sites inspected where perforations of aluminum pipe were evident. In no instance, however, was the condition of the aluminum pipe serious enough to consider replacement or repair.

The cause of corrosion at a few sites in Rancho California has not been well established. The possibility of stray current corrosion from nearby cathodically-protected

ClibPDF - www.fastio.com

buried gas lines was considered and rejected after field testing. At one location, 78-12, galvanic corrosion is believed to be a contributing factor since the steel wire reinforcing mesh on the concrete head walls was found to be bonded to each of the three 48-inch diameter pipes. (Laboratory tests in the soil from this location showed the galvanic current flow between coupled aluminum and steel to be significantly greater than that measured in other soils in the Rancho California area where no significant corrosion has occurred.)

Our spectrographic analyses of the soils from Rancho California, however, show no significant differences between those locations where aluminum has not corroded beyond the cladding and the three locations where perforations have occurred. (See Table II.) Except for Sites 78-13 and 78-17, the results of the analyses of soluble salts in the soil (Table III) showed no significant differences. At these sites (78-13 and 78-17) there appears to be a measurable amount of mercury (0.01 mg/ℓ) in the soil. The presence of trace amounts of soluble mercury compounds would be expected to be detrimental to the performance of aluminum and, fortunately, the occurrence of soluble mercury compounds in soils is a rarity.

At Site 71-021, on Florin Road in Sacramento County, a few pinhole perforations were found in only one of the three pipes at this location. Ultrasonic thickness measurement survey showed the perforations were contained in a relatively small area in one or two 2-foot lengths of the one pipe. Nothing unusual was detected from the chemical analyses of the soil (71-021C in Tables II and III) taken from behind the metal sample with a perforation. As shown in Figure 2, the overall appearance and structural soundness of the culvert has been unaffected.

At the Chula Vista location (67-178) there have been no perforations and corrosion is limited to the cladding on the soil side. However, deep pitting (53 mils maximum) was

ClibPDF - www.fastio.com

reported on the water (invert) side. (See F-92.) Although some soil and miscellaneous debris were lying in the invert, there was not enough to analyze and to determine the cause of this water side corrosion.

CONCLUSION

The 1978 inspection results confirm earlier inspection reports showing aluminum culvert to have excellent resistance to corrosion throughout the State of California. (Most culverts have now been in use for 14 to 18 years.) In nearly every instance, the maximum depth of corrosion is still confined to the thin protective cladding layer. This is attributable to the cathodic protection which the 7072 cladding alloy provides to the 3004 core alloy. Experience has shown that the 7072 cladding layer must be corroded away before there is any significant pitting of the 3004 core alloy.

Some people have expressed concern that once the 7072 cladding has been consumed, corrosion failure of the 3004 will follow shortly thereafter. This is unlikely for two basic reasons. First, the 3004 is inherently more resistant to corrosion than 7072. (Maximum pit depths for 3003 and 5052 were only 0.1 to 0.4 that of 7072 after 10 years in seawater at three locations.) Second, with aluminum alloys like 3003, 3004 and 5052, corrosion rates (pit depth) have been shown to diminish with time, even without the benefit of protection of a cladding alloy. (See H. Godard, "Corrosion of Light Metals", p. 135, and W. Ailor, "Handbook for Corrosion Testing and Evaluation, p. 557.) As a result, when the cladding can no longer provide cathodic protection, the corrosion rate of culvert* is expected to increase slightly as pitting in the 3004 begins. However, pitting of the 3004 core is not likely to begin for some time since the majority of the culverts show the 7072 cladding layer to be largely intact and providing cathodic protection after upwards of 18 years' service.

*Based on maximum pit depth.

ClibPDF - www.fastio.com

Of all the culverts inspected, there were only eight which showed pitting corrosion beyond the depth of the 7072 cladding layer. Two of these were test installations, rather than in-service drainage pipe, and could be classified as "failed", i.e., requiring repair or replacement in order to protect the integrity of the backfill. Both of these are in soil/water conditions which are outside Kaiser Aluminum's recommended limits of pH and resistivity. At the other six locations, all in-service pipes are still structurally sound. Corrosion at four of these six sites appears to be explainable by either being outside the pH and resistivity guidelines, galvanic corrosion from bonding to steel wire reinforcement, or the presence of excessive amounts of soluble heavy metals (copper and mercury). At this time, we have no explanation for the deep pitting and/or isolated pinhole perforations at the other two locations (67-178 and 71-021C). Additional study is planned.

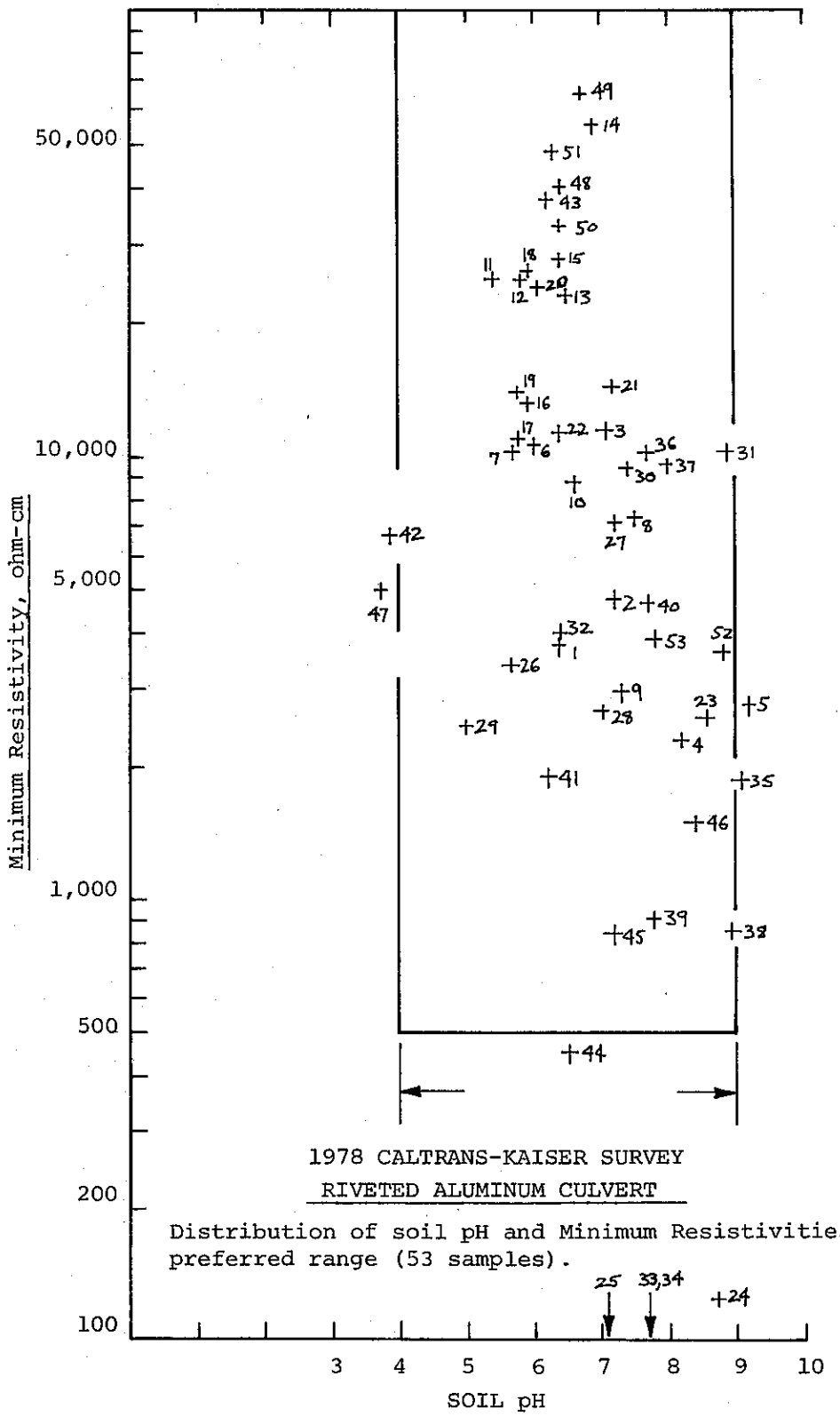
RECOMMENDATIONS

The State of California (Caltrans) should accept Alclad (7072) 3004 as a drainage product for applications requiring a 50-year life expectancy. Suitability of soils and drainage waters with aluminum should be based on the existing recommendations of pH 4 to 9 and minimum resistivity of 500 ohm-cm.

ACKNOWLEDGMENTS

We wish to express our appreciation for the interest and support provided by those in the Metallography and Analytical Sections of CFT. We also acknowledge the cooperation and assistance of the Riverside County Engineer's office, especially that of Dan Rasp. Finally, we are grateful for the cooperative spirit of Ken Mori and Forrest Myhres of Caltrans, who shared the field inspections with us, and their supervisors, Bill Green and Don Spellman.

ClibPDF - www.fastio.com



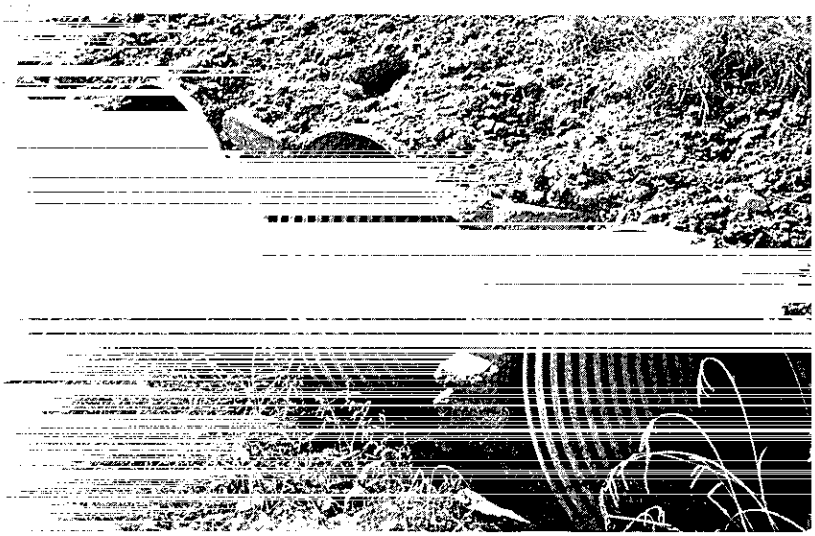
1978 CALTRANS-KAISER SURVEY

RIVETED ALUMINUM CULVERT

Distribution of soil pH and Minimum Resistivities around preferred range (53 samples).

FIGURE 1

ClibPDF - www.fastio.com



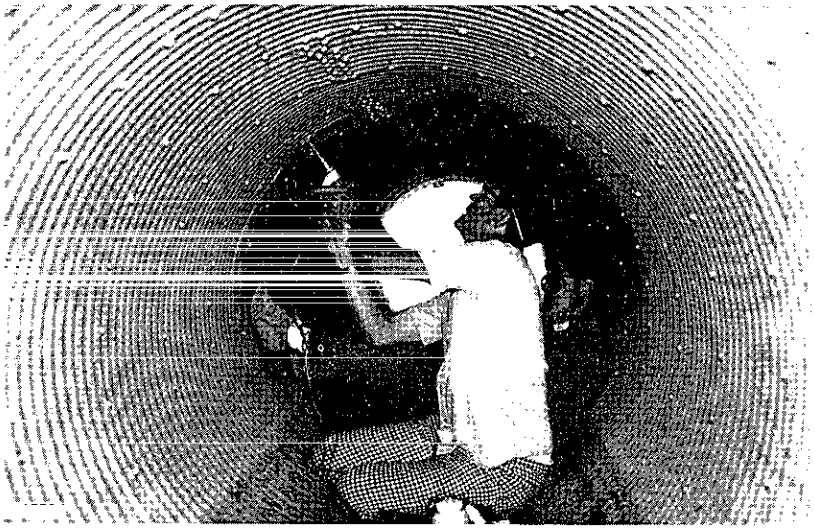
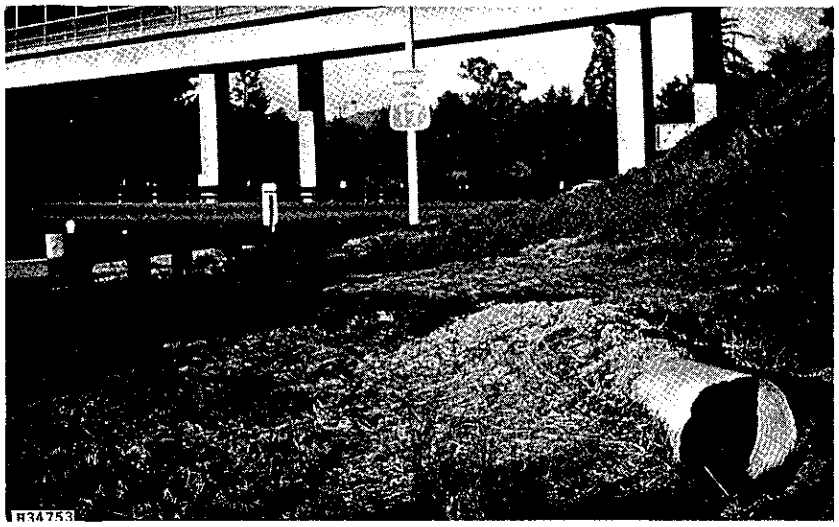


Figure 2

Site #71-021 - SACRAMENTO COUNTY - FLORIN RD.

Three 48-inch diameter, 12 gage Alclad 3004 pipes were installed in 1963. In 1978 (15 years), a few pinhole perforations were found in one two-foot section of one of the three pipes. The photo on the right shows where one pinhole perforation is marked by the black square and another pinhole is marked by black arrows. Ultrasonic thickness gage was used to determine extent of corrosion on soil side around these pinhole perforations. Full thickness was measured within 0.25 inches of each pinhole. The overall good appearance and condition of the pipe is indicated in the lower left photo, showing patch placement over the metal samples taken (see F21, 22 and 23).

ClibPDF - www.fastio.com



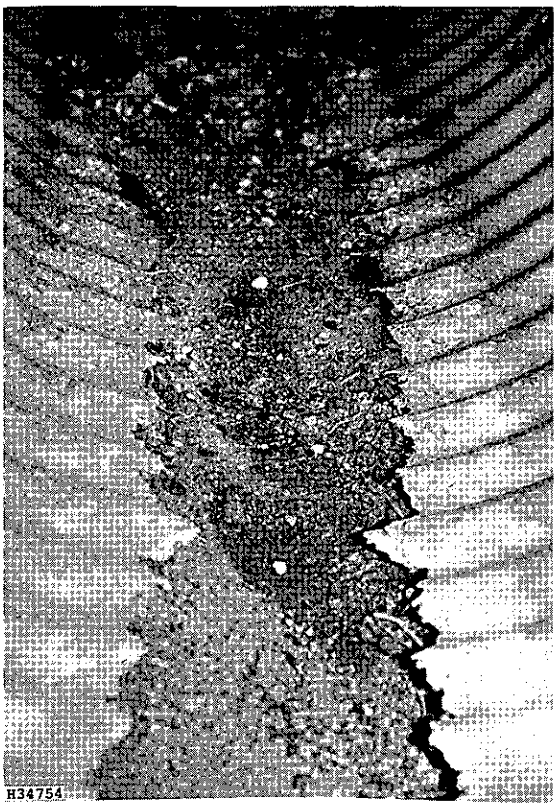


Figure 3

Site #78-28 - SANTA CRUZ - SCOTT'S CROSSING
(IV-SCr-5-A)

Installed in 1962. Believed to be one of the eight test sites in the HRR #95 report by Nordlin and Stratfull. (See Figures 12 and 13 of their report.)

In 1978, pH and minimum resistivity were measured as 3.8 and 5,000 ohm-cm. In 1964, they were reported as 3.7 and 330 ohm-cm.

In 1964, the invert was reported to have corroded through (perforated) in 0.83 years. (See Fig. 13 of Nordlin & Stratfull report.) In 1978, the invert (above) was found to be completely corroded through as the result of water side corrosion. However, soil side corrosion is still confined to the cladding thickness. See Figures F54 and F55 in this report.

ClibPDF - www.fastio.com

Site #67-126 - CALAVERAS COUNTY - HIGHWAY 4, EAST OF CAMP CONNELL

Installed in 1962 - 24 inch diameter, 14 gage pipe

Shown is the invert of aluminum pipe with an extension of galvanized steel pipe in foreground. The aluminum pipe was found to be in excellent condition, invert and soil sides. See Figure F33.

The galvanized steel pipe has begun to rust in the invert.

ClibPDF - www.fastio.com

TABLE I

PERFORMANCE OF ALUMINUM RIVETED CULVERT
- 1978 CALTRANS-KAISER ALUMINUM SURVEY -

No.	Sample No.	Location	Soil[1] pH	Soil[1] Minimum Resistivity, ohm-cm	Pipe/Soil[2] Potential, volts
1	67-008A	Sacramento - 24th Street	6.4	3,780	-.58
2	67-008B	" " "	7.2	4,390	-.70
3	71-025	" - 32nd Street	7.1	11,670	--
4	71-027A	" - W. 2nd Street	8.2	2,320	-.68, -.67
5	71-027B	" - W. 2nd Street	9.2	2,770	-.72, -.78
6	71-021C	" - Florin Rd.	6.0	10,710	(-.60)
7	71-021B	" - Florin Rd.	5.7	10,280	-.65, -.60
8	71-022	" - Green Rd.	7.5	7,250	-.60
9	71-022	" - Green Rd.	7.3	2,960	--
10	71-143	Groveland - Tuolume Co.)	6.6	8,820	--
11	71-144	" " "	5.4	25,000	(-.60)
12	71-145	" - " "	5.8	25,000	-.50
13	67-134	Calaveras Co. - Rte. 4	6.5	23,330	-.70
14	67-136	" - Rte. 4	6.9	56,000	-.58
15	67-140	" - Rte. 4	6.4	28,000	-.51
16	67-122	Nevada Co. - Alta Sierra	5.9	13,180	--
17	71-134	" " "	5.8	11,070	--
18	71-135	" " "	5.9	25,830	-.59
19	67-161	" " "	5.8	14,090	--
20	71-020	" - Grass Valley	6.1	24,000	--
21	67-115-71	" - " "	7.2	14,500	--
22	67-115-71A	" - " "	6.4	11,400	--
23	67-179-78	San Diego Co. - Chula Vista	8.6	2,540	-.82
24	67-180-78A	" - Sweetwater Cr.	8.7	126	--
25	67-180-78B	" - "	7.1	40	--

.....continued...

ClibPDF - www.fastio.com

Performance of Aluminum Riveted Culvert
- 1978 Caltrans-Kaiser Aluminum Survey -

No.	Sample No.	Location	Soil[1] pH	Soil[1] Minimum Resistivity, ohm-cm	Pipe/Soil[2] Potential, volts
26	78-12	Riverside Co.-Rancho California	5.7	3,400	(-.65)
27	78-13	" " - " "	7.2	7,200	(-.60)
28	78-14	" " - " "	7.0	2,690	-.83 (-.68)
29	78-17	" " - " "	5.0	2,460	-.68
30	78-18	" " - " "	7.4	9,440	-.80
31	78-20	" " - " "	8.9	10,310	--
32	78-23	" " - " "	6.4	3,950	--
33	70-016	Imperial Co.-Salton Sea	7.7	4	--
34	70-016	" " " "	8.0	19	-1.0
35	70-018	Ventura Co.-Oxnard	9.1	1,910	-.80
36	70-019	" " -Thousand Oaks	7.7	10,330	--
37	70-020	" " " "	8.0	10,000	--
38	70-021	" " " "	8.9	860	-0.6
39	70-021	" " " "	7.8	910	(-0.6)
40	70-024	" " " "	7.7	4,730	--
41	67-005-70	Alameda Co.-Hayward	6.2	1,960	-.65
42	67-023-70	Contra Costa Co.-Orinda	3.9	6,670	-.60
43	78-27	Monterey Co.-Big Sur	6.2	38,000	-.55
44	67-024-78	Solano Co.-Dixon	6.5	450	-.69
45	67-034-78	" " - "	7.2	830	--
46	67-038-78	" " - "	8.4	1,500	-.60
47	78-28	Santa Cruz-Scotts Crossing	3.7/3.8	5,000	-.60
48	67-126-70	Calaveras Co.-Rte. 4	6.4	40,000	
49	67-129-70	" " " "	6.7	65,000	
50	67-131-70	" " " "	6.4	33,750	
51	67-138-71	" " " "	6.3	48,300	
52	71-137	Nevada Co.-Grass Valley	8.8	3,600	
53	70-023	Ventura Co.-Thousand Oaks	7.8	3,860	

(1) pH and resistivities measured per Method 643B.
(2) Potentials measured with Cu/Cu SO_4 reference electrode placed against soil where metal samples were taken from invert, side or crown. Crown values in parenthesis.

