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PERFORMANCE OF CULVERT MATERIALS IN VARIOUS COLORADO ENVIRONMENTS

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16. Abstract

This report describes various soil and water environments in Colorado in which culvert pipe materials have been placed. The performance of these pipe materials has been observed, recorded and reported. Results of laboratory tests on culvert materials are also reported. Some conclusions and recommendations are made for implementation and future evaluations.

Culvert materials listed from the most susceptible to corrosion are standard galvanized, stainless steel, concrete Type II and asbestos bonded asphalt dipped. Those materials showing little or negligible corrosion are transite, plastic, aluminum and concrete Type V. Concrete made with Type V cement is the most resistant of the concrete materials to alkali conditions.

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INTRODUCTION

This report addresses extreme corrosive environments which may be found at various isolated sites in Colorado. Corrugated metal and Type II concrete pipes are considered quite adequate for normal installations whereas the special culvert materials discussed here should be considered at isolated sites.

Colorado's culvert research program started in 1962 by comparing the performance of different types of culverts in various environments.

A report entitled REPORT ON EXPERIMENTAL PROJECT ALUMINUM CULVERTS March 1965 was published and covers installation and experiences on aluminum culvert installations in three different Colorado environments. Another report published in August of 1968 CULVERT PERFORMANCE AT TEST SITES IN COLORADO describes five types of culverts in different Colorado environments for a six year period.

In recent years interest in culvert materials and environments has fluctuated considerably. Renewed interest was generated when in 1972, a Corrugated Metal Pipe near Straight Creek failed after only a few years. Soil and water analysis at this site showed pH of 2.25 and 3.0 respectively. This highway had not yet been paved or opened to traffic at the time of failure. The corroded and collapsing CMP was replaced by a Type II cement concrete culvert.

This acidic soil and water is very unusual in Colorado. Historically the major problem areas causing culvert corrosion in Colorado are soils and water which are alkaline and/or carry high salt contents. These conditions are found quite extensively throughout Colorado and the Western United States. In Colorado most soils below 7,000 feet (2,134 m) in elevation are alkaline to some extent. This elevation generally delineates climate and runoff characteristics. The lower elevations are generally semiarid to arid and low gradients are encountered. Another factor which contributes to the formation of high alkaline soils and water is the geology. Generally marine sediments containing high concentrations of chlorides and sulfates (shales, silts, mudstones) are the origin of alkaline soils and waters. Water from local precipitation or from springs dissolves the salts from the rock or soil and carries them to the surface where precipitation of the salts takes place due to rapid evaporation of water into the dry air. Field test sites were established under these conditions.

In the spring of 1976 some laboratory experiments were begun with small samples of various culvert materials placed in soils and waters of various chloride and sulfate concentrations. This series of tests was initiated to confirm the validity of criteria established in 1975 currently being used in design specifications.

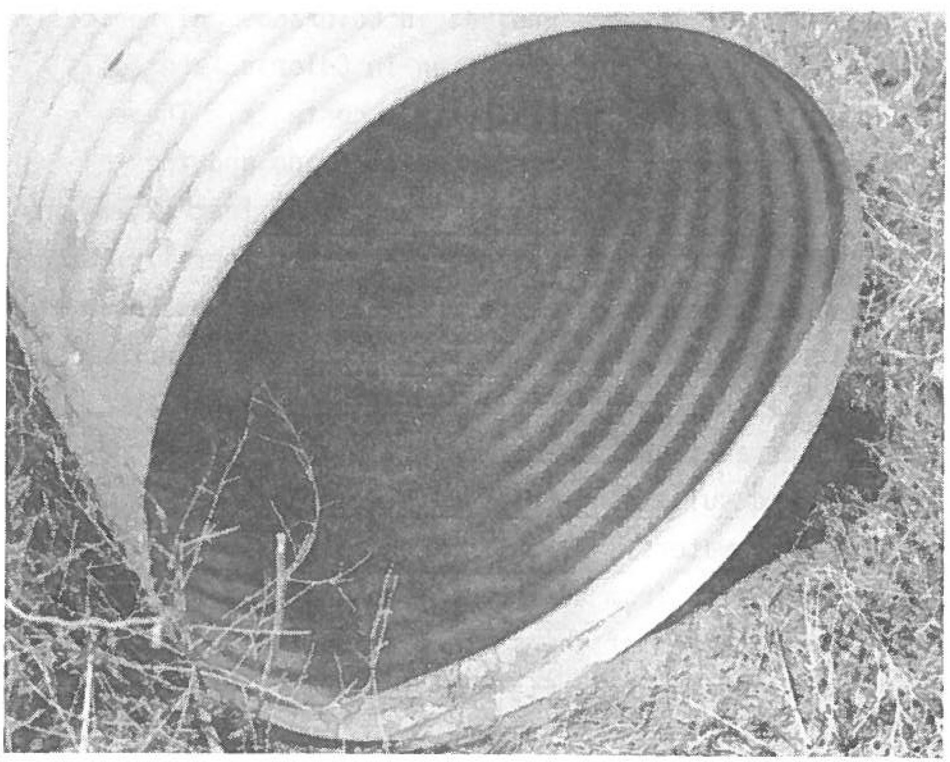
TEST SITES

Figure 1 shows the location of culvert test sites in Colorado.

Site 1 - Thirteen miles (21 km) south of Punkin Center on State Highway 71. The environment at this location is in clay soil derived from Pierre Shale in a semiarid part of eastern Colorado. A typical analysis of the soil is:

Loss on ignition	4.76%
Insoluble residue	87.22%
Iron and Aluminum Oxides	5.40%
Calcium Oxide	1.61%
Magnesium Oxide	0.79%
Sulfates as SO_4	3.5%
Alkali as SO_4 (water soluble)	0.8%
pH	8.1

Intermittent flow in this stream



Photograph No. 1

This aluminum pipe at Punkin Center is as good today as it was when it was installed in 1962.

Site 2 - On State Highway 96, 6.85 (11 km) west of junction of State Highway 165 west of Wetmore. In the spring of 1962, an aluminum culvert was placed 6 feet from a standard corrugated galvanized steel culvert for comparison of performance. The pH of the disintegrated Pikes Peak granite type of backfill averages 6.4. Stream flow is intermittent.

Site 3 - On State Highway 56 east of Berthoud and approximately 0.7 mile (1 km) west of I 25 is a 36" aluminum culvert. Approximately 0.6 mile (1 km) west of this culvert is an aluminum culvert. Both culverts were placed in 1962 with an A-6(7) type soil for backfill. The soil pH is 7.0 and the water pH is 7.4.

Site 4 - Between U. S. 50 and the east right-of-way fence approximately 1 mile(1.6 km) north of Whitewater. A single aluminum culvert was placed in a very damp alkaline soil in 1962. The pH ranges between 7.4 and 7.9.

Site 5 - At Fossil Creek between the roadway and the west right-of-way fence on Interstate 25 approximately 0.75 mile (1.2 km) north of the Windsor Interchange (SH 392). The running water has a pH of 7.4, a sulfate content of 1160 ppm and a bicarbonate alkalinity of 533 ppm. The soil has a pH of 9.2 and has a high calcium carbonate and magnesium sulfate content.

Site 6 - Along U. S. Highway 6, at the east edge of Fruita near Grand Junction. Culverts have been placed between the roadway and the north right-of-way fence in a very alkaline area. Approximately one-third of the time, the culverts are under water. Some culverts were placed in 1964. The pH of the soil ranges from 8.2 to 8.4 (see Photograph No. 3 below).

Photograph No. 3

General view of the Fruita site with pipe samples.

Note alkali on the surface.

Site 7 - Along U. S. 50 between Delta and Montrose 2.8 miles (4.5 km) south of Olathe in the east borrow ditch. There is water in this ditch all the time and both the water and soils are very alkaline.

Site 8 - Straight Creek - along the north borrow ditch of Interstate 70 about 0.6 mile (2 km) east of the Dillon Interchange. Slow percolating ground water emerges from the adjacent coal and shale members of the Dakota formation rock cut. Precipitates of sulfur on the exposed rock indicate abundance of sulfates. The pH of water varies from 1.0 off the wall to 3.0 and 6.0 in the ditch near the culvert inlet. (See Photograph No. 4 below.)

Photograph No. 4

General view of pipe samples at Straight Creek.

The concrete end section to the cross culvert under the highway is at the lower center