ClibPDF - www.fastio.com

Table II

PERFORMANCE OF ALUMINUM RIVETED CULVERT
1978 SURVEY, CALTRANS AND KAISER ALUMINUM

Semi-Quantitative Spectrographic Analysis of Soils, Weight Percent

Site	Al	Si	Na	K	Mg	Ca	Ba	Ti	Fe	Cu	Mn	Cr	Ni	V	Pb(1
67-008B	MAJ	MAJ	1.7	.8	.43	1.4	.04	0.20	1.9	<.001	.06	.004	.007	.009	ND
71-027A	MAJ	MAJ	1.5	1.4	1.3	0.8	.04	0.24	4.8	.002	.10	.017	.018	.015	-
71-021C	MAJ	MAJ	1.8	.9	1.2	1.6	.04	0.24	3.1	.001	.06	.02	.012	.012	-
71-022	MAJ	MAJ	1.3	.8	0.6	1.2	.03	0.30	2.6	<.001	.06	.015	.008	.010	-
67-115-71	MAJ	MAJ	0.18	.55	0.26	0.24	.03	0.51	9	.004	.07	.005	.01	.032	-
71-143	MAJ	MAJ	0.29	1.4	0.32	0.12	.04	0.22	3.0	.002	.05	.007	.008	.014	-
71-145	MAJ	MAJ	1.3	1.3	0.58	.68	.04	0.29	4.4	.002	.04	.007	.008	.015	-
67-134	MAJ	MAJ	0.85	1.3	2.9	0.33	.04	0.23	4.2	.002	.03	.025	.027	.014	-
67-136	MAJ	MAJ	1.9	1.0	1.5	1.4	.05	0.28	4.9	.001	.10	.004	.008	.016	-
67-122	MAJ	MAJ	0.18	1.0	0.26	0.2	.04	1.1	6.5	.011	.05	.007	.015	.024	-
71-135	MAJ	MAJ	0.18	1.0	0.75	0.2	.05	0.8	10	.017	.10	.005	.01	.030	-
67-179	MAJ	MAJ	1.2	1.0	0.67	-	0.1	0.25	3.2	.003	.06	.003	<.01	.005	ND
67-180	MAJ	MAJ	1.7	1.0	0.76	-	.1	.23	4.4	.05	.11	.01	<.01	.003	ND
78-12	MAJ	MAJ	1.8	1	0.45	-	0.1	.70	2.1	<.001	.03	.003	<.01	.003	-
78-13	5.2	MAJ	1.3	1-2	0.56	2.1	.04	.15	2.1	.001	.04	.002	ND	.01	ND
78-14	MAJ	MAJ	1.7	1	0.54	-	.1	.24	2.3	.002	.06	.003	<.01	.002	ND
78-17	9.5	MAJ	2.1		0.87	2.7	.04	.19	3.2	.001	.04	.007	ND	.005	ND
78-18	5.4	MAJ	1.4	.5	0.52	1.9	.04	.14	2.4	.001	.04	.001	ND	.005	ND
78-20	5.0	MAJ	2.4	1-2	0.53	2.1	.04	.08	1.5	.001	.03	.002	ND	.005	ND
78-23	MAJ	MAJ	1.9	.5	0.79	-	.05	.27	4.0	.001	.08	<.001	<.001	.003	ND
78-24	3.7	MAJ	1.3	1-2	0.41	1.7	.04	.06	1.1	<.001	.03	.001	ND	.005	ND

Continued ...

ClibPDF - www.fastio.com

Table II. (Continued)

PERFORMANCE OF ALUMINUM RIVETED CULVERT
1978 SURVEY, CALTRANS AND KAISER ALUMINUM

Semi-Quantitative Spectrographic Analysis of Soils, Weight Percent

Site	Al	Si	Na	K	Mg	Ca	Ba	Ti	Fe	Cu	Mn	Cr	Ni	V	Pb
70-016	4.2	MAJ	7.2	1-2	2.0	12	0.04	0.23	2.5	0.005	.05	.003	ND	.005	ND
70-018	MAJ	MAJ	1.1	1.0	0.15	-	0.1	0.16	1.4	<.001	.03	.003	<.01	.002	ND
70-021	MAJ	MAJ	.95	1.0	2.3	-	0.05	0.77	6.1	0.003	0.1	.02	.01	.005	ND
67-005-70	MAJ	MAJ	1.4	1.0	.72	-	0.1	0.9	2.7	.003	.06	.04	.01	.005	ND
67-023-70	MAJ	MAJ	1.4	1.0	.26	-	0.1	0.5	1.9	.003	.03	.024	<.01	.003	ND
78-27	MAJ	MAJ	1.2	1.0	.31	-	0.1	.14	1.1	.002	.03	.002	<.01	.002	ND
78-28	10	25	2.0	2.0	.6	-	.06	0.5	4.0	.003	.04	.02	-	.001	-
67-024-78	MAJ	MAJ	.98	1.0	1.0	-	0.1	0.30	3.8	.004	.06	.01	.01	.005	ND
67-034-78	MAJ	MAJ	.95	1.0	1.3	-	0.1	0.37	4.7	.004	.31	.04	.03	.005	ND
67-038-78	MAJ	MAJ	.94	1.0	0.9	-	0.1	0.29	2.9	.003	.05	.01	.01	.005	ND

(1) ND - Not detectable, i.e. less than 0.01 percent.

ClibPDF - www.fastio.com

Table III

PERFORMANCE OF ALUMINUM RIVETED PIPE

JOINT CALTRANS-KAISER ALUMINUM SURVEY, 1978

Atomic Absorption Analysis of Boiling Water Leach of Soil (Concentrations are in mg/ℓ)

Site	Location	Cl	SO_4	NO_3	PO_4	Fe (1)	Cu (1)	Hg (1)
67-008B	Sacto - 24th St.	88	50	20	7	19	ND	-
71-027A	" - W. 2nd St.	92	30	35	8.5	23		-
71-021C	" - Florin Rd.	80	<20	22	<.5	1		ND
71-022	" - Green Rd.	80	<20	7	<.5	2		-
71-143	Tuolome-Groveland	92	30	15	1	19		-
71-145	" - "	80	50	4	2	<.5		-
67-134	Calaveras-Camp Connell	100	30	1	.5	<.5		-
67-136	" " "	80	20	4	1	.8		-
67-135	" " "	92	20	<1	.5	2		-
67-122	Nevada, Alta Sierra	60	40	<1	<.2	49		-
67-115-71	" " "	80	40	11	0.3	36		-
67-179-78B	San Diego, Chula Vista	160	30	40	9.0	39.0		-
67-180-78A	" " National City	5240	1750	20	5.0	<0.4	0.7	ND
67-180-78B	" " " "	17500	1750	30	11.0	0.4	ND	ND
70-016	Imperial, Salton Sea	141500	8000	40	2	2		-
70-018	Ventura, Oxnard	340	<20	12	8	<0.4		-
70-020	" Olson Rd.	400	<20	30	7	0.4		-
70-021	" Olson Rd.	80	250	30	3	19		-

.....(continued)....

ClibPDF - www.fastio.com

Table III. (Continued)

Performance of Aluminum Riveted Pipe

Joint Caltrans-Kaiser Aluminum Survey, 1978

Atomic Absorption Analysis of Boiling Water Leach of Soil (Concentrations are in mg/ℓ)

Site	Location	Cl	SO_4	NO_3	PO_4	Fe(1)	Cu(1)	Hg(1,2)
78-12	Riverside, Rancho California #3	200	<20	30	3.0	4.1	ND	ND
78-13	" " #8	50	<20	20	3.0	1.1	ND	0.01
78-14	" " #11	90	30	260	10	53.0		-
78-17	" " #17	180	<20	160	20	1.0		0.01
78-18	"	80	30	30	10	9.0		-
78-20	"	60	<20	30	6	2.9		-
78-23	"	140	20	30	7	8.5		-
67-005-70	Alameda, Hayward	70	<20	40	9	6.5		-
67-023-70	Contra Costa, Orinda	80	30	60	30	45		ND
78-27	Monterey, Big Sur	80	20	12	2	<0.4		ND
67-024-78	Solano, Main Prairie	20	1750	55	1.2	<0.5		-
67-034-78	" " "	80	320	20	12	20		-
67-038-78	" " "	80	100	12	2	1		-

(1) ND - Not detectable. For soluble copper and iron, this means less than 0.4 mg/ℓ. For soluble mercury, the minimum detectable level was 0.01 mg/ℓ.

(2) Only eight soils were analyzed for mercury.

ClibPDF - www.fastio.com

ClibPDF - www.fastio.com

Table IV

Distribution of Maximum Pit Depth by Pipe Gauge, 1978-1979 (11 to 18 Years)

Max. Pit Depth (mils)	Gauges (Inches) 16 (.060) Soil	16 (.060) Water	14 (.075) Soil	14 (.075) Water	12 (.105) Soil	12 (.105) Water	10 (.135) Soil	10 (.135) Water	8 (.164) Soil	8 (.164) Water
0(#)	3	7	7	14		1	1	3	1	
1					1					
2	2		2		1	2				
3	* 3		7	1		1				
4			* 6	3	1	1				
5					* 5	1				
6										
7							* 2			
8									*	1
9										
10										
10-60				1						
Perforation			4		3					
TOTALS	8	7	26	19	11	6	3	3	1	1

(#) No measurable attack.

* Horizontal lines indicating cladding thickness for each gauge.

Conclusion: With few exceptions, the maximum depth of pitting remains confined to the protective 7072 alloy cladding layer. Also, corrosion appears to be lower on the water side than the soil side.

TABLE V

DISTRIBUTION OF MAXIMUM PIT RATE FOR CULVERTS SAMPLED THREE TIMES

Corrosion Rate, (mils/yr)	First Sampling 1967	Second Sampling 1970-71	Third Sampling 1978-79
0.00-0.20	4	1	12
0.20- .40	1	5	18
0.40- .60	4	7	2
0.60- .80	6	8	
0.80-1.0	3	5	
1.0 -1.2	3	2	
1.2 -1.4	3	-	
1.4 -1.6	2	1	
1.6 -1.8	3	-	
>2.0			1
Perforation		1	3
Median Rate, mpy	0.6 to 0.8	0.6 to 0.8	0.2 to 0.4
Culvert age, range	3 to 7 yrs.	6.5 to 10 yrs.	11 to 17 yrs.
Average Age	4.6	7.8	15

CONCLUSION:

The median corrosion rate has diminished with time.

ClibPDF - www.fastio.com

ClibPDF - www.fastio.com

TABLE VI

SINGLE SURFACE vs. LAP JOINT

(One out of every three samples taken in each geographic location was a lap-joint sample.)

	Site Location	County - Place	Figure Page No.	Gage	Maximum Measured Depth of Attack, Mils: Crown Soil/Lap/Water	Honch Soil/Lap/Water	Invert Soil/Lap/Water
1)	71-134	Nevada - Grass Valley	F2 and 3	16	1 / 0 / 0		
2)	71-135	" - " "	F4 and 5	16	1 / 0 / 0		
3)	67-115	" - " "	F14	16	1.5/ 0 / 0		
4)	78-20	Riverside - Rancho California	F80	16	1 / 0 / 1		
5)	67-134	Calaveras - Camp Connell	F37	14	0 / 0 / 0		
6)	71-144	Tuolume - Groveland	F44 and 45	14		4*/1.5/ 0	
7)	67-023(1)	Contra Costa - Orinda	F48 and 49	14		3*/4* / 0(1)	
8)	70-019	Ventura - Thousand Oaks	F58 and 59	14			0 / 0 / 0
9)	70-016	Imperial - Salton Sea	F88 and 89	14			4*/ 4*/ 4*
10)	67-179	San Diego - Chula Vista	F93 and 94	14	0 / 4*/ 0		
11)	67-008B	Sacramento - 24th Street	F18	12			1 / 5*/11*
12)	67-024	Solano - Dixon	F30	12			5*/ 5*/ 3
13)	78-27	Monterey - Big Sur	F51 and 52	10	7*/ 0 / 0		

* Maximum depth of attack coincides with cladding thickness.

(1) Perforation away from lap

CONCLUSION: Lap corrosion (concentration cell or crevice corrosion) is no more severe than the corrosion on a single surface.

FIELD INSPECTION PROCEDURE

Cooperative Caltrans-Kaiser Aluminum 1978 Inspection.

At each culvert location, use an inspection report form provided. Confirm the identification of the test culvert. Prepare an overall map/sketch of the location of the culvert and confirm its position against instructions provided from previous inspections. (Use permanent markers, highway mile posts, etc. Other things may not be as long-standing.) Also, spray paint the identification of the culvert on the inside of the crown area, one end or the other.

Inspect overall appearance outside the culvert.

(1) Follow the inspection sheet form. Fill in the blanks regarding fill height, diameter, gage, etc.

(2) Take photographs, as required, to illustrate pipe condition--both inside the culvert and from the ends.

(3) If a water sample is to be taken, take the sample before the inspection party has tramped through the water on the upstream end.

(4) Inside culvert inspection: clean out loose debris, spider webs, etc. before beginning an inspection. Make an over-all general inspection, look for evidence of perforations or mechanical damage in the invert, crown area. Indicate, if possible, the location of earlier metal samples. Carry out ultrasonic thickness measurements to detect areas of corrosion (or abrasion) and to select locations of metal samples. Measure the gage of the pipe with a micrometer. Use the pH paper to check pH of any water (or moist soil once the metal samples have been removed). Use the copper copper/sulfate potential meter to measure the soil to pipe potentials, at the metal sample locations; also at the end of the culvert.

(5) Sample Locations:

On the inspection form, report location and description of the metal and soil samples. (Take the soil from the backfill where the metal sample was removed.) For each culvert location, a crown metal sample, and the soil behind the sample shall be taken. In addition, a lap sample and an invert sample will be taken from every 3rd culvert inspection at each location.

(6) Prepare the metal patches to go over the crown, invert, and lap areas. Use Electro-Seal rubber adhesive and stainless steel screws to fasten the patches to the culvert. This will provide a water-tight patch.

ClibPDF - www.fastio.com

APPENDIX A-2

CULVERT INSPECTION REPORT

Sample No.

Road _____
State/County/City _____
Route/Project _____
Mile/Station/Intersection _____

Type Installation _____
Diameter _____ Gauge _____ Joint/Seam _____
Slope _____ Length _____ Coated/Paved _____
Inlet/Outlet _____ Fill Height _____
Terrain & Flow _____

Date Sample _____ by _____
Flow _____
Rocks/Debris _____
Alignment Condition _____
Joints Condition _____
Pipe Condition _____

Photos B/W _____
Photos C _____
Soil _____
Water _____
Coupon _____

Comment _____

Pipe Markings _____

Rating of Pipe (Rate Inside and Outside Surfaces Separately)

RATING	DESCRIPTION		CORROSION		ABRASION
100	Excellent	____	No Corrosion/Staining	___	No Effect
95	Very Good	____	Superficial Corrosion/Staining	___	Slight Roughening No Metal Loss
90	Good	____	Random Errosion/Staining	___	Slight Erosion Little Metal Loss
85	Fair	____	Over 50% Surface Corrosion No Attack of Core Metal	___	Erosion-Slight Progressive Metal Loss, Small Dents
80	Poor	____	Heavy Corrosion Entire Surface Deep Pitting into Core Metal	___	Abrasion-Slow Progressive Metal Loss, Dents & Gouges
75	Very Poor	____	Visible Perforations	___	Abusive-Considerable Metal Loss, Dents, Gouges

Rating _____ Outside _____
_____ Inside _____
_____ Abrasion _____

Date Installed _____ Years Service to Date _____
Estimated Life (Corrosion) _____ (Abrasion) _____

Soil pH _____ (Lab) r _____ (Lab)
Water pH _____ (Lab) r _____ (Lab)

ClibPDF - www.fastio.com

APPENDIX A-3

CULVERT INSPECTION REPORT

SAMPLE NUMBER

ad _____

tate/County/City _____

ute/Project _____

le/Station/Intersection _____

_____

_____

oil pH _____ _____ Date Sampled

inimum Soil Resistivity _____ _____ Date Sampled

ter pH _____ _____ Date Sampled

inimum Water Resistivity _____ _____ Date Sampled

te Installed _____

te Sampled _____ _____ _____

ears of Service to Date _____ _____ _____

orrosion Penetration (mils)

Crown _____ _____ _____

Side _____ _____ _____

Invert _____ _____ _____

vient of Abrasion _____

_____

_____

OMMENTS: _____

_____

_____

: _____ Dated: _____

Lab Book _____

Page No. _____

/78

ClibPDF - www.fastio.com

General Metric Conversions for Site Figures

Pipe Diameter - from inches to meters (m)	x 0.0254
Lengths - from feet to meters	x 0.3048
Depth of Attack - from inches to millimeters (mm)	x 25.4

Pipe Gage and Cladding Thickness

			Nominal Clad Thickness	
Gage	Inches	Millimeter	Inches	Millimeter
16	0.060	1.5	0.0030	0.0762
14	0.075	1.9	0.0038	0.0965
12	0.105	2.7	0.0053	0.1346
10	0.135	3.4	0.0068	0.1727
8	0.164	4.2	0.0082	0.2083

Pipe Diameter Conversion

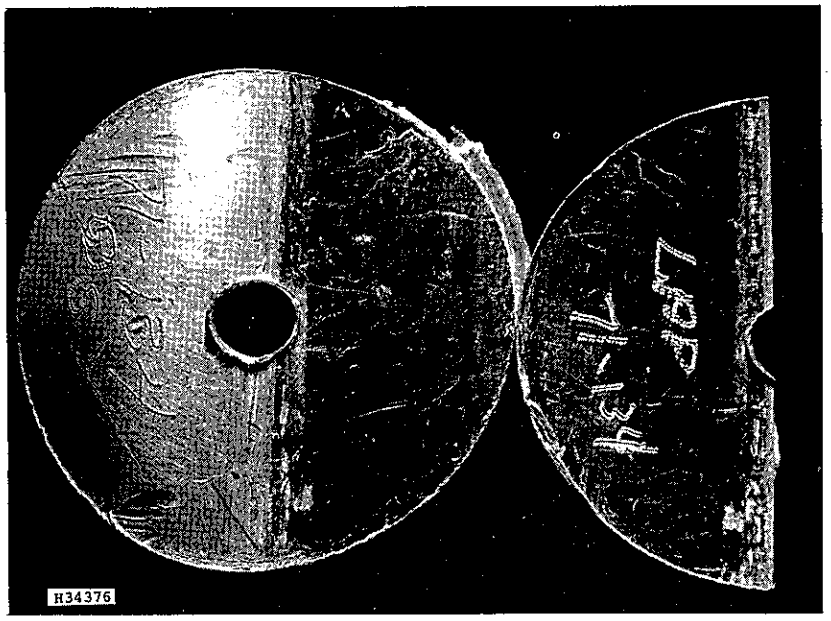
Diam. Inches	Diam. Meters
12	0.31
15	0.38
18	0.46
24	0.61
30	0.76
36	0.91
42	1.1
48	1.2
60	1.5
72	1.8

Arch Pipe

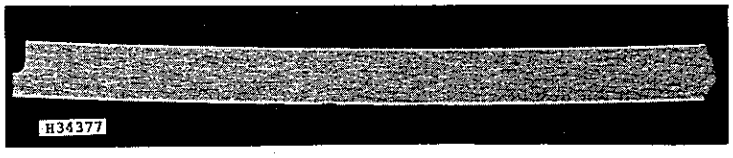
Inches	Meters
22 x 13	0.56 x 0.33
29 x 18	0.74 x 0.46
43 x 27	1.09 x 0.69
53 x 36	1.35 x 0.91

ClibPDF - www.fastio.com

Crown-Lap, Interface



Lap Interface
1.5X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-134 Nevada Co., Grass Valley, Alta Sierra Development, unmarked Rd., 150 feet south of Post Marking Lots 13 and 14 on Birch Meadows Ranch

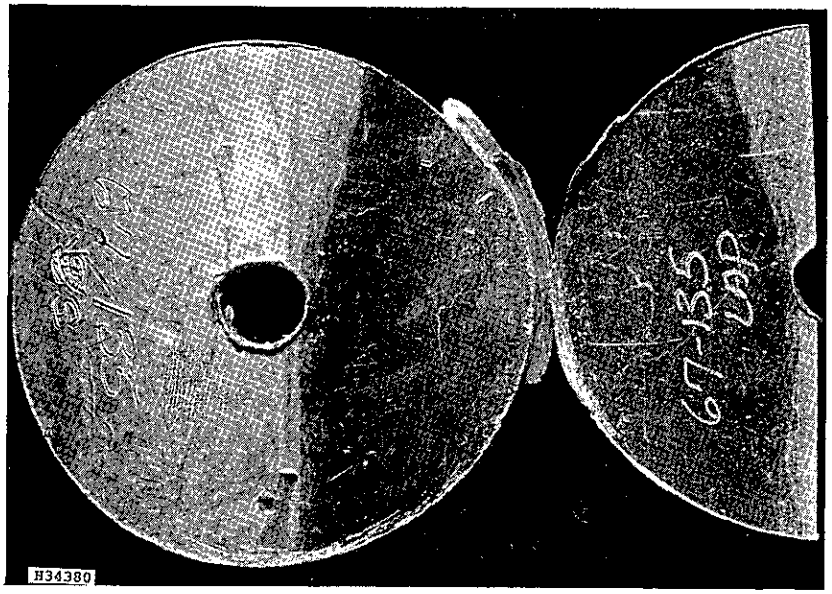
Alclad 3004, 18" diam, 16 ga., installed 1962
Soil pH - 5.8, Rmin - 11,100 ohm-cm

Lap Interface: No attack

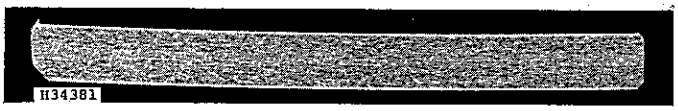
Water Side: No corrosion, slight mechanical damage

ClibPDF - www.fastio.com

Crown Lap, Interface



Lap Interface*
1.5X, Cleaned (CrO_3/H_3PO_4)



5X(Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-135 Nevada Co., Grass Valley,
Alta Sierra Development, Oak Meadows Rd.

Alclad 3004, 18" diam, 16 ga.,
installed 1962
Soil pH - 5.9, R_{min} - 25,800 ohm-cm

Lap Interface: No attack

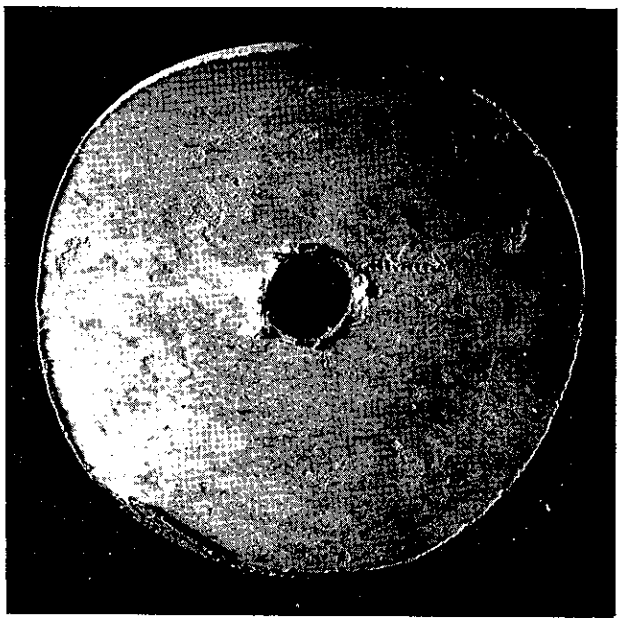
Water Side: No attack

*Scribed sample number was mis-identified, should read 71-135.

ClibPDF - www.fastio.com

Crown

From the Inlet End



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)

Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-161 Nevada Co., Grass Valley
Alta Sierra Development, Gary Way

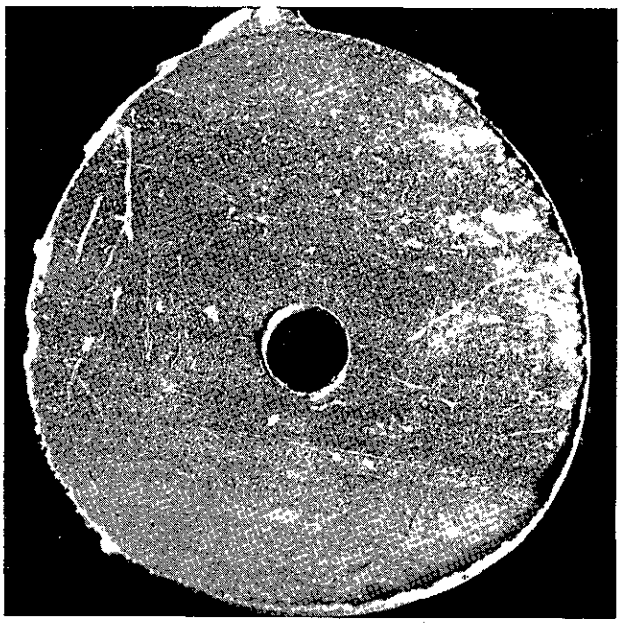
Alclad 3004, 12" diam, 16 ga.,
installed 1963
Soil pH - 5.8, R_{min} - 14,100 ohm-cm

Soil Side: General surface etch, with small pits limited to the cladding, 0.002 inch

Water Side: Light staining with several etched areas limited to the cladding surface

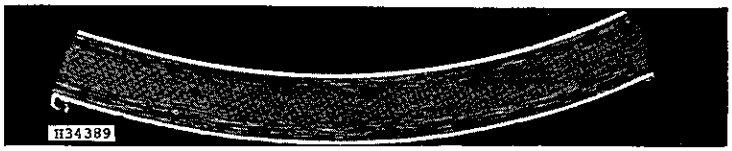
ClibPDF - www.fastio.com

Invert
From the Inlet End



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-122 Nevada Co., Grass Valley,
Alta Sierra Development, Gary Way

Alclad 3004, 24" diam, 14 ga.,
installed 1963
No soil was removed from invert.

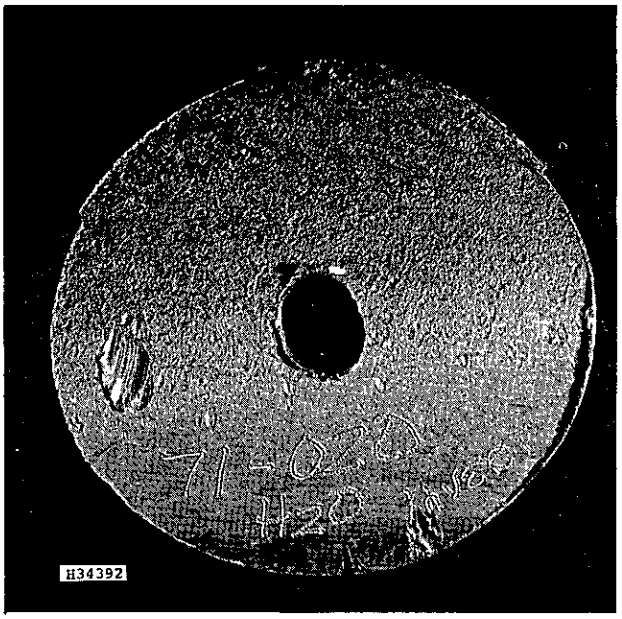
Soil Side: Several small pits (0.001 inch deep)

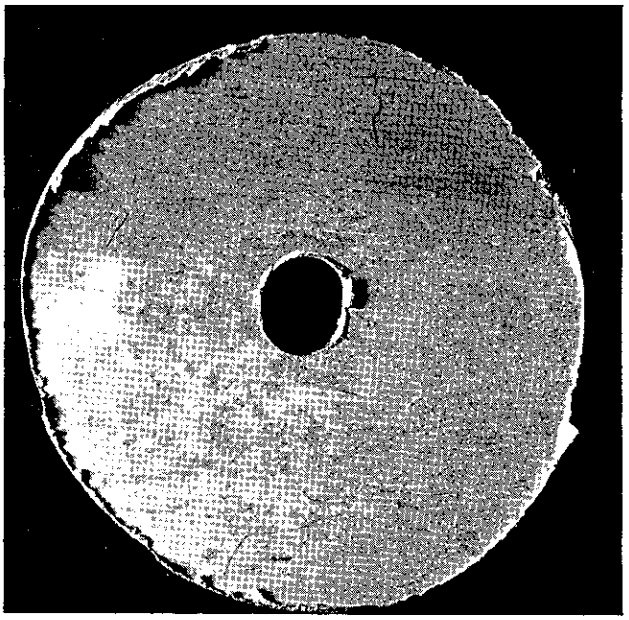
Water Side: Slight abrasion (0.0015-inch deep) of cladding layer, no corrosion

ClibPDF - www.fastio.com

Invert

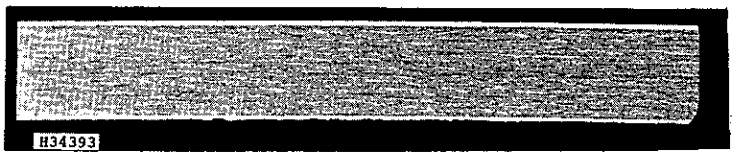
8-Feet From Outlet End





Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-020-A Nevada Co., Adj. to Alta Sierra, Norvin Way, 0.1 mi. west of Dog Bar Rd.

Alclad 3004, 48" diam, 12 ga.,
installed 1963
no soil removed

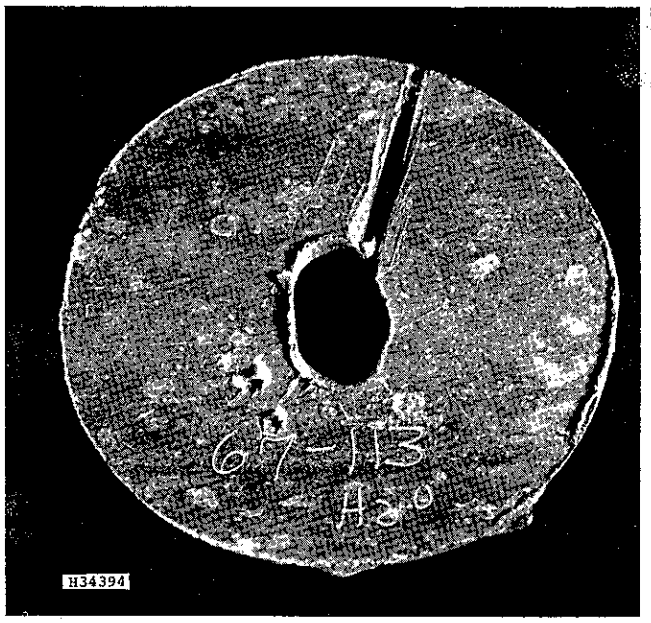
Soil Side: Staining only, no corrosion

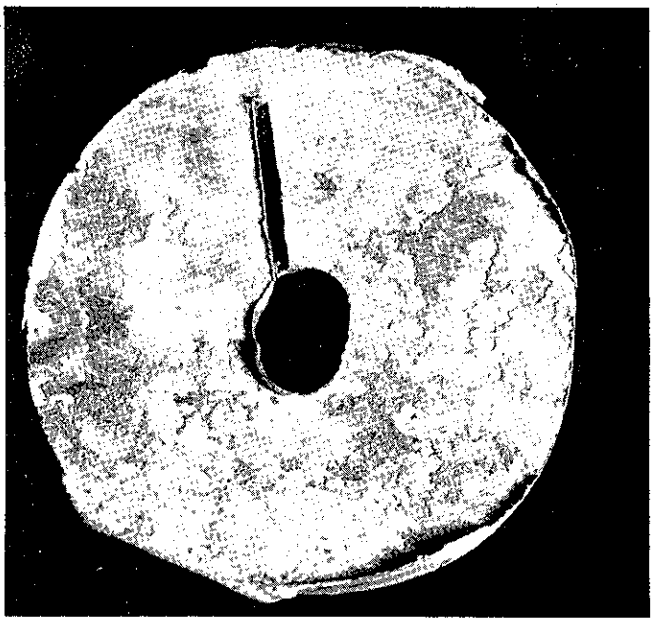
Water Side: Abrasion of invert to a depth of 0.0025-inch (cladding layer 0.0053-inch)

ClibPDF - www.fastio.com

Crown

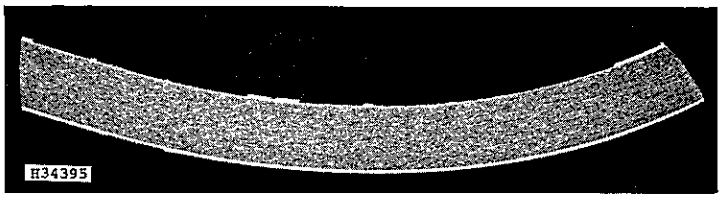
14-Feet from Inlet End





Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-113 Nevada Co., Grass Valley,
Idaho-Maryland Rd. near Brunswick Rd.

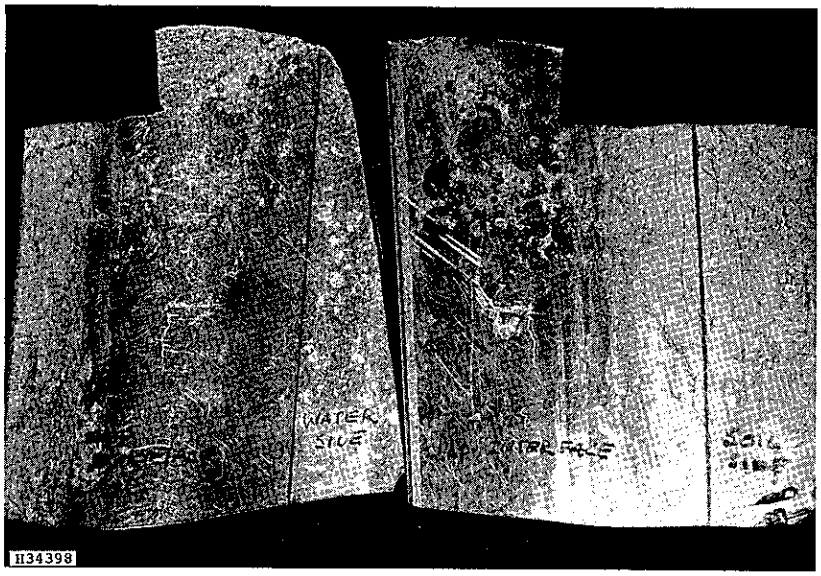
Alclad 3004, 36" diam, 14 ga.,
installed 1962
Soil pH - 6.9, R_{min} - (insufficient soil sample)

Soil Side: Corrosion limited to the cladding layer to 0.0034-inch

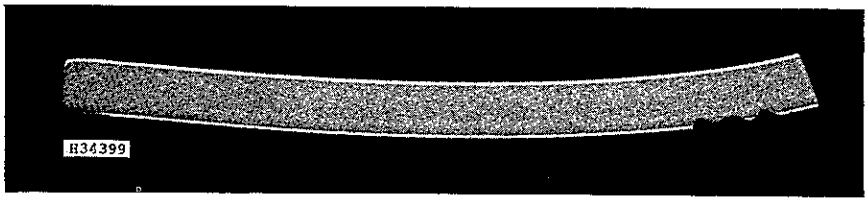
Water Side: No corrosion

ClibPDF - www.fastio.com

Crown Lap Interface



Lap Interface
1.0X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-115 Nevada Co., Grass Valley, Rattlesnake Rd.

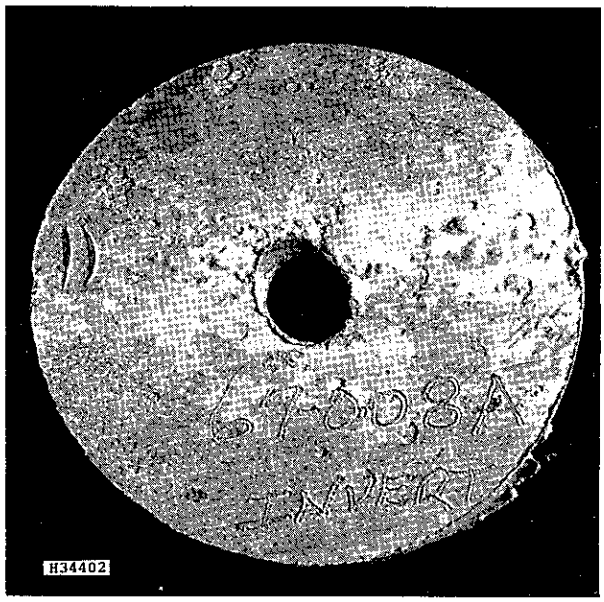
Alclad 3004, 18" diam, 16 ga.,
installed 1963
Soil pH - 7.2, R_{min} - 14,500 ohm-cm

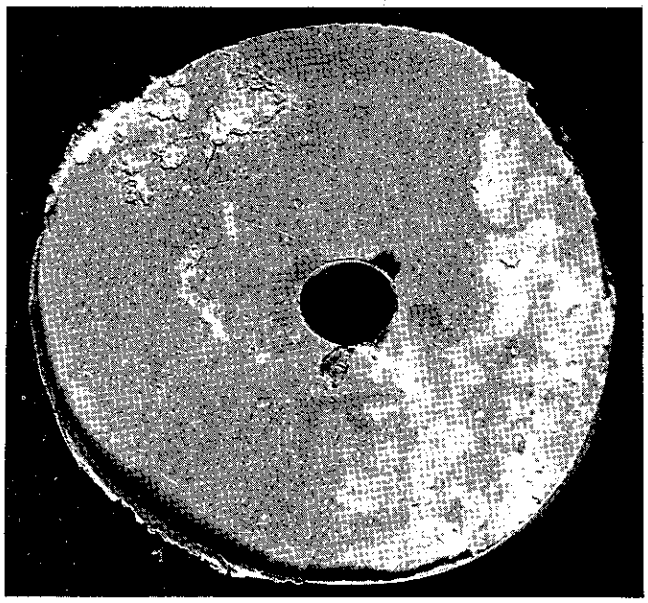
Lap Interface: Partially stained,
no corrosion

ClibPDF - www.fastio.com

Invert

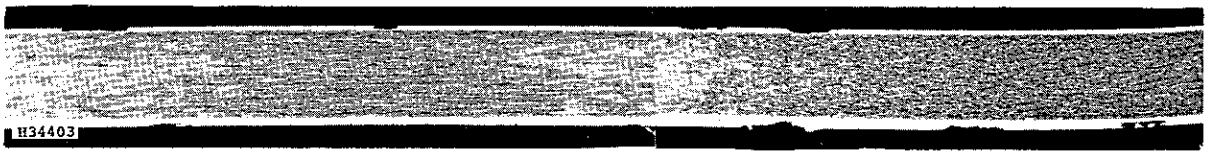
West End





Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-008A

Sacramento Co., Sacramento, 24th Street, 700'S. of intersection with Elkhorn

Alclad 3004, 42" diam, 12 ga.
installed 1964
Soil pH - 6.4, R_{min} - 3,780 ohm-cm

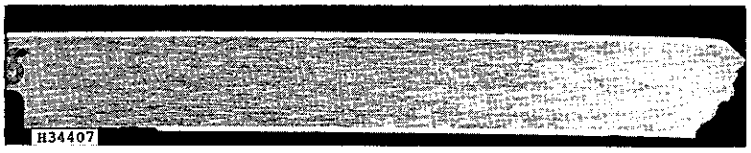
Soil Side: Pitting limited to the cladding layer, 0.005-inch

Water Side: Slight abrasion, mechanical damage and slight pitting, limited to cladding layer (depths 0.004-inches)

ClibPDF - www.fastio.com

Invert Lap, Interface

Interface
1.25X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Soil Side Up (Lap Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-008-B

Sacramento Co., Sacramento, 24th Street, 700' S. of intersection with Elkhorn

Alclad 3004, 42" diam, 12 ga., installed 1964
No soil or water sample from invert

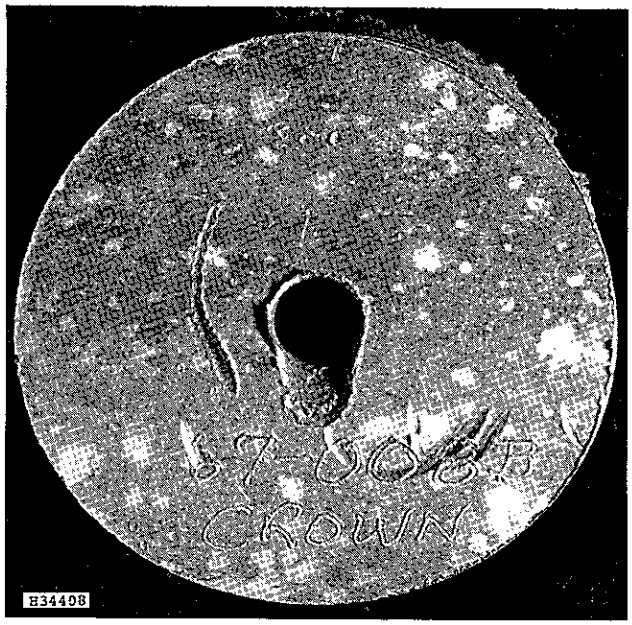
Soil Side: Slight etch type of attack, no pitting

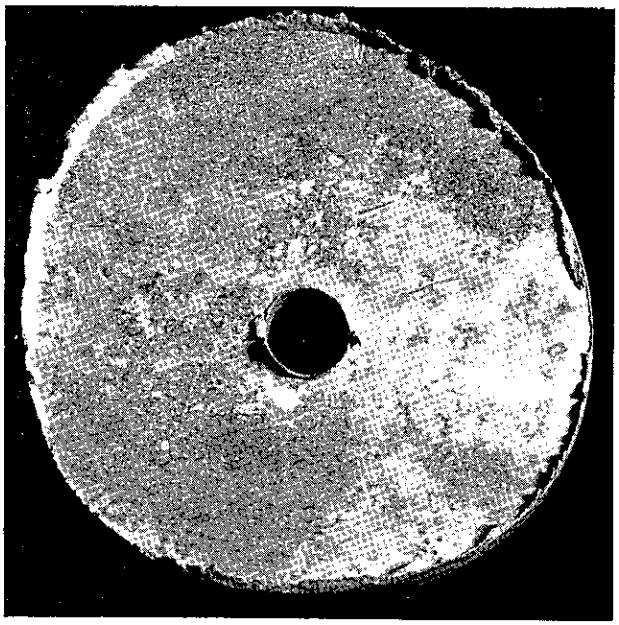
Lap Side: Attack of lap interface is limited to the cladding layer, 0.005 inches

ClibPDF - www.fastio.com

Crown

6-Feet from West End

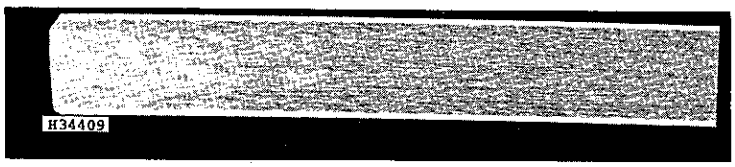




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-008B Sacramento Co., Sacramento, 24th Street, 700' S. of Intersection with Elkhorn

Alclad 3004, 42" diam, 12 ga.
installed 1964
Soil pH - 7.2, R_{min} - 4,400 ohm-cm

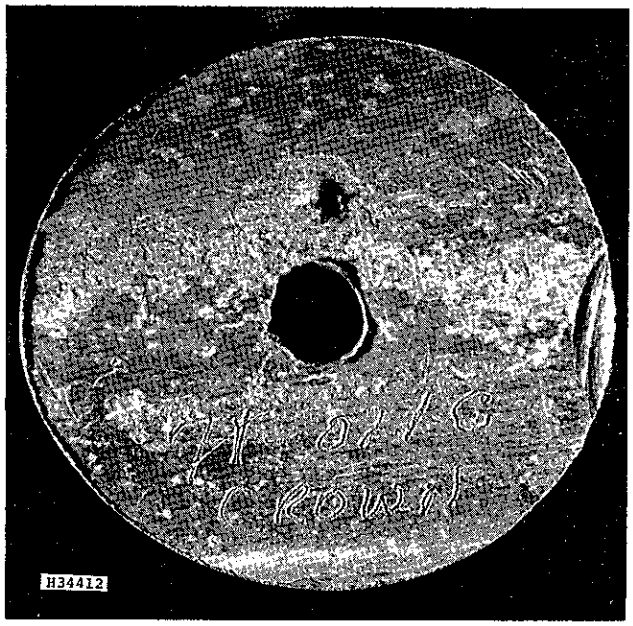
Soil Side: Slight discoloration only, no attack

Water Side: No attack

ClibPDF - www.fastio.com

Crown

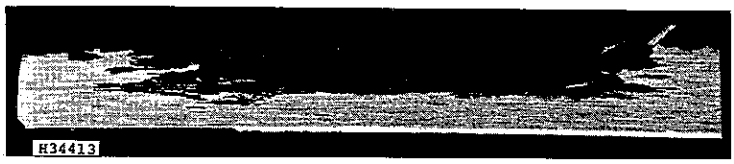
15-Feet from Inlet End



Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-021C Sacramento Co., Sacramento, Florin Rd.

Alclad 3004, 48" diam, 12 ga., Pipe #C
installed 1963
Soil pH - 6.0, R_{min} - 10,700 ohm-cm

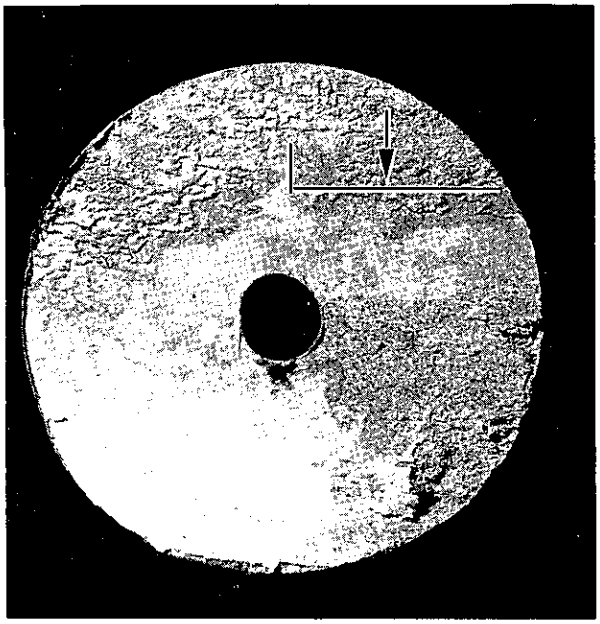
Soil Side: Perforation* of pipe from the soil side, with attack limited to ≈1.0-inch diam.