Location of Culvert Test Sites

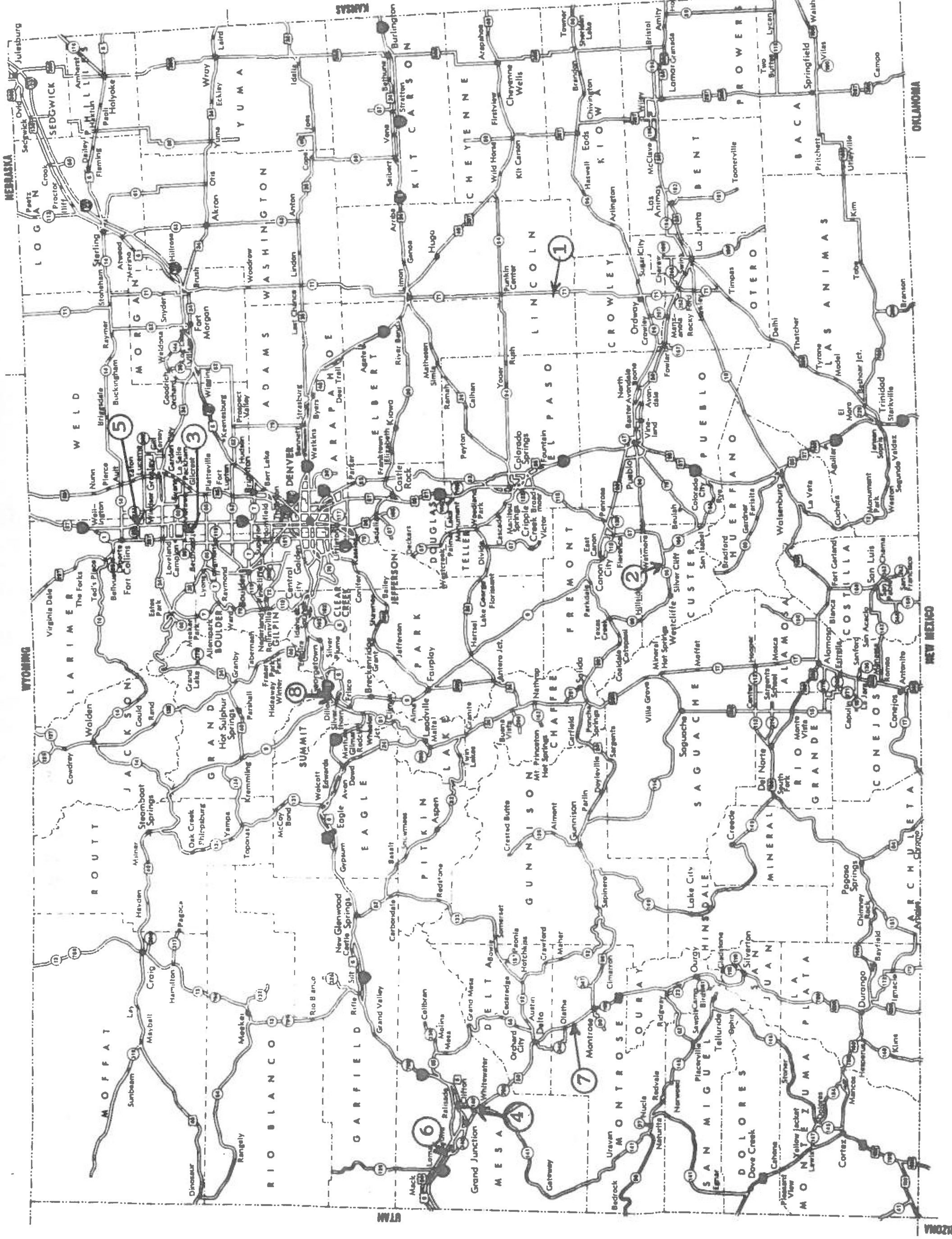


Figure 1

PERFORMANCE OF CULVERT MATERIALS

Aluminum

Aluminum culverts have been installed at all sites except Number 7 near Olathe. All of these have been reported on in previous reports except the installation at Straight Creek. After five years in the acidic environment at Straight Creek, aluminum pipes show some corrosion of the cladding in the areas submerged in the water or in contact with the soil. Each attacked area is covered with a hard mud-like crust build-up which is very similar to corrosion of aluminum culverts in alkaline environments.

Aluminum culvert materials have been installed in various test locations for may years. Following is a summary:

Installation	Date	Test for Resistance to . .	
Westcliffe	1962	Scour and Abrasion	No noticeable effect
Punkin Center	1962	Slight Alkali Pierre Shale	No visible corrosion
Fruita	1962	Heavy Alkali Mancos Shale	Considerable attack on cladding-no perforations
Whitewater	1962	Heavy Alkali Mancos Shale	Considerable attack on cladding-no perforations
Berthoud	1962	Mild Conditions	No attack
Fossil Creek	1966	Alkaline Swamp Condition	Considerable attack on cladding-no performations
Straight Creek	1972	Acid Condition	Slight attack on cladding-no perforations

As a result of these long term installations, the following conclusions are submitted:

1) Aluminum culvert has better corrosion resistance than galvanized culvert material as long as their exposure is within the limits suggested by the manufacturers.
2) The cladding seems to prevent perforation type corrosion and limits the attack to the cladding, which is about 10% of the cross sections area of 16 gage sheeting. (Photograph No. 5, on the following page, is a good example of this.)

Photograph No. 5

This is an aluminum sample at Fruita.

It has been in place since 1962. There has been attack and encrustation of the cladding but the base aluminum is still sound

3) It requires more careful handling during transportation and installation, since it is softer and not as stiff or "springy" as galvanized steel.

Colorado specifications allow the use of aluminum culvert and structural plate pipe when some other specific culvert material is not specified and therefore, no action is required. Field testing of aluminum culvert is therefore concluded.

Contractors have been hesitant to use aluminum for fear of damage in transit or installation. It is suggested that aluminum culverts could be used where light equipment is required such as rest areas and bike paths.

Stainless Steel

Samples of stainless steel culverts have been placed at Sites 5, 6, and 8. These samples in alkaline conditions of Fruita and Fossil Creek have many holes corroded through, some as large as 6 inch (15 cm) diameter. The sample at the Straight Creek site shows no sign of attack on the stainless steel but the steel rivets are rusting.