Water Side: Attack confined to cladding layer

*Metallographic cross-section does not show perforated area.

ClibPDF - www.fastio.com

Crown Area



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_4PO_4)

Soil Side Up, 5X (Etch, HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-021C Sacramento Co., Sacramento, Florin Rd.

Alclad 3004, 48" diam, 12 ga.,
installed 1963
Soil pH - 6.0, R_{min} -10,700 ohm-cm

CORRELATION OF FIELD ULTRASONIC THICKNESS MEASUREMENTS WITH ACTUAL THICKNESSES BY METALLOGRAPHIC CROSS-SECTION.

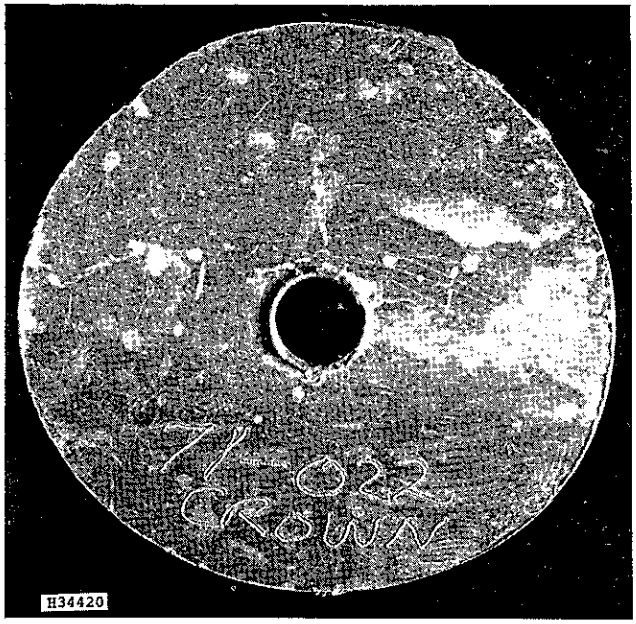
Water Side: An ultrasonic metal thickness of 0.104-inch was measured in the field, in the area scribed, then x-sectioned in the lab.

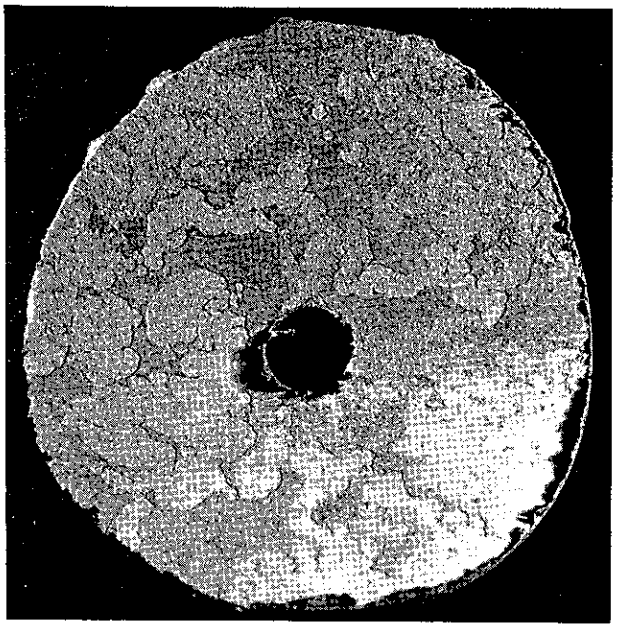
Soil Side: Corrosion of the cladding layer and into the core alloy was measured at 0.094-0.098 inches.

ClibPDF - www.fastio.com

Crown

14-Feet from Inlet End

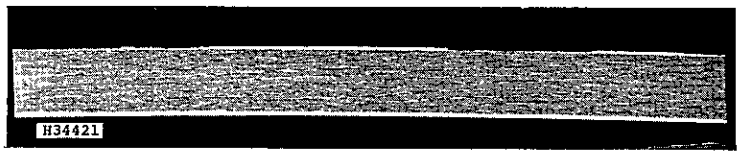




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2So_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-022 Sacramento Co., Sacramento, Green Rd.

Alclad 3004, 24" diam, 14 ga.,
installed 1963
Soil pH - 7.5 R_{min} - 7,250 ohm-cm

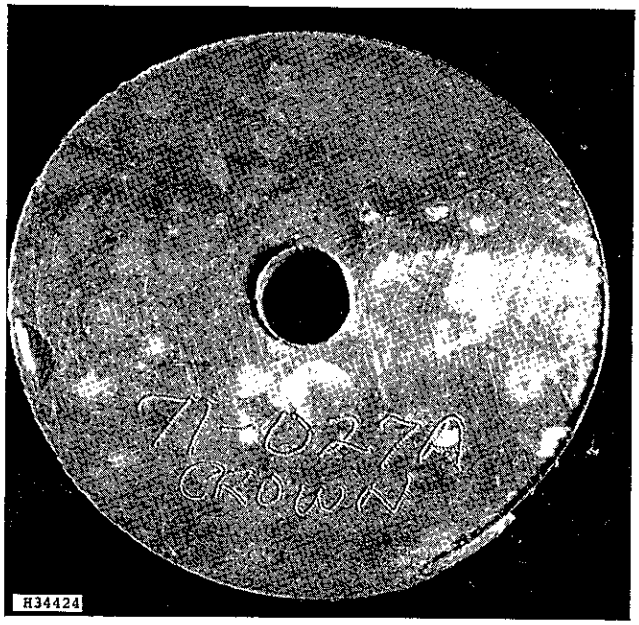
Soil Side: Attack limited to the cladding, 0.003-inch

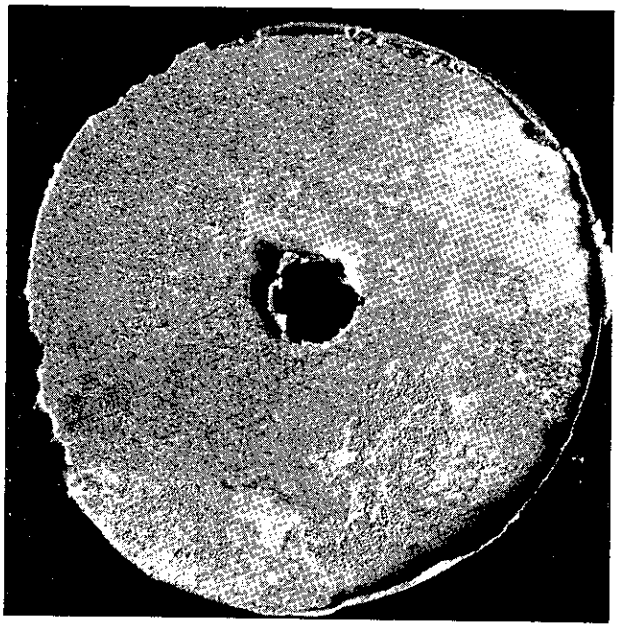
Water Side: No corrosion present

ClibPDF - www.fastio.com

Crown

9-Feet from Inlet End

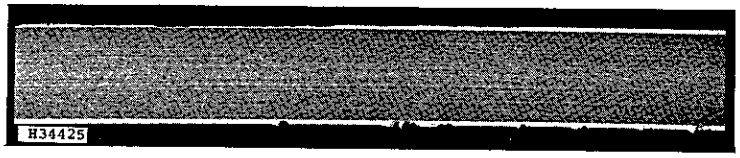




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-027A

Sacramento Co., Sacramento,
W. 2nd St. (North Pipe)

Alclad 3004, 58" x 36", Arch Pipe, 12 ga., installed 1964
Soil pH - 8.2, R_{min} - 2,300 ohm-cm

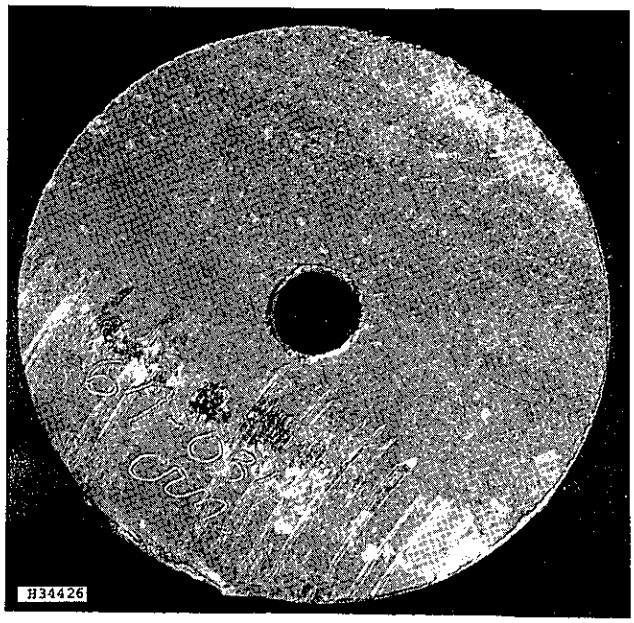
Soil Side: Corrosion of the cladding to 0.0045 inch.

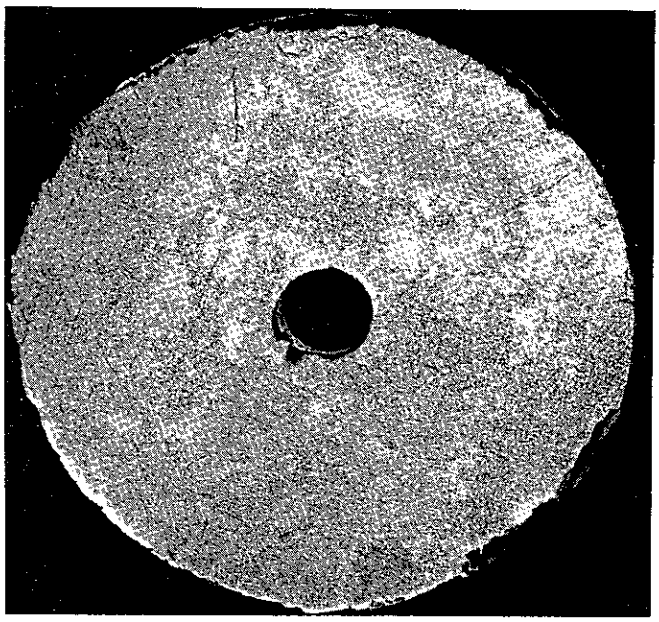
Water Side: No corrosion; some mechanical nicks.

ClibPDF - www.fastio.com

Crown

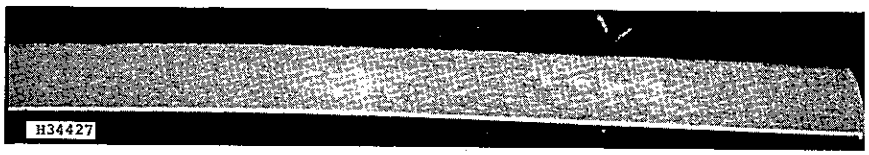
7-Feet from South End





Water Side Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch, HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-034

Solano Co., Dixon, Pedrick Rd.,
1.0 mi. north of Maine Prairie

Alclad 3004, 30" diam, 14 ga.,
installed 1963
Soil pH - 7.2, R_{min} - 830 ohm-cm

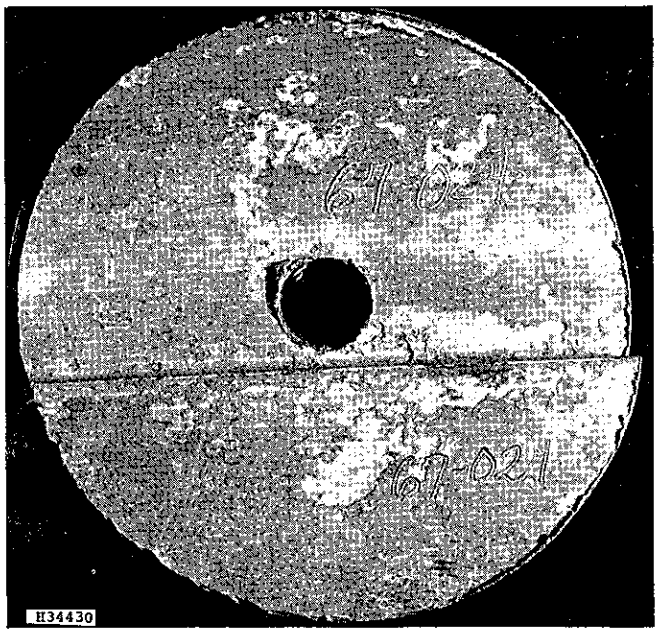
Soil Side: General attack of cladding layer to 0.003 inches (cladding, 0.00375")

Water Side: No corrosive attack, scratches or mechanical abrasion only

ClibPDF - www.fastio.com

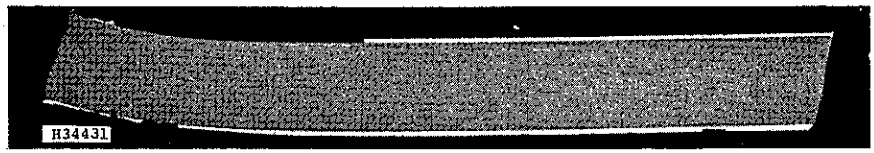
Lap Seam - Invert

10-Feet from South End

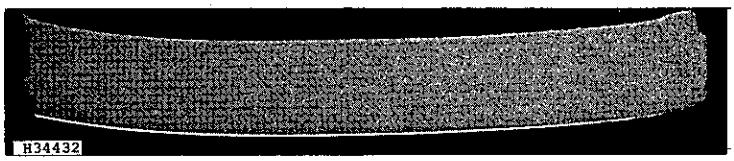


Water Side Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch, HF/H_2SO_4)



Lap Interface Up, Water Side Down
5X (Etch, HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-024 Solano Co., Dixon, Intersection of Maine Prairie & Robben

Alclad 3004, 43" x 27" Arch Pipe, 12 ga., installed 1964
Soil pH - 6.5, R_{min} - 450 ohm-cm
Water pH - 6.8, R - 2,500 ohm-cm

Soil Side: Attack limited to the cladding layer, 0.005 inch

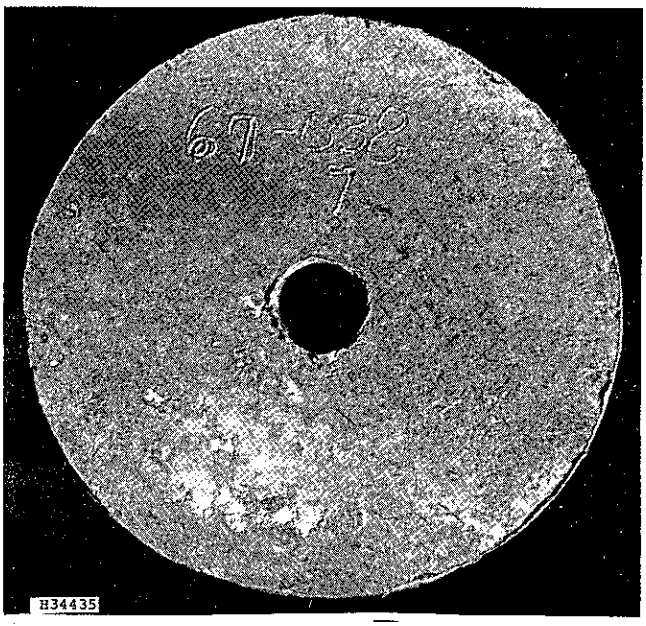
Lap Side: Same as soil side

Water Side: Corrosion of cladding, 0.003 inch

ClibPDF - www.fastio.com

Invert

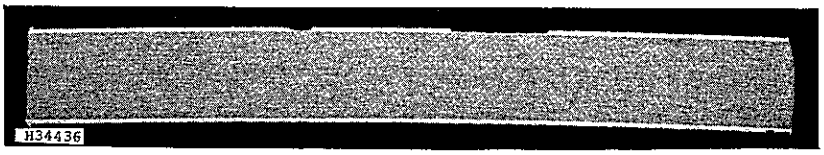
5-1/2 feet from East End



Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-038 Solano Co., Dixon, Hwy 113 and Binghampton Rd.

Alclad 3004, 50" x 31" Arch Pipe, 12 ga., installed 1962
Soil pH - 8.4, R_{min} - 1500 ohm-cm
Water pH - 7.6, R - 3100 ohm-cm

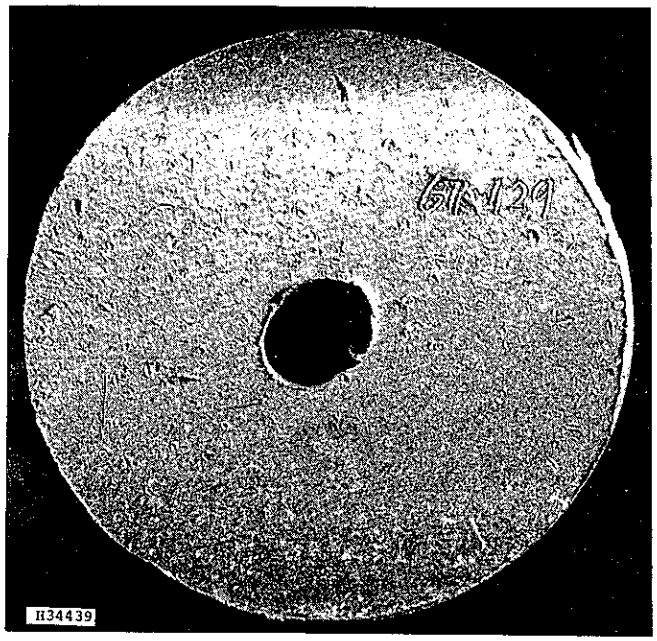
Soil Side: Attack of cladding to 0.0045 inch

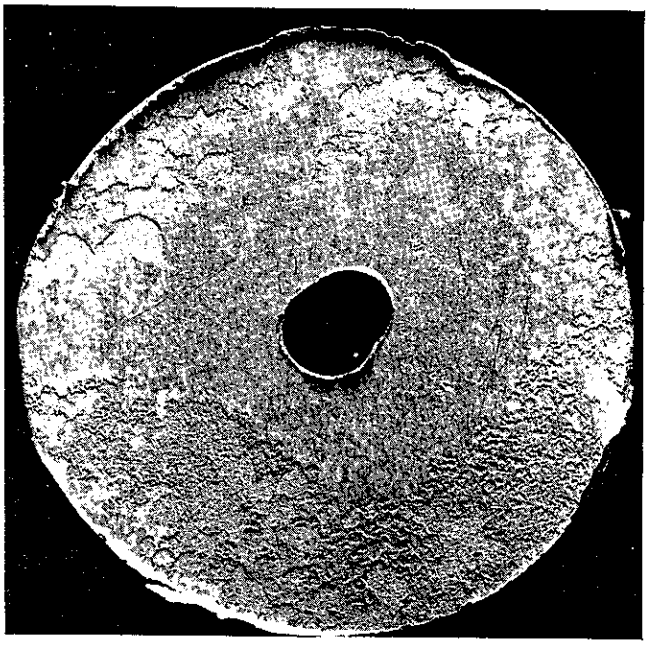
Water Side: Small areas of cladding attack, 0.002 inch

ClibPDF - www.fastio.com

Crown

5 Feet from Inlet End

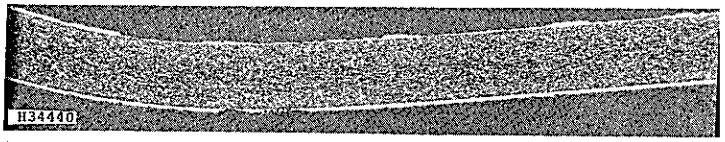




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-129 Calaveras Co., Highway 4, East of Camp Connell

Alclad 3004, 24" diam, 14 ga., installed 1962
Soil pH - 6.7, R_{min} - 65,000 ohm-cm

Soil Side: Attack limited to the cladding layer (0.0038-inch)

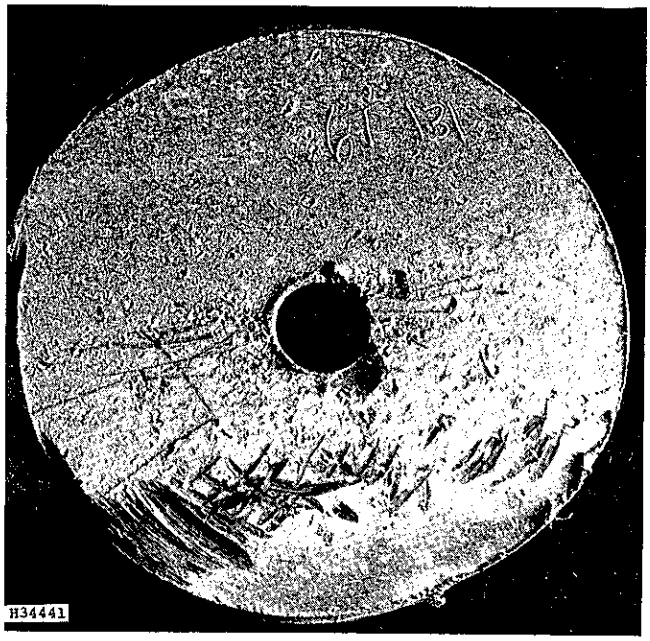
Water Side: Abrasion limited to the cladding 0.0038 inch

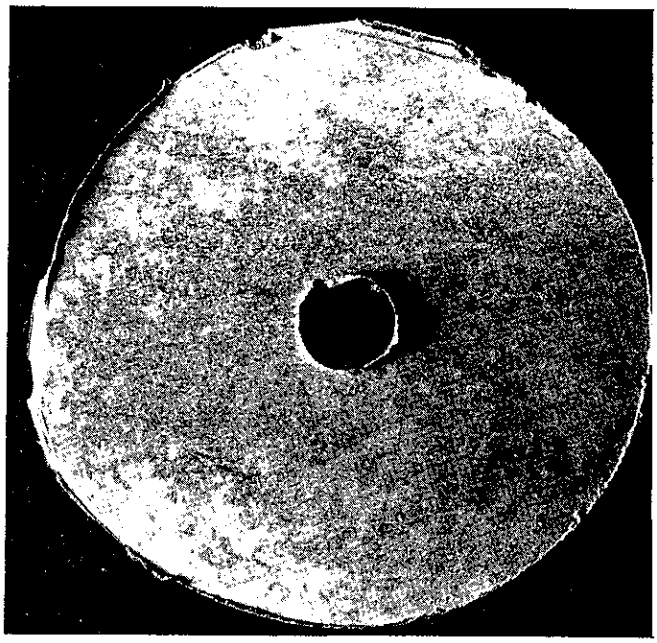
NOTE: Crown sampled at 1 - o'clock. Abrasion of crown indicates high water flow.

ClibPDF - www.fastio.com

Crown

9 Feet from Inlet End

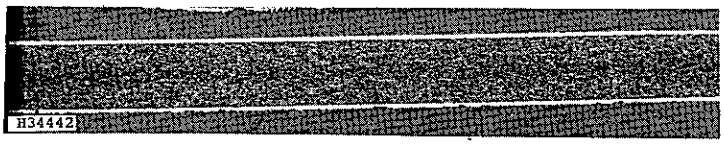




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-131 Calaveras Co., Highway 4, East of Camp Connell

Alclad 3004, 24" diam, 14 ga.,
installed 1962
Soil pH - 6.4, R_{min} - 33,800 ohm-cm

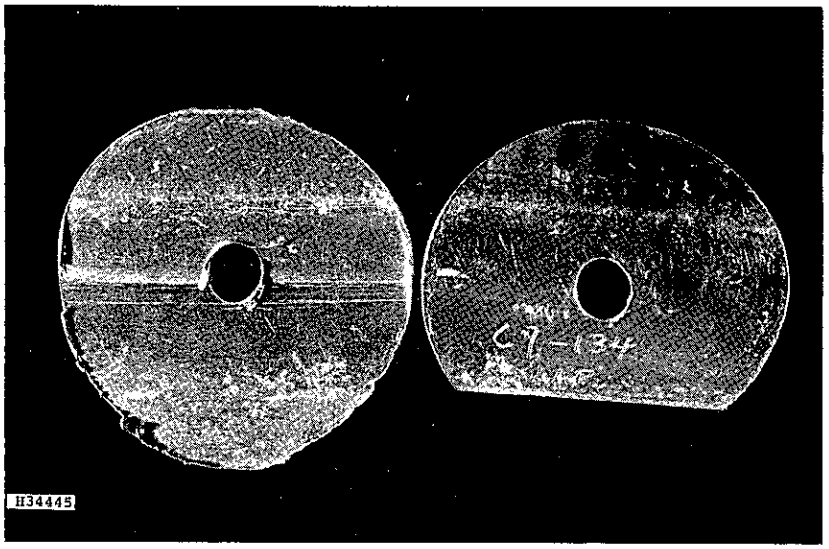
Soil Side: Slight surface etching, no measurable corrosion

Water Side: Abrasion limited to the cladding layer to a depth of 0.0025 inch

NOTE: Mechanical damage to water side of coupon during sampling

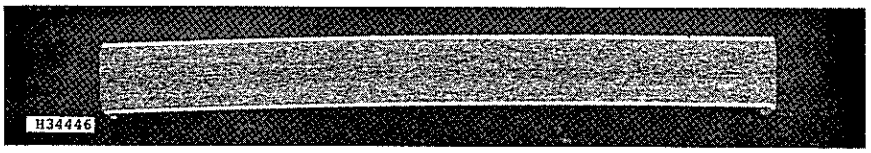
ClibPDF - www.fastio.com

Crown - Lap Interface



Lap Interface

1.0X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)

Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-134 Calaveras Co., Camp Connell, Hwy 4, in Camp Sites

Alclad 3004, 24" diam, 14 ga., installed 1963
Soil pH - 6.5, R_{min} - 23,300 ohm-cm

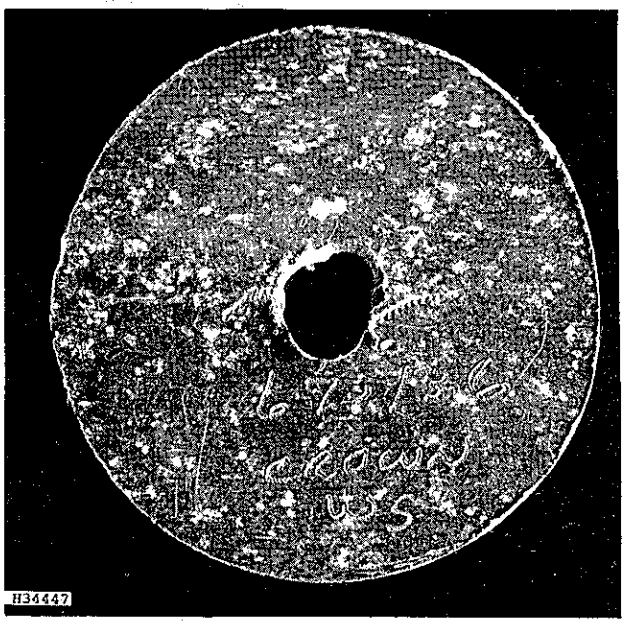
Lap Interface: No attack

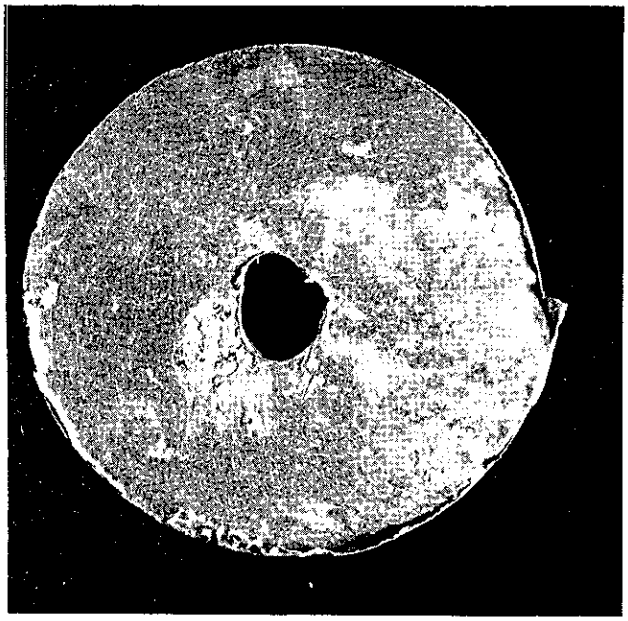
Water Side: No attack

ClibPDF - www.fastio.com

Crown

10-Feet from Outlet End

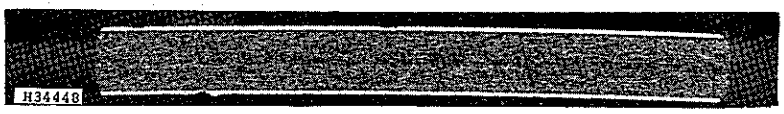




Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X(Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-136 Calaveras Co., Camp Connell, Hwy 4, in Camp Connell

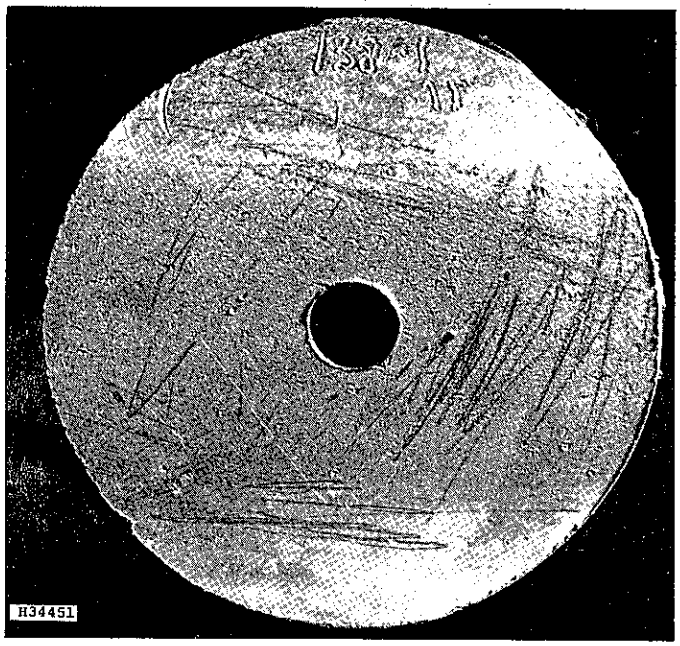
Alclad 3004, 24" diam, 14 ga., installed 1963
Soil pH - 6.9, R_{min} - 56,000 ohm-cm

Soil Side: Small areas of cladding attack
Pits limited to the cladding, 0.003 inch

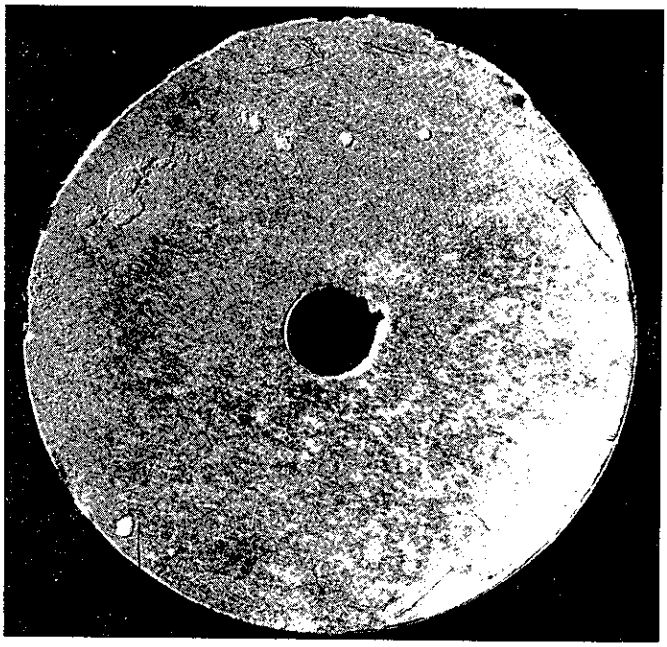
Water Side: No attack

ClibPDF - www.fastio.com

Honch (9 o'clock)
9-1/2 Feet from Inlet End

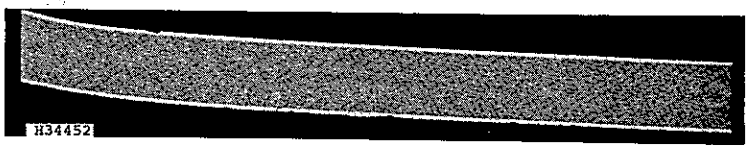


Water Side



Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X, (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-138

Calaveras Co., Highway 4,
East of Camp Connell

Alclad 3004, 24" diam, 14 ga.,
installed 1962

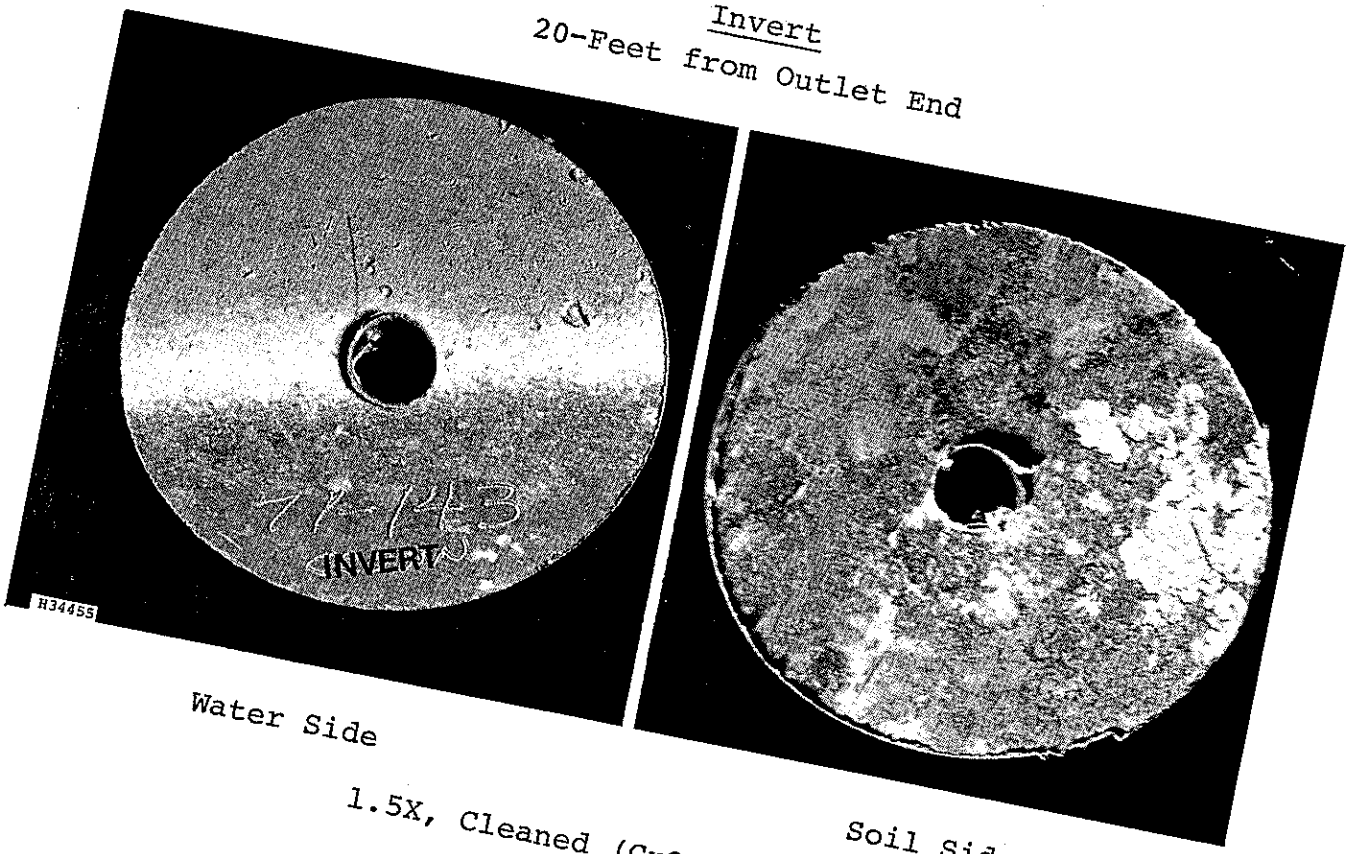
Soil pH - 6.3, R_{min} - 48,300 ohm-cm
Water pH - 7.6, R - 16,000 ohm-cm

Soil Side: Small areas of attack limited to the cladding layer (0.0038 inch)

Water Side: Abrasion of the cladding layer to 0.0017 inch.

ClibPDF - www.fastio.com

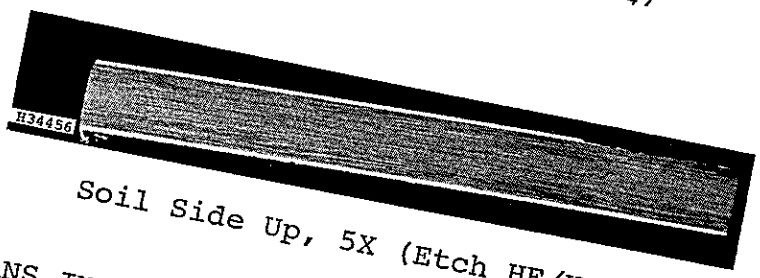
Invert
20-Feet from Outlet End



Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-143

Tuolome Co., Groveland, Yosemite Highlands Development, Merrell Rd.

Alclad 3004, 30" diam, 14 ga., installed 1962
Soil pH - 6.6, Rmin - 8,800 ohm-cm

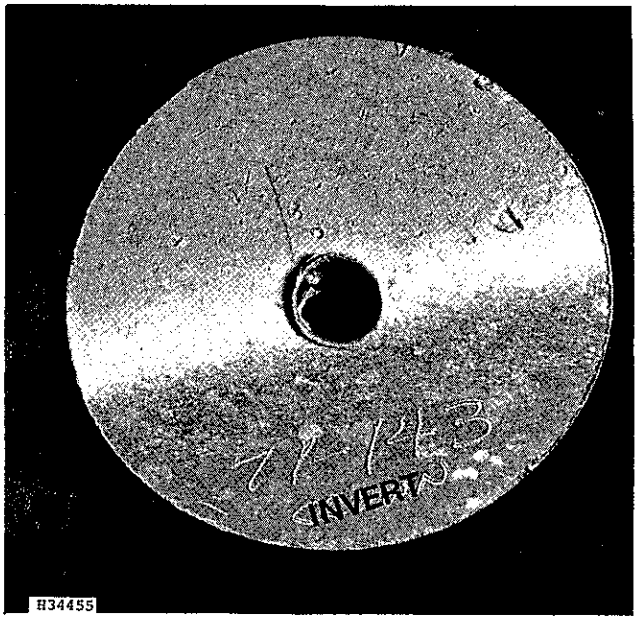
Soil Side: Corrosion limited to the cladding layer, 0.0038 inch

Water Side: Abrasion of cladding layer 0.0025 inch deep

ClibPDF - www.fastio.com

Invert

20-Feet from Outlet End



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)

Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-143 Tuolome Co., Groveland, Yosemite Highlands Development, Merrell Rd.

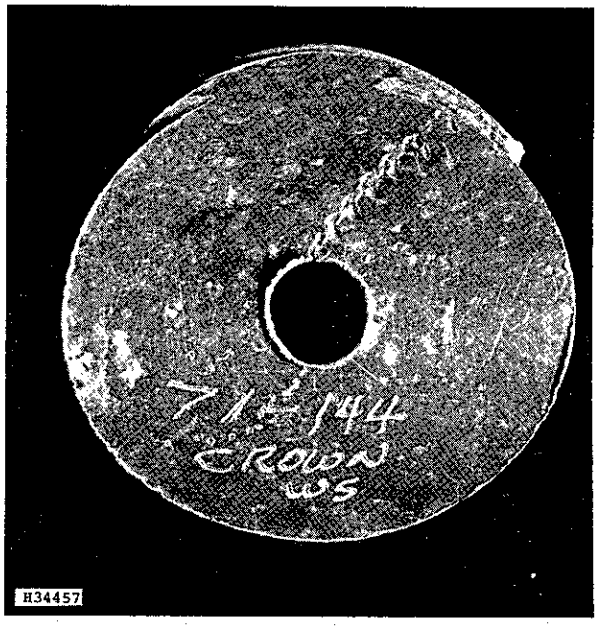
Alclad 3004, 30" diam, 14 ga., installed 1962
Soil pH - 6.6, R_{min} - 8,800 ohm-cm

Soil Side: Corrosion limited to the cladding layer, 0.0038 inch

Water Side: Abrasion of cladding layer 0.0025 inch deep

ClibPDF - www.fastio.com

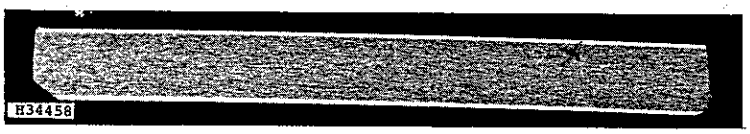
Crown
31-Feet from Inlet End



Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #71-144

Tuolome Co., Groveland, Yosemite Highlands Development, North Dome Ct.

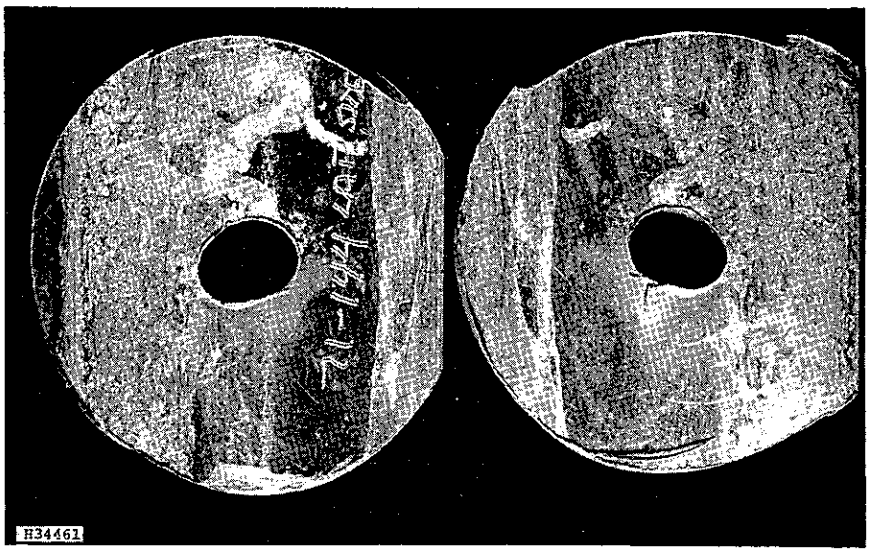
Alclad 3004, 30" diam, 14 ga., installed 1962
Soil pH - 6.5, R_{min} - 8,700 ohm-cm

Soil Side: Slight surface etching, no measurable attack

Water Side: No attack

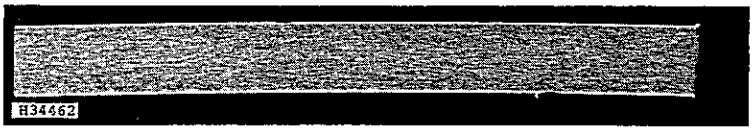
ClibPDF - www.fastio.com

Lap Interface



Interface

1.25X, Cleaned (CrO_3/H_3PO_4)



5X, (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE 71-144 Tuolome Co., Groveland, Yosemite Highlands Development, North Dome Ct.