Stainless steel should not be used in high salt or alkaline environments.

Standard Galvanized

The history of galvanized steel culverts in Colorado has generally been a record of good performance. Only in the areas where there exists extremes of high concentrations of acids, alkali and/or salts, has this type of culvert shown a limited life.

When the type of material for culvert pipe is not specified in a construction contract in Colorado, galvanized corrugated steel is selected by the low bidder in more than 90% of the contracts.

Photograph No. 6

This was a galvanized steel pipe sample at Fruita.

This sample has been in this environment for 14 years. A white clot inside the pipe shows the holes eroded away. The rest of the pipe is very thin and fragil

Samples of galvanized metal pipes have been placed at test Sites 5, 6, and 8. The samples in the alkaline environment are badly corroded with many holes rusted clear through. (See Photograph No. 6 above.) The galvanizing has been heavily attacked in large patches about 2 inches (5 cm) in diameter on the Straight Creek sample. Where the galvanizing is gone, the base metal is heavily pitted. No rust color is apparent, however, and attack areas seem to be limited to a few local areas that were underwater.

The original corrugated metal culvert installed under the roadway at the Straight Creek site was replaced after only six years because of excessive corrosion.

Galvanized metal should not be used in these extreme environments.

Asbestos Bonded and Asphalt Dipped Metal Pipes

Asbestos bonded and/or asphalt dipped pipes seem to be slightly more resistant to corrosion than the bare metal but the protection is only good as long as the coating material is intact. The coating can be damaged during transportation and installation. Mechanical abrasion and thermal cracking as well as loss of ductility because of oxidation and age are responsible for the ineffectiveness of the protective coating after a few years.

A sample of asbestos bonded pipe at Straight Creek has spots where the asphalt has become brittle and broken off exposing the asbestos bonding. A sample of asphalt dipped pipe also at the Straight Creek site shows cracking and checking of the asphalt where it is exposed to the sun and water. (See Photographs No. 7 and 8.)

Photograph No. 7

This asbestos bonded asphalt dipped cross culvert at Fossil Creek has been in place since 1963.

The exterior is cracked and being eroded away.

Photograph No. 8

This is the inside of the same asbestos bonded asphalt dipped pipe as shown in Photograph No.

Note: The asphalt and asbestos are gone below the high water line.

The metal bottom is corroded through in many places.

An asbestos bonded asphalt dipped metal pipe installed in 1963 during construction at Fossil Creek is corroded through and eaten away. All of the coating above the water line is checked and cracked exposing the metal which is rusting. The asphalt coating and asbestos has been removed near and below the water line. During an inspection in the spring of 1976 one man tried to walk through the pipe and fell through twice.

Photograph No. 9

This asphalt dipped sample at Fossil Creek was rolled up for the photograph to show that the asphalt belo the water line is gone. T asphalt above the water li is cracked and being erode off.

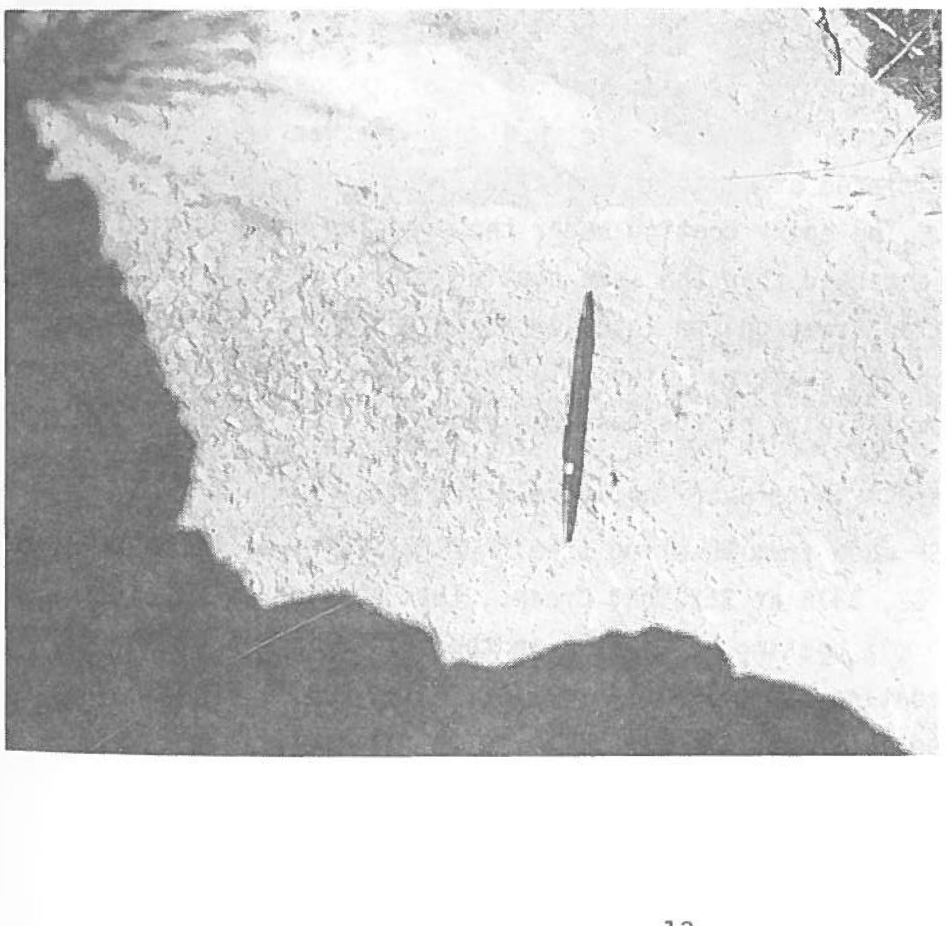
Asphalt and asbestos coatings seem to provide only temporary protection in these harsh conditions.