Alclad 3004, 30" diam, 14 ga., installed 1962
Soil pH - 5.4, R_{min} - 25,000 ohm-cm

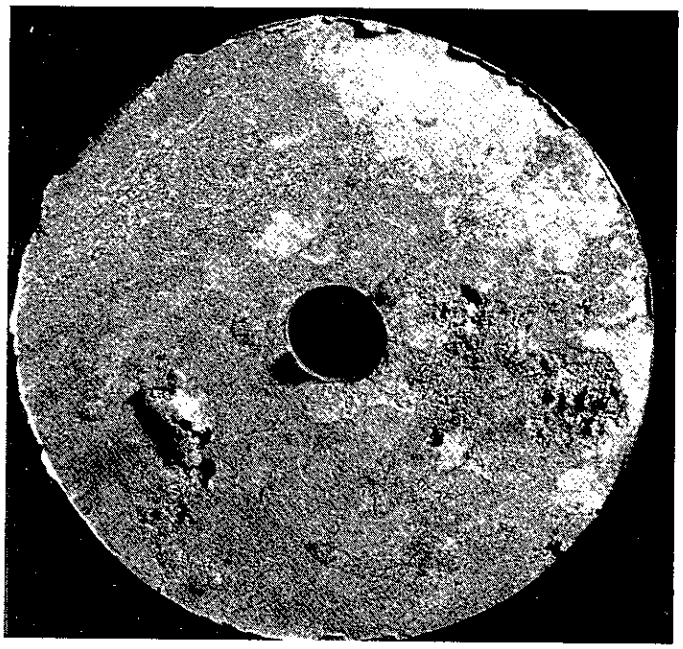
Lap Interface: Slight attack of cladding, 0.0015 inch (Note: Cladding layer thickness, 0.002 inch)

Water Side: No corrosion, slight mechanical damage

ClibPDF - www.fastio.com

Crown

8.5 Feet from Inlet End



Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)

Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-023

Contra Costa Co., Orinda,
Neider Lane (Miner Rd.)

Alclad 3004, 24" diam, 14 ga.
installed 1963
Soil pH*- 3.9, R_{min} - 6670 ohm-cm (1967 pH 7.6)

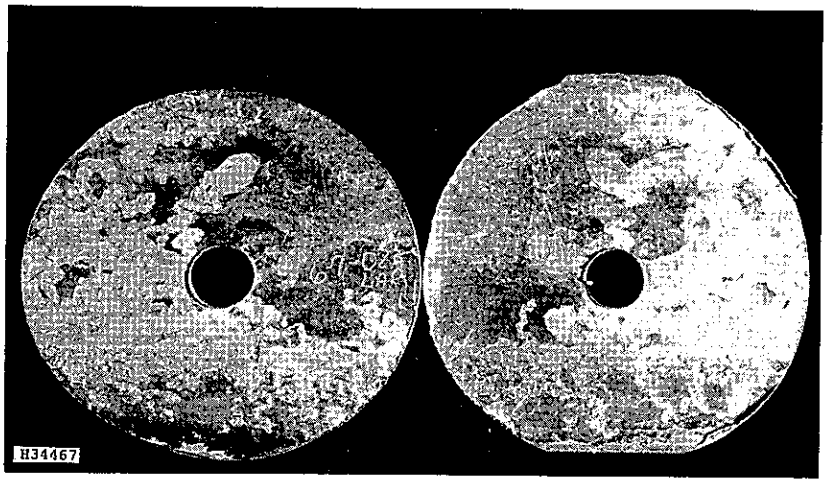
Soil Side: Perforation originating from the soil side

Water Side: Perforated from soil side corrosion

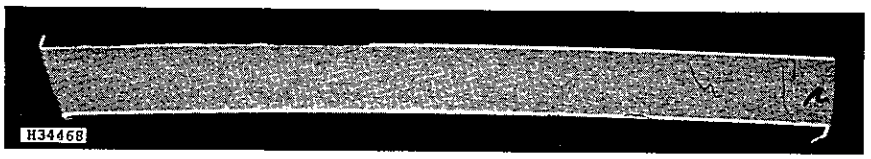
*A pH recheck of the same soil sample 1 month later was pH 5.3.

ClibPDF - www.fastio.com

Honch (Lap Interface)



Lap Interface
1.25X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-023 Contra Costa Co., Orinda,
Neider Lane (Minor Rd.)

Alclad 3004, 24" diam, 14 ga.,
installed 1963
Soil (no soil taken from the honch)

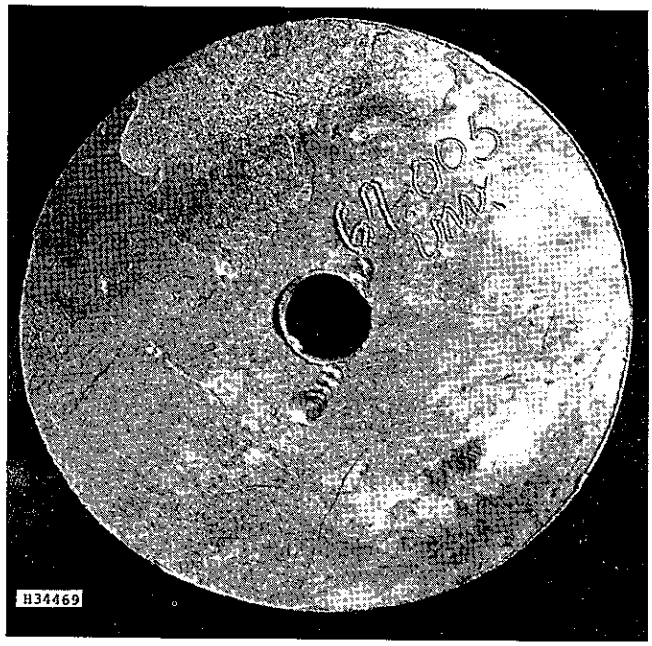
Lap Interface: Attack of the cladding layer, 0.0038 inch

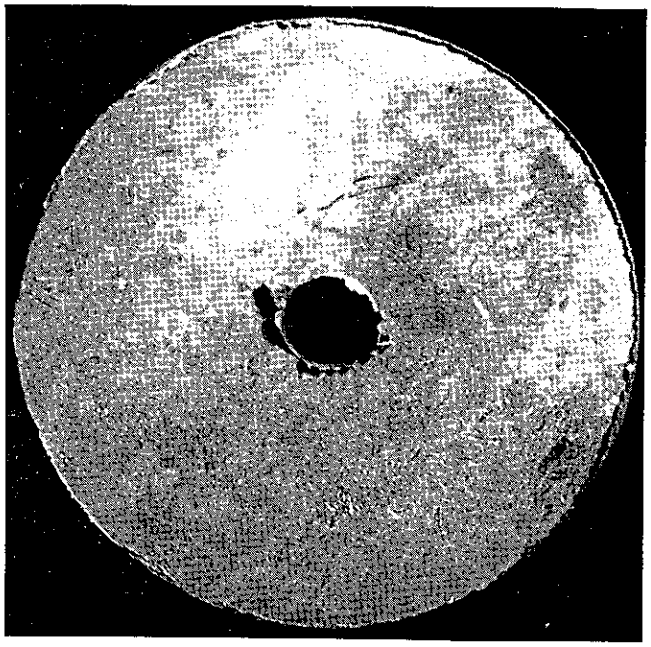
Water Side: Staining of the cladding, no measurable attack

ClibPDF - www.fastio.com

Invert

1 Foot from North End

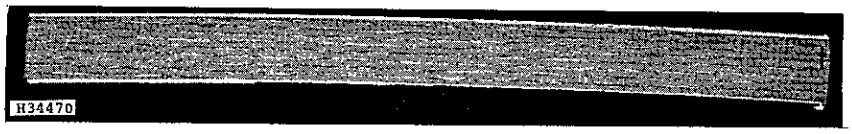




Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-005

Alameda Co., Hayward, Folsom Ave. and Taylor St.

Alclad 3004, 24" diam, 14 ga., installed 1960
Soil pH - 6.2, R_{min} - 1,960 ohm-cm

Soil Side: Surface etching, no measurable attack

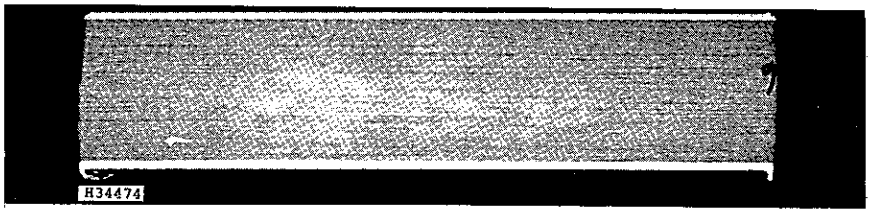
Water Side: Attack of the cladding layer, 0.0038 inch

NOTE: Soil was in the water side (culvert half full of soil).

ClibPDF - www.fastio.com

Crown Lap (Interface)

Lap Interface
1.25X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (water side down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-27 Monterey Co., Big Sur, Coast Rd., off Cabrillo Highway

Alclad 3004, 72" diam. 10 ga., installed 1965
soil (none taken in crown)

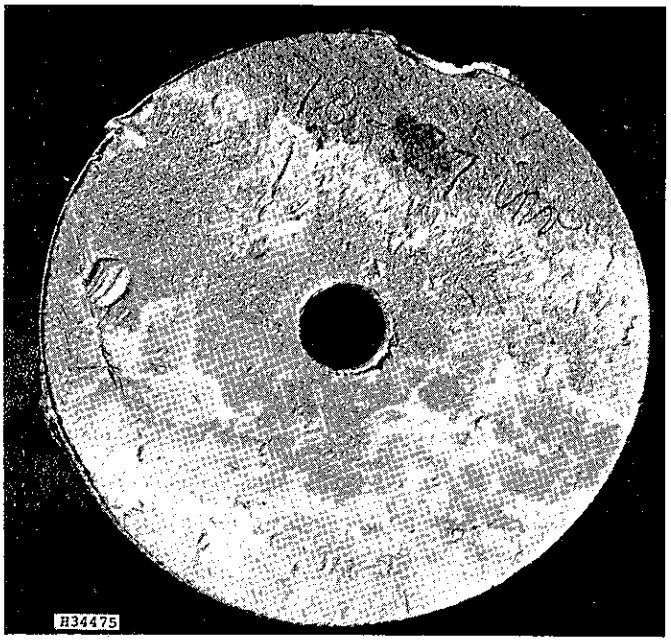
Lap Interface: Slight staining, no measurable attack

Water Side: Slight etching, no measurable attack

ClibPDF - www.fastio.com

Invert

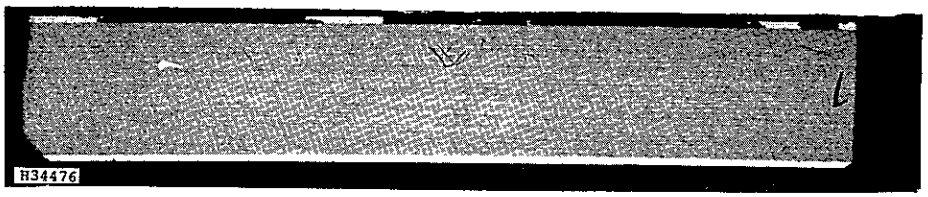
14-1/2 Feet from Inlet End



Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-27 Monterey Co., Big Sur, Coast Rd., off Cabrillo Highway

Alclad 3004, 72" diam, 10 ga., installed 1965
Soil pH - 6.2, R_{min} - 38,000 ohm-cm

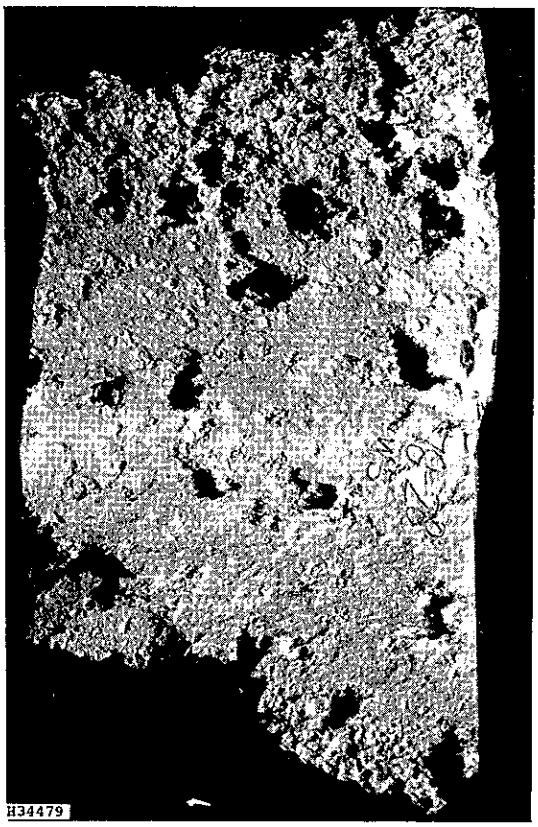
Soil Side: Attack of the cladding layer, 0.0068 inch

Water Side: Abrasion of the cladding layer, 0.0035 inch

ClibPDF - www.fastio.com

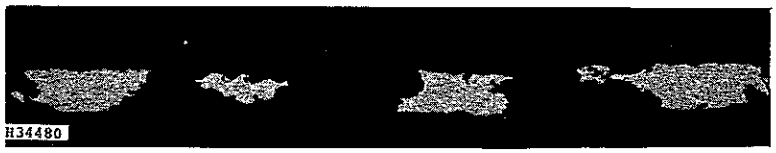
Invert

2 Feet from Outlet End



Water Side Soil Side

1.5X, Cleaned ($CrO_3H_3PO_4$)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-28 Santa Cruz Co., Highway 17, Scott's Crossing

Alclad 3004, 36" diam, 14 ga.,
installed 1962
Soil (invert) pH - 3.8, R_{min} - 5,000 ohm-cm
Soil (20' from pipe) pH - 3.7-3.9,
R_{min} - 5,000 ohm-cm

Soil Side: Perforations and large areas of invert corroded away, from soil side corrosion

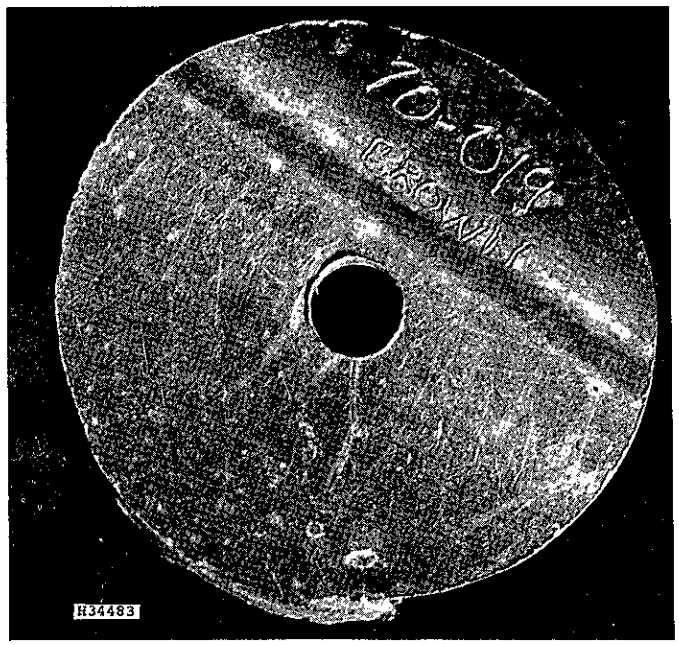
Water Side: Severe corrosion from soil side

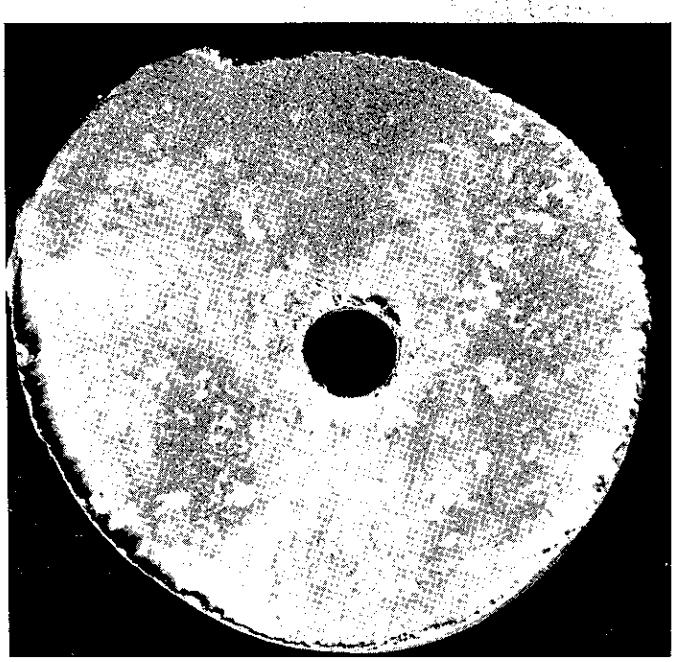
Note: pH is below 4.0

ClibPDF - www.fastio.com

Crown

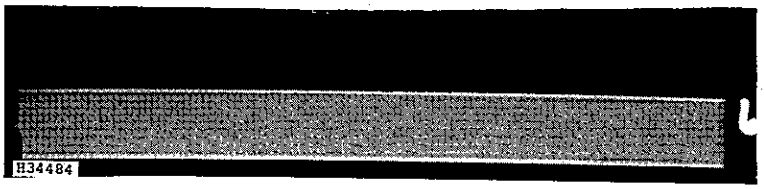
10-Feet from Inlet End





Water Side Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-019 Ventura Co., Thousand Oaks,
Olson Rd., near Moorpark

Alclad 3004, 30" diam, 14 ga.,
installed 1963
Soil (Crown backfill) pH - 7.7,
R_{min} - 10,300 ohm-cm

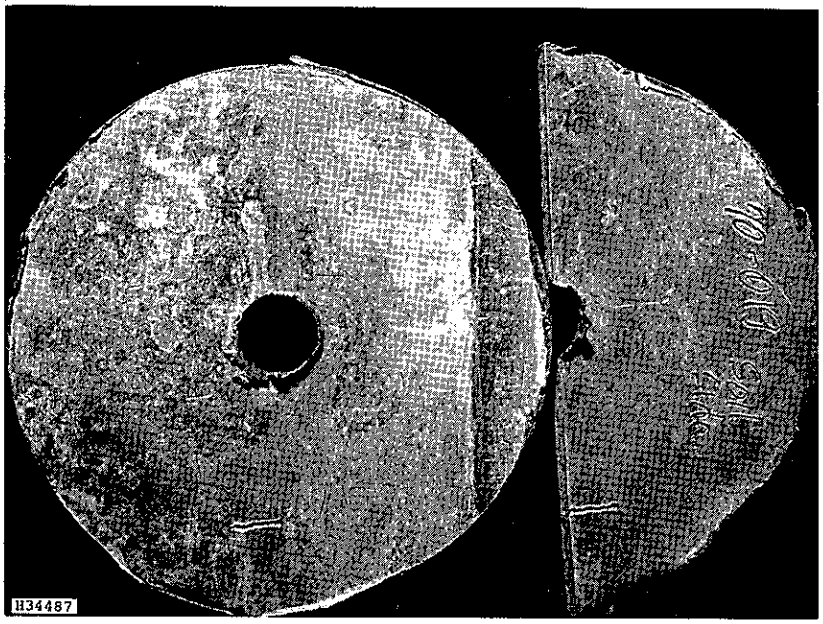
Soil Side: Slight attack of cladding layer,
0.0020 inch

Water Side: No attack

Site 70-019 continued

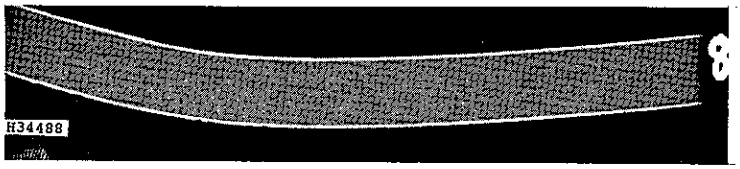
ClibPDF - www.fastio.com

Invert Lap



Lap Interface

1.6X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-019 Ventura Co., Thousand Oaks, Olson Rd., near Moorpark

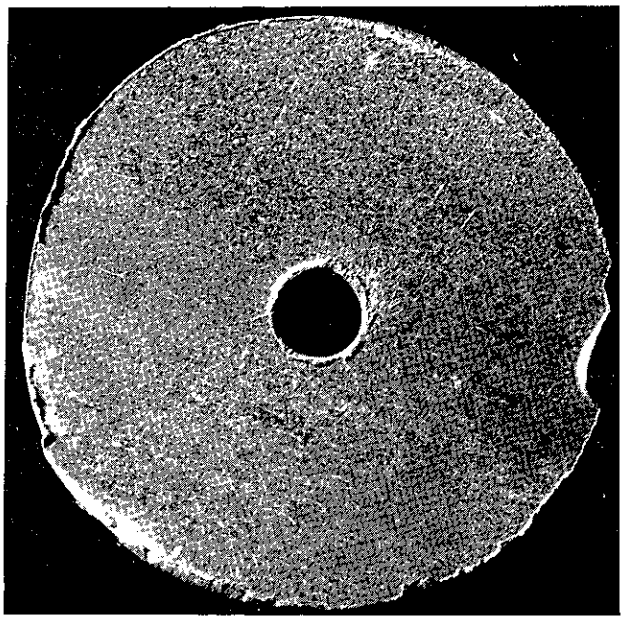
Alclad 3004, 30" diam, 14 ga., installed 1963
Soil - no soil removed from invert

Lap Interface: Surface etching only, no measurable attack

Water Side: Abrasion of the cladding layer, 0.0030 inch

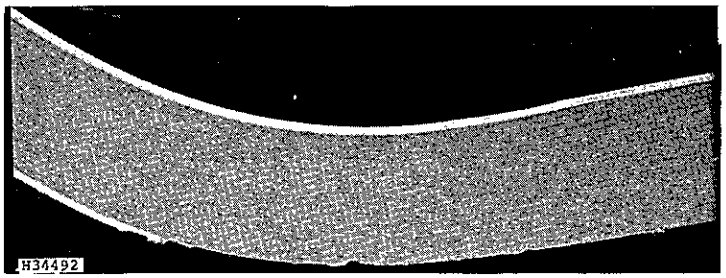
ClibPDF - www.fastio.com

Invert
37-Feet from Outlet End



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-020 Ventura Co., Thousand Oaks,
Olson Rd., near Pederson Rd.