<u>Concrete</u>

Concrete sections made of Type II cement, Type II low alkali, Type II low C_3A and Type V cements were placed at the Fruita and the Olathe sites in 1974 and 1975. Samples made with Type II and Type V cement were placed at Fossil Creek in 1966. All of the above concrete samples are sound and in good condition.

Sections of concrete pipe, one made with regular aggregate and one with limestone aggregate have been exposed to the acidic conditions of the Straight Creek site for five years. The inlet end of the reinforced concrete pipe-Class III made from Type II cement which replaced the corroded metal pipe under the highway in 1970 is included in the group of test specimens at Straight Creek.

The areas exposed to the water show definite attack by the acid water. Attack has only removed the cement surface, exposing the aggregate. (See Photograph No. 10.)



Photograph No. 10

This is the bottom of the inlet end section of the concrete cross culvert at Straight Creek. This pipe was placed in 1970.

The top .2" (5 mm) of concrete mortar has been etched leaving silicate aggregate exposed.

The attack is not very serious and the pipe under the highway is expected to remain in service for at least another twenty years. The limestone aggregate in the sample listed above has also been attacked.

Nexon Coated Metal

Samples of Nexon coated pipes were placed at the Fruita and Olathe sites in 1974. At the lock seams, the Nexon coating had been cut through by the seam forming rolls during fabrication. These seams were not repaired. Those places in contact with the soil show heavy attack. There is also a separation of the Nexon coating from the galvanized steel sheet at the edges on the end of the pipe, with rust showing between the two layers. This does not extend into the sheet very far, however. The coating is in good condition wherever it is not damaged.

Another sample at Fruita was Nexon coated inside, epoxy coated outside, then wrapped with polyvinyl plastic sheet. Where moisture was trapped under the sheet, the epoxy coating has rusted more than where the pipe was not covered. The Nexon interior is in good condition except where small damage had occurred during fabrication and installation.

Samples of Nexon coated interior and the exterior coated with yellow epoxy, one wrapped in clear plastic sheet and another without the plastic, were placed at Straight Creek in 1972. The plastic sheeting did not help. The epoxy coating under the wrapping seemed to be more heavily attacked than the same coating not so wrapped. There was no attack apparent on the interior Nexon coating although it was stained in the submerged area. There was some separation of the sheet from the pipe at the upstream edge.

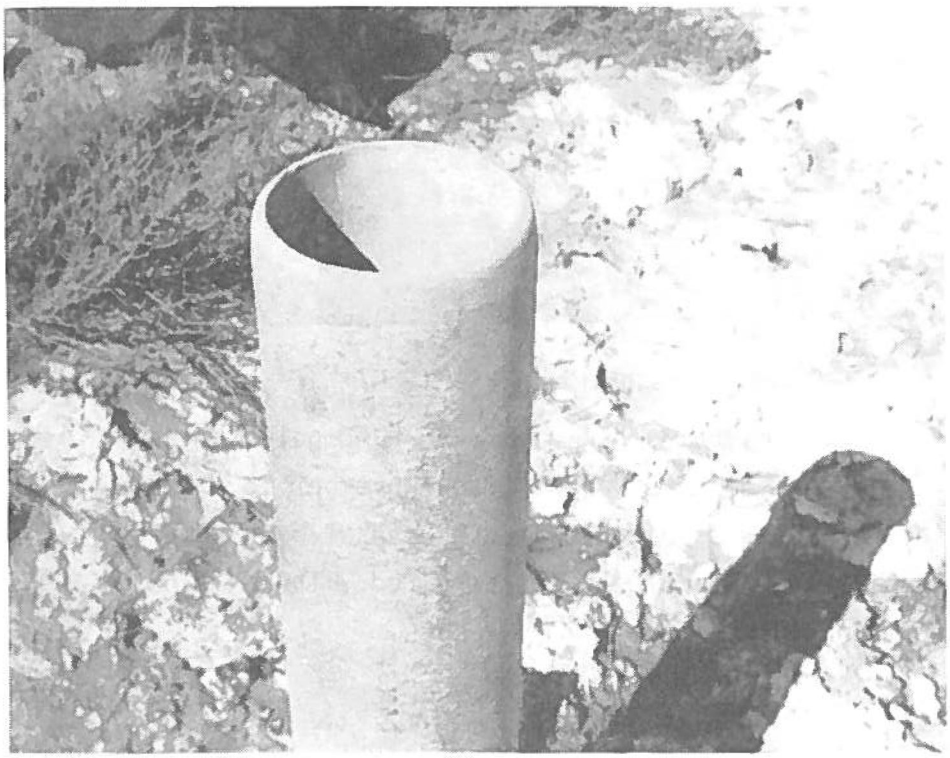
Plasticote

A piece of CSP made from Wheeling Steel's PLASTICOTE was installed on September 22, 1976 at Straight Creek. This section of spiral pipe has a 10 mil coating of plastic on the outside and a green epoxy paint coating 0.3 mils thick on the inside. Similar samples were installed at Fruita and Olathe in May of 1976.

These pipes are all in good condition to date but more time is needed to evaluate their performance.

Transite Pipe

Samples of transite pipe were placed at Fruita and Straight Creek in 1972. They are both in very good condition and show no evidence of corrosion. (See Photograph No. 11.)

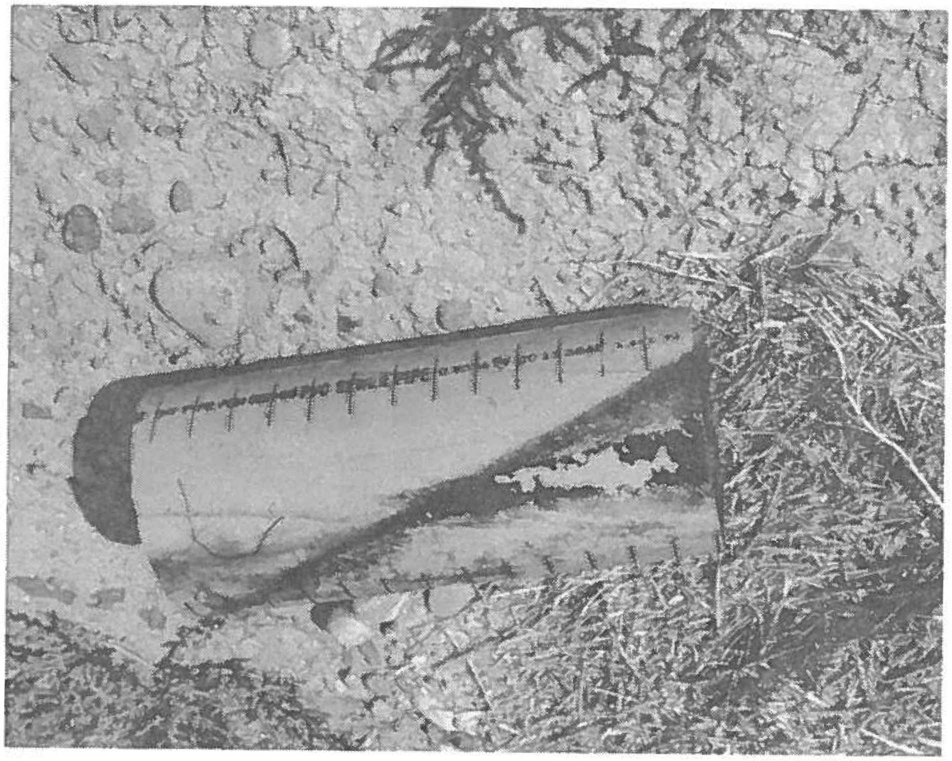


Photograph No. 11

This transite pipe at Fruita since 1972 is unharmed by the harsh environment

Plastic Drain Pipe

Pieces of plastic pipe were placed at Straight Creek in 1972 and at Olathe in 1975. The sample at Straight Creek was missing after the second year but showed no corrosion until then. The one at Olathe is in excellent condition. (See Photograph No. 12.)



Photograph No. 12

Plastic drain pipes appear unaffected by harsh environments.

The stains are only on the surface.

BLAC-KLAD

A piece of 16 gage helical steel pipe BLAC-KLAD polyethylene precoated was installed at Straight Creek November 16, 1973. There were a few ruptures of the cladding caused by handling prior to installation which were not repaired. There is no sign of attack on this pipe.

LABORATORY TESTING

On March 4, 1976, a program designed to investigate various culvert materials was started. Forty-nine sets of samples were prepared for the project. Twenty-four were used for metal materials and the balance for concretes. About one half of each type were exposed to either soil or water environments, with various concentrations of Chloride or Sulfate salts.