Alclad 3004, 48" diam, 8 ga.,
installed 1963
Soil pH - 8.0, R_{min} - 10,000 ohm-cm

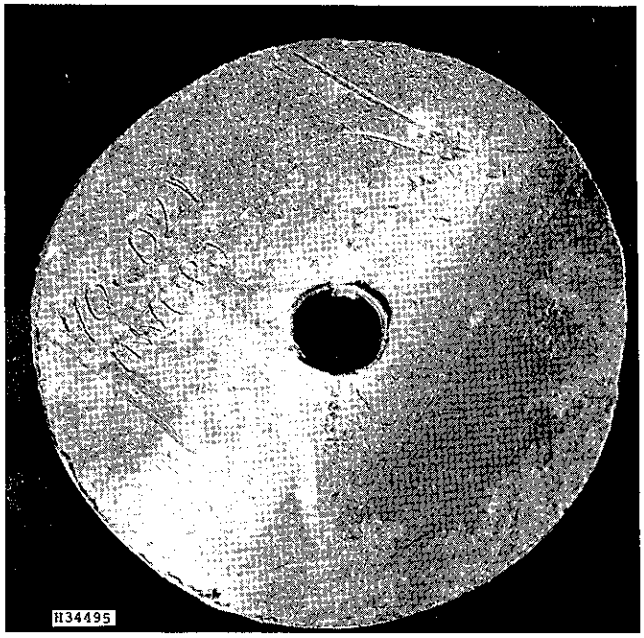
Soil Side: No attack

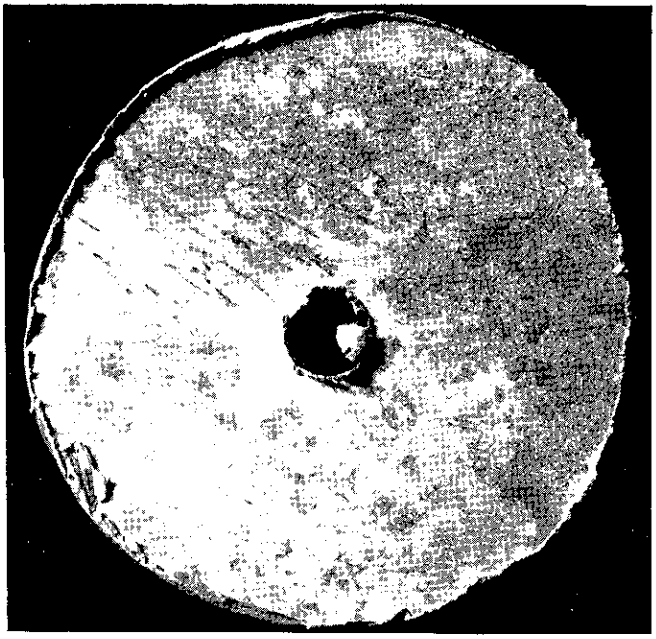
Water Side: Attack largely confined to the cladding layer, maximum depth about 0.0080 inch

ClibPDF - www.fastio.com

Invert

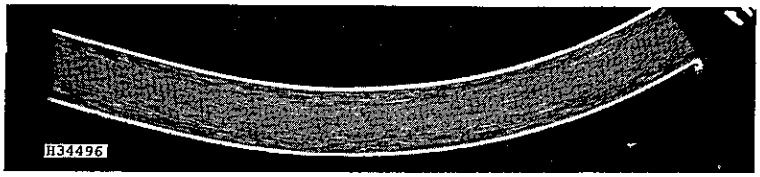
4-Feet from Outlet End





Water Side Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM PIPE - 1978

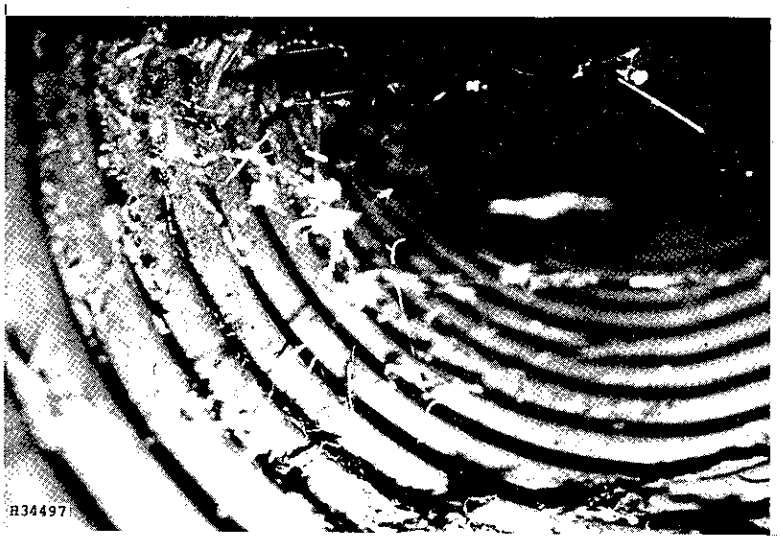
SITE #70-021 Ventura Co., Thousand Oaks,
Olson Rd., near Mountcliff Blvd.

Alclad 3004, 29" x 18" Arch Pipe, 14 ga.,
installed 1963
Soil - Crown backfill pH - 7.8, R_{min} - 910 ohm-cm
Invert pH - 8.9, R_{min} - 860 ohm-cm

Soil side: Stain-etch attack, no measurable attack

Water Side: Slight abrasion limited to the cladding layer, 0.0025 inch

ClibPDF - www.fastio.com



Springline & Invert

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-022 Ventura Co., Thousand Oaks, Olson Rd., 500 feet east of Morland

Alclad 3004, 18" diam, 14 ga., installed 1963

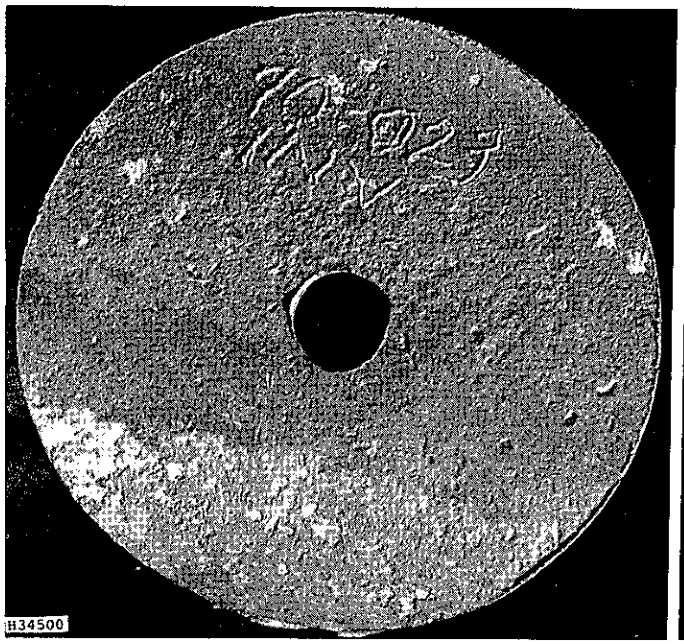
No metal coupon, soil or water taken, pipe was inaccessible.

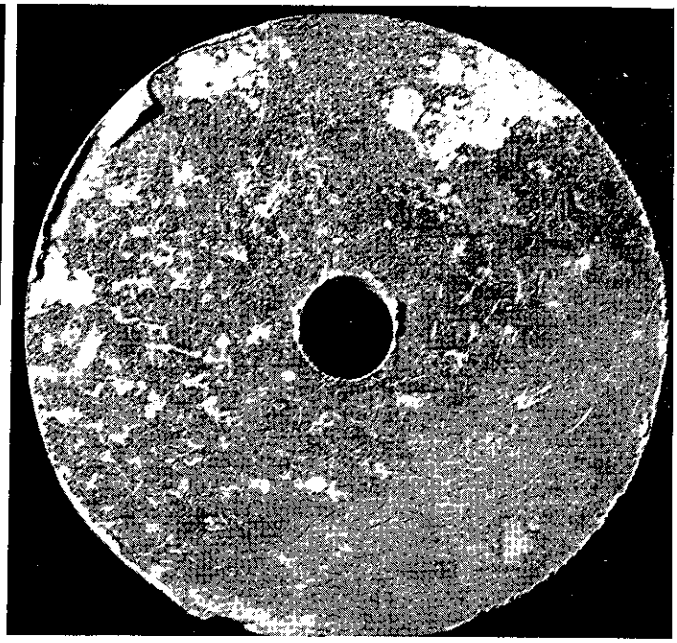
Photo and visual inspection show culvert was extremely dirty and appears to be in excellent condition

ClibPDF - www.fastio.com

Invert

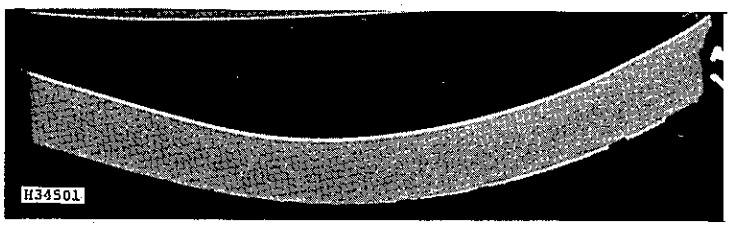
23-Feet from Inlet End





Water Side Soil Side

2X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-023 Ventura Co., Thousand Oaks,
Olson Rd., near Highway 23

Alclad 3004, 30" diam, 14 ga.,
installed 1963
Soil pH - 7.8, R_{min} - 3860 ohm-cm

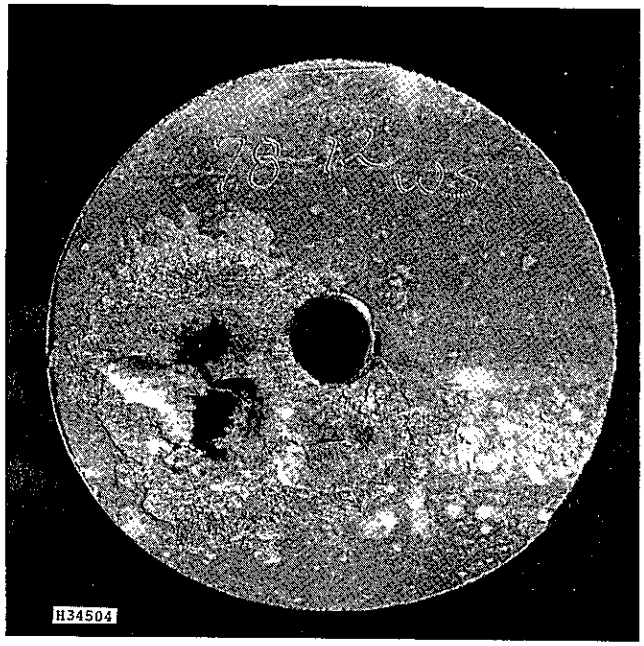
Soil Side: Corrosion limited to the cladding layer, 0.0038 inch (not in cross section)

Water Side: Abrasion and corrosion limited to the cladding layer, 0.0038 inch

ClibPDF - www.fastio.com

Crown

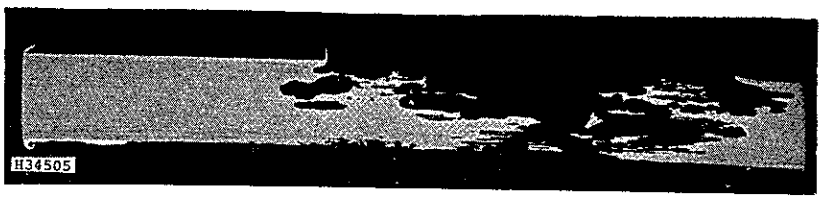
34-Feet from Outlet End, Center Pipe



Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-12 Riverside Co., Rancho California, Ynez Rd., (Site #3)

Alclad 3004, 3 each, 48" diam, 12 ga., installed 1965-1967
Soil pH - 5.7, R_{min} - 3400 ohm-cm

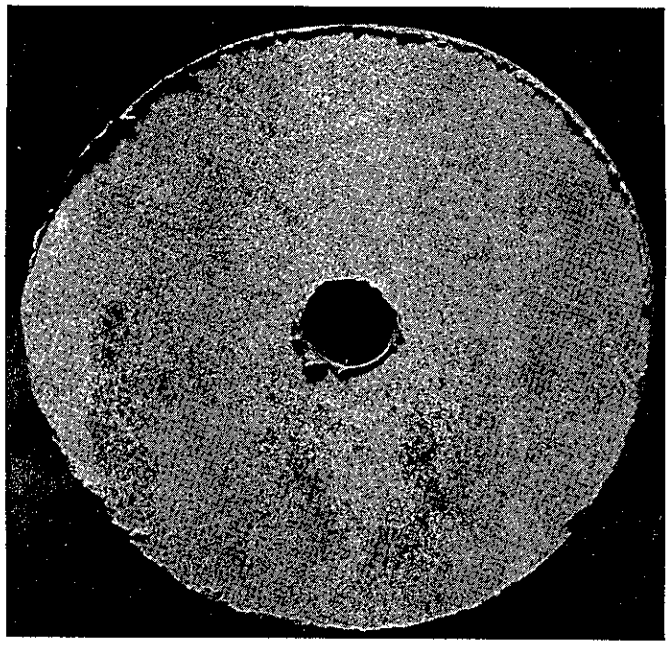
Soil Side: Large perforations originating from the soil side

Water Side: Perforations from the soil side

ClibPDF - www.fastio.com

Crown

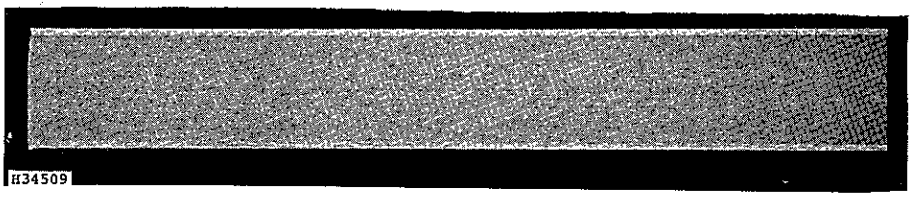
26-Feet from Outlet End of North Pipe



Water Side

Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-14 Riverside Co., Rancho California, Ynez Rd., 150' N. of Flores Dr. (Site #11)

Alclad 3004, 2 ea., 60" diam, 10 ga., installed 1965-1967
Soil pH 7.0, R_{min} 2,700 ohm-cm

Soil Side: Slight surface etch, no measurable attack

Water Side: No attack

ClibPDF - www.fastio.com

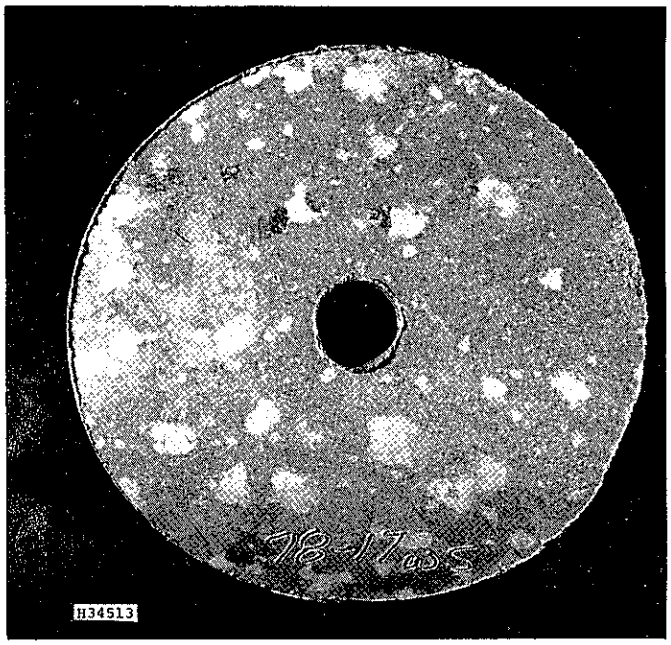
KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

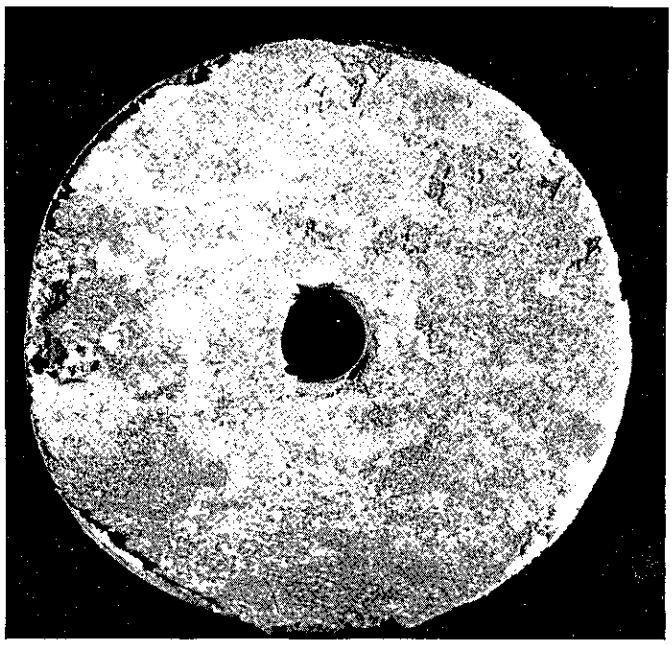
SITE #78-16 Riverside Co., Rancho California, Pauba, 400 feet east of Ynez (Site 49)

DID NOT INSPECT CULVERT

ClibPDF - www.fastio.com

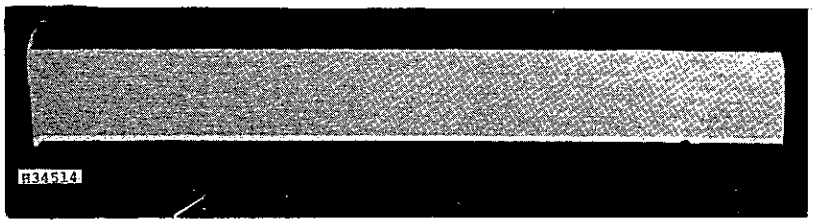
Crown





Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-17 Riverside Co., Rancho California, Solana Rd., (Site #17)

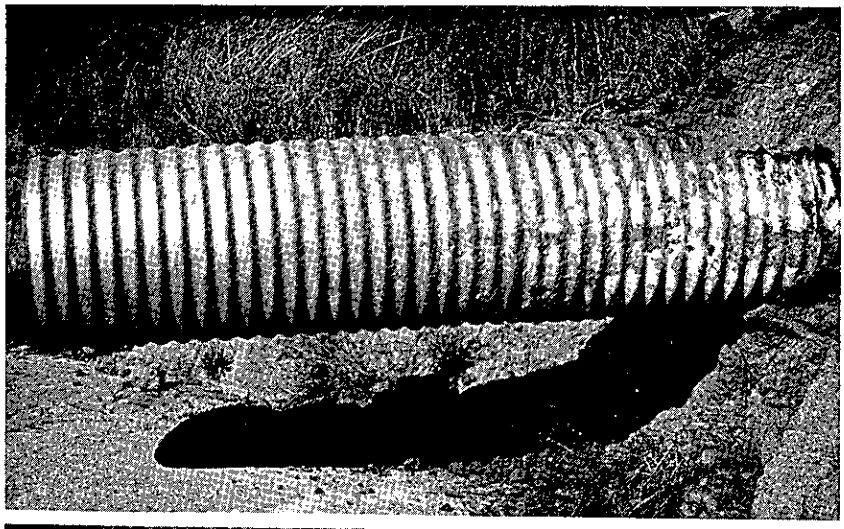
Alclad 3004, 48" diam, 12 ga.
installed 1965-1967
Soil pH 5.0, R_{min} 2,460 ohm-cm

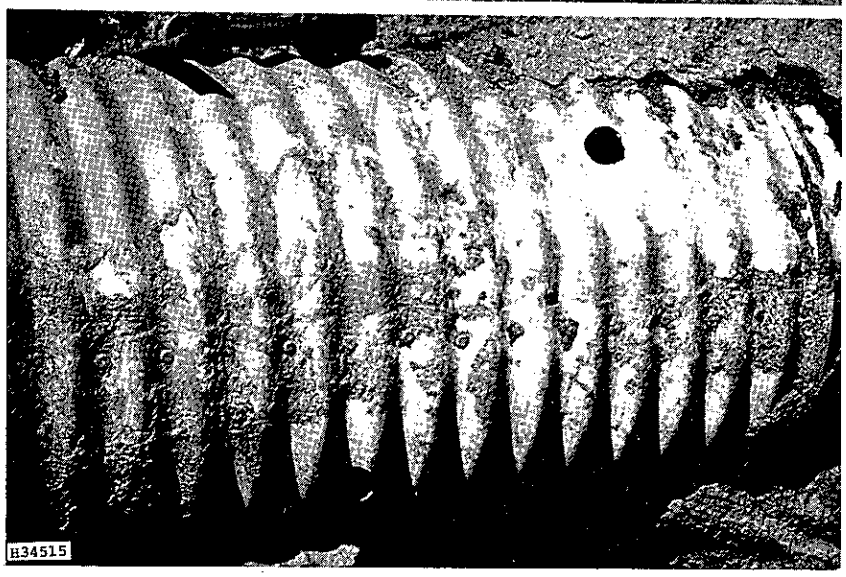
Soil Side: Deep pitting attack on the edge of the sample, with attack of the 0.005 inch thick cladding layer on the remainder

Water Side: Occasional pits in cladding

NOTE: This coupon was taken adjacent to (within 1/4 inch) the perforated sample on the page to the left.

ClibPDF - www.fastio.com





KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-18 Riverside Co., Rancho California, Margaretta Rd., (Site 38)

Alclad 3004, 24" diam, 16 ga., installed 1965-1967

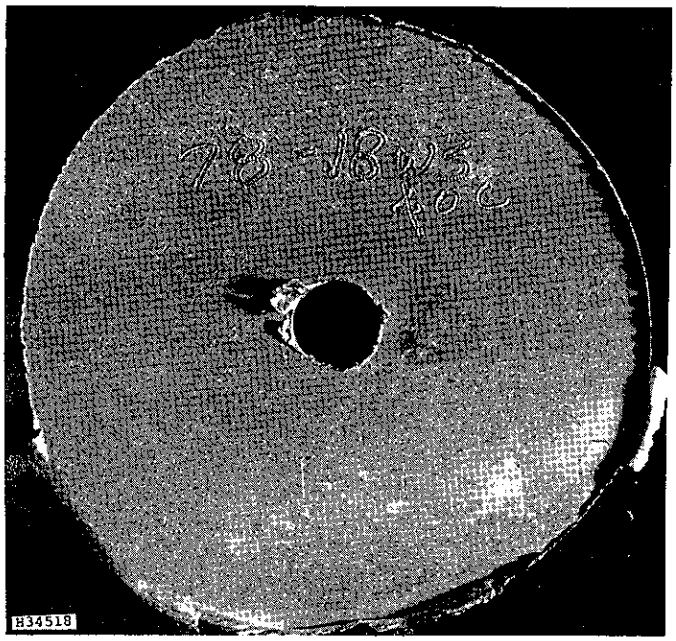
Upper Photo: Overall photo of pipe showing 6 feet of exposed pipe (previously buried) caused by heavy rains and flooding at Rancho California.