The investigation had several objectives, as follows:

1. Development of a 'rapid' laboratory method for evaluating relative effectiveness of culvert materials.
2. Evaluation of several culvert materials and special protective measures which are in use, or proposed, to extend the life of culverts.

3. Verification of the limits established by the Culvert Committee which are used to determine the level of protection required for structures and culverts on Colorado projects.

Materials considered were divided into two types; 1) Metal and 2) Concrete. Metals investigated include clad and unclad Aluminum, galvanized steel both plain and with various types of special coatings. Concrete samples included samples made using each of four types of cement available in this area. Each of the samples used in the evaluation measured about two by six inches.

Metal Specimens Tested

1) Aluminum; Clad on both sides, clad one side only
2) Galvanized steel, 2 oz. Zinc.
3) Two oz. galvanized steel with one of the following treatments:
    a) U. S. Steel NEXON coating one side, epoxy paint one side
    b) U. S. Steel NEXON coating both sides
    c) Wheeling Corrugating PLASTICOTE one side, epoxy one side
    d) Inland Steel BLAC-CLAD coating both sides
    e) Asphalt Dipped
    f) Asbestos Bonded Asphalt Dipped
4) Kenitex Corp. Kinkote plastic coating, one sample each on steel and Aluminum. (Table I, W-10; Table II, S-11)

Concrete Specimens Tested

1) Type I cement
2) Type II cement
3) Type II, Low C_3A cement
4) Type V cement

Environments and Salt Concentrations

Distilled water and soil free of Sulfate and Chloride, passing a no. 4 sieve were utilized for test environments for each type of specimens.

Magneisum Sulfate and Sodium Chloride were the salts used to prepare each of the test samples, as follows:

Metal/Water: None, 250 ppm Cl; 500ppm Cl; 1000ppm Cl; 1000ppm SO_4; 2000ppm SO_4; 4000ppm SO_4; 250ppm, Cl, 150ppm SO_4; 500ppm Cl, 1000ppm SO_4; 1000ppm Cl, 2000ppm SO_4; 2000ppm Cl, 4000ppm SO_4. (Table I)

Metal/Soil: None; 0.20% Cl; 1.0% Cl; 2.0% Cl; 3.0% Cl; 0.2% SO_4; 0.5% SO_4; 1.0% SO_4; 2.0% SO_4; 0.1% Cl; 0.1% SO_4; 1.0% Cl, 0.5% SO_4; 2.05% Cl; 1.0% SO_4. (Table II)

Concrete/Water: Same salt concentrations as Metal/Water. (Table III)

Concrete/Soil: Same salt concentrations as Metal/Soil, with additional sample of 3.0% Cl, 2.0% SO_4. (Table IV)

Soil samples were prepared at approximately 10% moisture.

Evaluation

Selective evaluations were made on the samples at one and three months exposure. Detailed evaluations were made at six months and eighteen months. To simplify the evaluation process, a numerical scale of 0 - 5, was selected to describe observed conditions. These scales, for metal and concrete types are:

Metal:
- 5 - No visible corrosion
- 4 - Light salt deposit or rusting at edges and/or staining
- 3 - Mild salt deposit or rusting, blistering near edges
- 2 - Extensive rusting and formation of blisters
- 1 - Severe corrosion or rusting
- 0 - Very severe rusting or loss of adhesion of protective coating.

Concrete:
- 5 - No apparent change except slight staining
- 4 - Light pitting and/or salt deposits
- 3 - Moderate loss of surface mortar and salt accumulation
- 2 - Moderate loss of aggregate
- 1 - Extensive aggregate loss, swelling and/or warping of coupon
- 0 - Total failure of coupon

Generally, except for the Aluminum coupons, Chlorides have a more detrimental effect on metal coupons than Sulfates. The opposite effect seems to be true with concrete coupons. Numerical ratings for six month and eighteen month ratings may be found in Table I - IV. Deviations in rating values may be in part equated to changes in salt deposits at different rating periods and experience developed in evaluation, which is vital in a test such as this.

Ratings of Individual Materials

Aluminum

These samples performed very well. Clad specimens generated somewhat low ratings because of the loss of cladding material. Base metal showed very little attack. The cladding is provided as a sacrificial protection similar to galvanizing on steel, therefore this rating is not considered to be serious.

Galvanized Steel

This material exhibited poor resistance to Chloride attack. Sulfates and combinations of Sulfate and Chloride, except at quite high concentrations, seem to have only minimal effect on it.

Nexon

Coupons prepared using this material performed quite well except for those exposed to combinations of salts in water. Some loss of adhesion and blistering was evident however. The epoxy coating did not fare well, especially in environments where Chloride was present. The epoxy coating is not intended to provide protection. It is strictly decorative.

Plasticote

Samples of this material used in this series of tests did not perform well. Information received from the manufacturer indicated the material tested was not representative of production.

Asphalt Dipped Galvanized Steel

This treatment seems to be very effective except at very high salt concentrations.