Lower Photo: Sampled areas of pipe in the honch (2 o'clock) and springline (4 o'clock) positions. Sampled in areas with cladding attack (next pages).

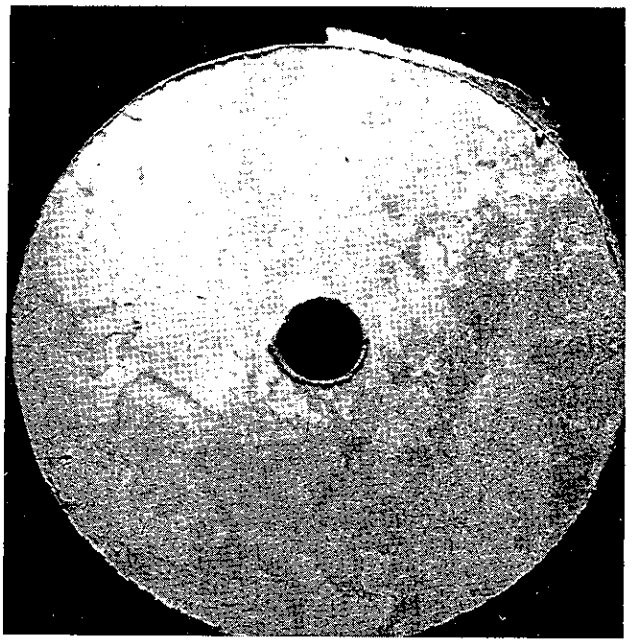
ClibPDF - www.fastio.com

Springline (4 o'clock)

6-Feet from Inlet End

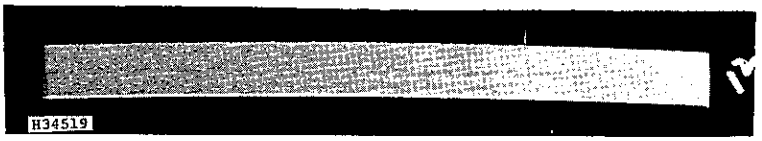


Water Side



Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

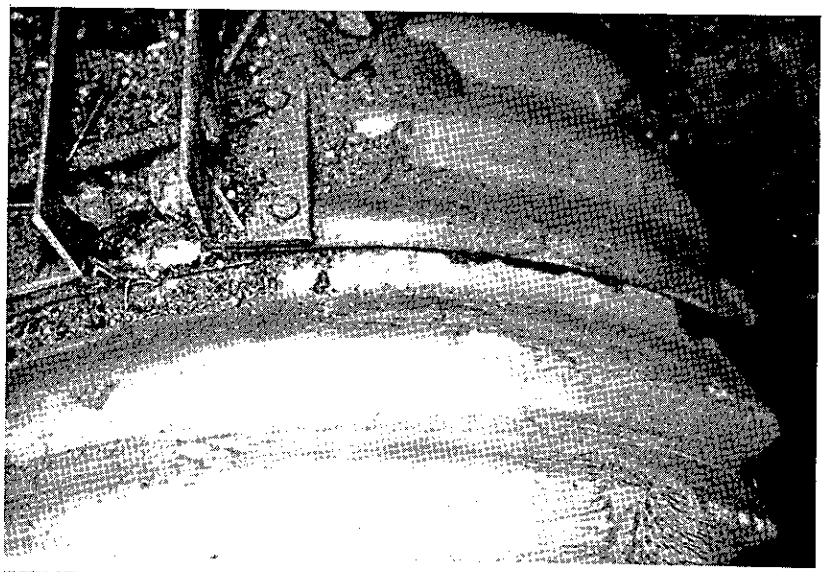
SITE #78-18 Riverside Co., Rancho California, Margaretta Rd., (Site #38)

Alclad 3004, 24" diam, 16 ga., installed 1965-1967
Soil pH - 7.4 , R_{min} - 9,440 ohm-cm

Soil Side: Attack limited to the cladding layer, 0.003 inch

Water Side: Staining, no measurable attack

ClibPDF - www.fastio.com



KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-19

Riverside Co., Rancho California, De Los Caballos Rd., 0.15 Miles N.E. of Hwy 79 (Site #70)

Alclad 3004, 4 ea. 24" diam, 1 pipe 16 ga., 3 pipes 10 ga., installed 1965-1967

No Sample removed; photos taken in crown area*

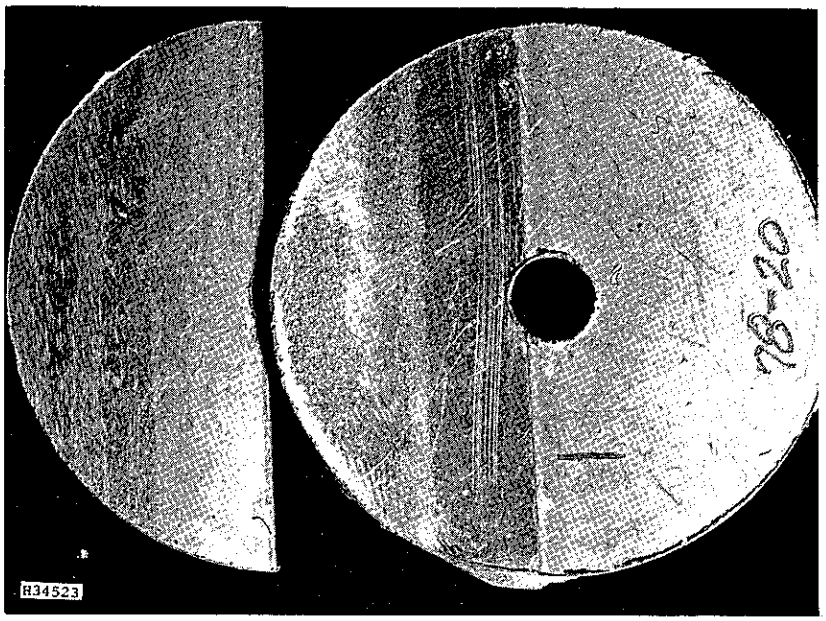
Crown: showing band coupler, light superficial etch attack, no pitting

Crown: Small area of cladding attack

*Culvert was inspected at the edge of asphalt, due to a wash-out of the shoulder

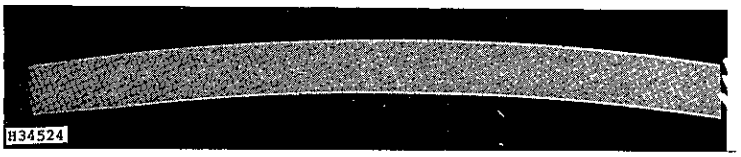
ClibPDF - www.fastio.com

Crown (Lap Interface)



Lap Interface

1.5X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

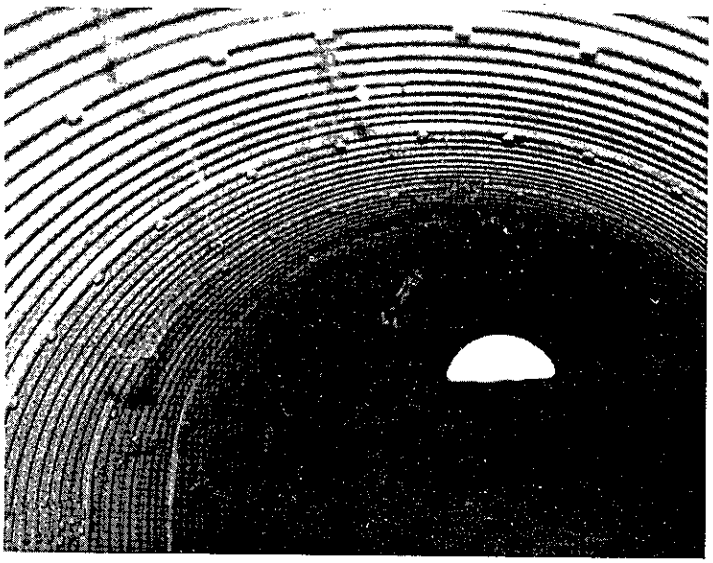
SITE #78-20 Riverside Co., Rancho California,
Los Cabaloss Rd., (Site #69)

Alclad 3004, 42" diam, 16 ga.,
installed 1965-1967
Soil pH - 8.9, R_{min} - 10,300 ohm-cm

Lap Interface: No attack

Water Side: Slight surface etch, no measurable attack

ClibPDF - www.fastio.com



KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-22 Riverside Co., Rancho California, Cabrillo Ave. at intersection with Vallejo Dr. (Site #48)

Alclad 3004, 2 ea. 48" diam, 8 ga., installed 1968

An inspection was made through both pipes, and they appear to be in excellent condition.

ClibPDF - www.fastio.com

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-25 Riverside Co., Rancho California,
intersection of Camino Del Vino and De Portola
installed 1965-1967 (Site #115)
Alclad 3004, 3 ea. 18" diam, ga. (unknown),
installed 1965-1967

Soil Side: The soil side was inspected at 10 feet from the outlet end (photo). Pipe is in excellent condition with several areas of corrosion limited to cladding.

ClibPDF - www.fastio.com

NO PHOTOS

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #78-26 Riverside Co., Rancho California, De Portola Rd., 0.7 - mi. from Pauba Rd. (Site #116)

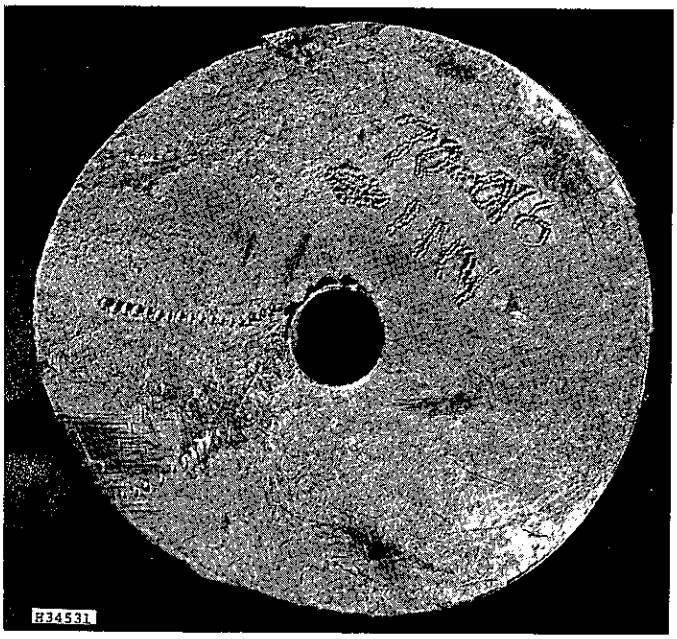
Alclad 3004, 2 ea. 13 x 22" arch, 12 ga., installed 1968

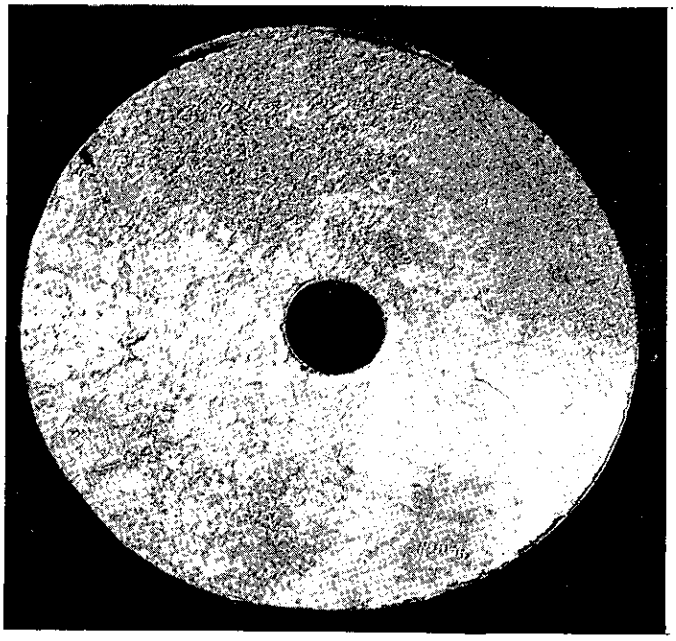
An inspection of pipes was made from the inlet and outlet ends. The culvert appear to be in excellent condition. No soil or metal coupons were taken.

ClibPDF - www.fastio.com

Invert

1-Foot from North End

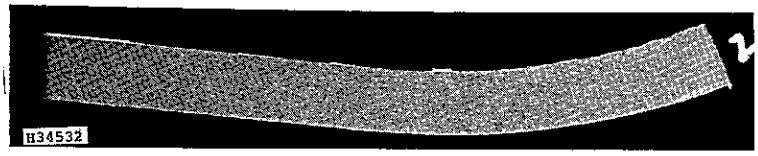




Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)



Soil Side Up 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-016 Imperial Co., Salton Sea, Hwy 3

Alclad 3004, 30" diam, 14 ga.,
installed 1961

Soil, invert, pH - 7.7, R_{min} - 3.8 ohm-cm
Water pH - 8.1, R_{min} 24 ohm-cm

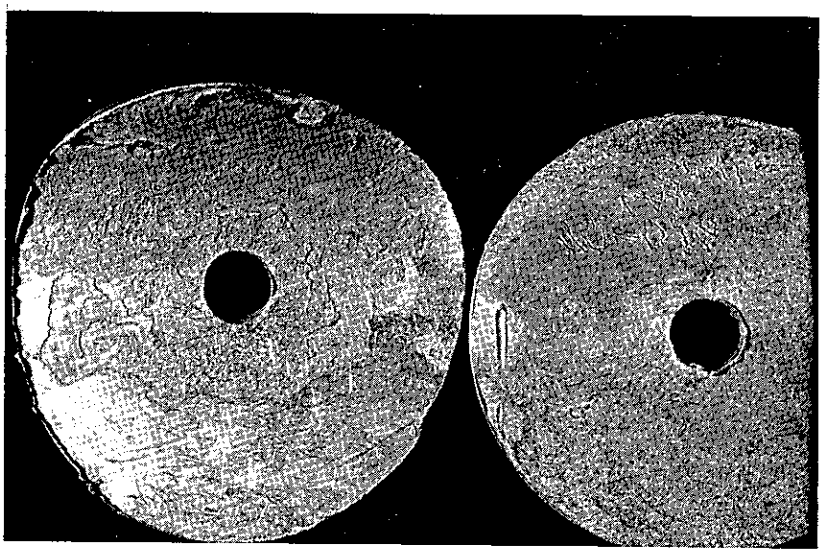
Soil Side: Attack limited to the cladding layer, 0.0038 inch

Water Side: Attack limited to the cladding layer, 0.0038 inch

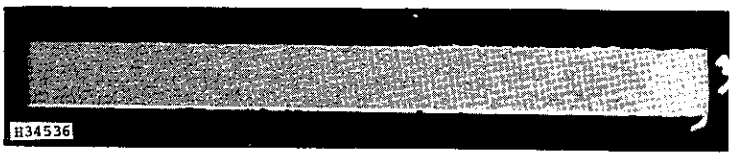
Site #70-016 continued...

ClibPDF - www.fastio.com

Invert Lap-Interface



Lap Interface
1.25X, Cleaned (CrO_3/H_3PO_4)



5X, (Etch HF/H_2SO_4)
Lap Interface Up (Waterside Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #70-016 Imperial Co., Salton Sea, Hwy 3

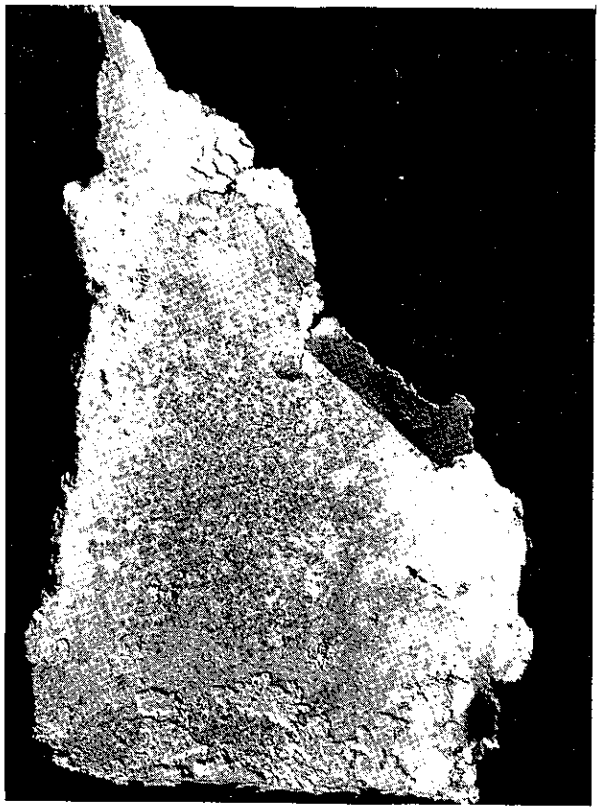
Alclad 3004, 30" diam, 14 ga.,
installed 1961
Soil pH - 7.7, R_{min} - 4 ohm-cm
Water pH - 8.1, Rmin - 24 ohm-cm

Lap Interface: Attack limited to the cladding layer, 0.0038 inch

Water Side: Attack of cladding, 0.0025 inch

ClibPDF - www.fastio.com

Crown



Water Side Soil Side

1.5X, Cleaned (CrO_3/H_3PO_4)

Soil Side, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-180 San Diego Co., National City, Interstate 5 at Sweetwater Creek

Alclad 3004, 30" diameter, 14 ga., installed 1961

Soil: Honch, pH - 7.1, R_{min} - 40 ohm-cm
Crown, pH - 8.7, R_{min} - 126 ohm-cm

Soil Side: Large perforations from soil side corrosion (not native backfill)

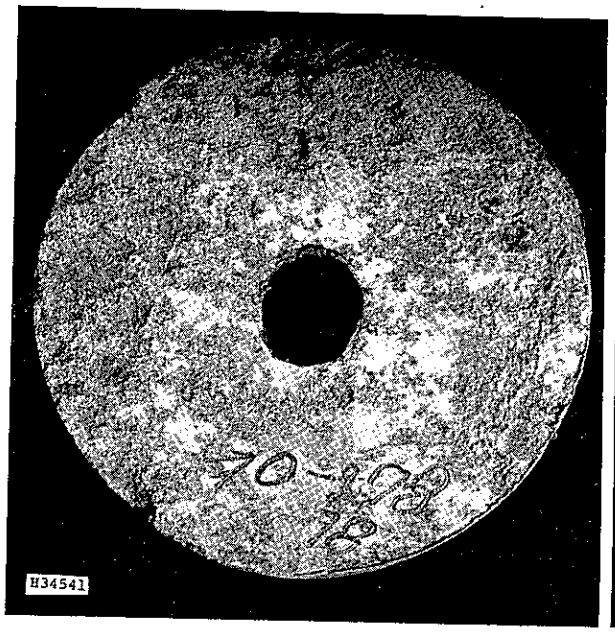
Water Side: Attack of cladding layer

Note: Sample 67-180 was mis-identified as #70-180.

ClibPDF - www.fastio.com

Honch (8:00)

1-Foot From Outlet End



Water Side

Soil Side

1.75X, Cleaned (CrO_3/H_3PO_4)

Soil Side Up, 5X (Etch HF/H_2SO_4)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-178

San Diego Co., Chula Vista, 2nd Street at Chula Vista St.

Alclad 3004, 18" diam., 14 ga., installed 1962

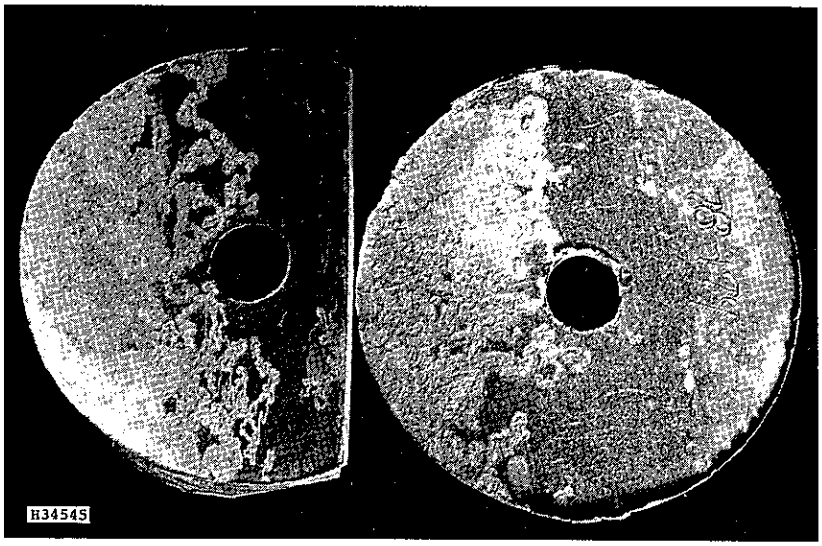
Soil: No soil; concrete headwall behind culvert where coupon was removed.

Soil Side: Attack limited to cladding layer, 0.0038-inch

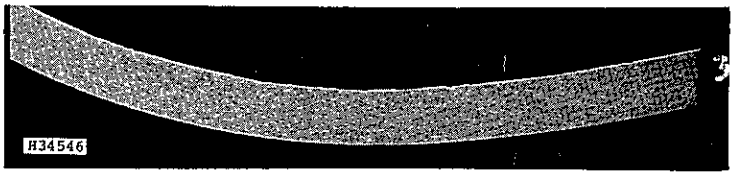
Water Side: Deep pitting to 0.053-inch. (Soil and debris lying in water side)

ClibPDF - www.fastio.com

Crown Lap (Interface)



Lap Interface
1.75X, Cleaned (CrO_3/H_3PO_4)



5X (Etch HF/H_2SO_4)
Lap Interface Up (Water Side Down)

KAISER/CALTRANS INSPECTION OF RIVETED ALUMINUM CULVERT - 1978

SITE #67-179 San Diego Co., Chula Vista, Second Street and C Street

Alclad 3004, 15" diam., 14 ga., installed 1962
Soil: pH 8.6, R_{min} - 2,500 ohm-cm

Lap Interface: Attack limited to the cladding layer, 0.0038 inch

Water Side: No attack on water side (thin cladding on 3004 core alloy).

ClibPDF - www.fastio.com

ClibPDF - www.fastio.com