BLAC-KLAD

This material did not perform well in any samples where the Chloride content was above 500 ppm. It does seem to be quite satisfactory for resistance to attack from alkali alone.

Asbestos Bonded Asphalt Coated

This type of treatment also appears to be very effective except at high salt concentrations.

Kinkote

Both the Aluminum and Iron specimens performed well.

Type I Cement

These samples are quite resistant to Chlorides, but break down rapidly at Sulfate concentrations over 0.2%.

Type II Cement

The same comment applies to these samples, except that the Sulfate failure level seems to be above 1.0%.

Type II, Low C_3A Cement

The performance of this material is only slightly better than Type II cement.

Type V Cement

Though specimens made using this type of cement suffered somewhat from Sulfate attack, they were the most resistant to alkali conditions.

LABORATORY TEST RESULTS

TABLE I

Sample Set		W-1		W-2		W-3		W-4		W-5		W-6		W-7		W-8		W-9		W-10		W-11		W-12	
Salt Conc.		None		250ppm CL		500ppm CL		1000ppm C1		150ppm SO_4		1000ppm SO_4		2000ppm SO_4		4000ppm SO_4		250ppm C1 150ppm SO_4		500 ppm C1 1000ppm SO_4		2000ppm C1 4000ppm SO_4		1000ppm C1 2000ppm SO_4	
Evaluation Period		6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo
Galvanized Steel	1	4	3	4	2	4	3	3	1	3	3	4	4	4	4	4	4	4	3	4	3	4	3	4	3
	2	4	3	4	2	4	1	3	2	3	3	4	4	4	4	4	4	4	3	4	3	4	3	4	3
Clad Aluminum	1	4	3	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3
(both Sides)	2	4	3	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3
Aluminum	1	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	2	5	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3	4	4	4	4	4	4	4	4
Nexon/Epoxy	1	4	3	4	4		4	4	4	4	4	3	3	4	4	4	4	4	4	4	3	4	2	4	3
	2	4	3	4	3	3	3	3	2	3	2	3	3	4	3	4	3	4	4	4	3	4	2	4	3
Nexon-2 sides	1	4	3	4	3	4	3	3	3	4	4	4	4	4	4	4	4	4	4	4	1	4	1	3	2
	2	4	3	4	2	4	3	3	3	4	4	4	4	4	4	4	4	4	3	4	3	4	2	3	2
Plasticote/Epoxy	1	4	3	4	2	3	2	3	2	3	4	4	4	4	4	4	4	4	2	3	2	3	0	3	0
	2	4	3	4	2	3	2	3	2	3	4	4	4	4	4	4	4	4	2	3	2	3	0	3	1
Blackclad	1	4	3	4	3	4	4	3	0	4	3	4	4	4	4	4	4	4	1	4	1	3	0	4	2
	2	4	3	4	3	3	3	2	0	4	3	4	4	4	4	4	4	4	0	4	0	3	2	4	1
Asphalt	1	5	5	4	5	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3
dipped	2	5	5	4	5	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3
Asbestos	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	1	5	1
Bonded	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	1	5	1
Kinkote Alum.	-																			5					
Steel	-																			5					

Metal Samples in Water Environments

Numerical values from 0 to 5 indicate severe corrosion to no visible corrosion respectively

LABORATORY TEST RESULTS

TABLE II

Sample Set		S-1		S-2		S-3		S-4		S-5		S-6		S-7		S-8		S-9		S-10		S-11		S-12	
Salt Conc.		None		0.2% Cl		1.0% Cl		2.0% Cl		3.0% Cl		0.2% SO_4		0.5% SO_4		1.0% SO_4		2.0% SO_4		0.1% Cl 0.1% SO_4		1.0% Cl 0.5% SO_4		2.0% Cl 1.0% SO_4	
Evaluation Period		6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo
Galvanized Steel	1	4	4	3	1	2	1	2	1	1	0	4	4	4	4	4	3	4	3	4	3	3	1	1	3
	2	4	4	4	2	3	1	2	1	2	0	4	5	4	4	4	3	4	3	4	3	3	1	1	3
Clad Aluminum (both sides)	1	4	2	3	3	3	3	3	3	3	3	4	4	4	3	4	4	4	3	4	3	3	3	2	2
	2	4	2	4	3	4	3	4	3	4	3	4	4	4	3	4	4	4	3	4	3	3	3	3	3
Aluminum	1	4	3	4	3	4	3	4	3	3	3	4	4	3	3	4	4	4	4	4	4	3	3	3	4
	2	4	4	3	3	3	3	3	3		3	3	3	3	3	4	4	4	3	3	3	3	3	3	4
Nexon/Epoxy	1	5	5	4	4	4	3	4	4	4	4	5	4	5	4	5	4	4	4	4	3	4	3	4	4
	2	5	5	4	4	3	1	2	1	2	1	4	3	4	3	4	4	4	4	4	3	3	3	2	2
Nexon-2 sides	1	5	5	4	3	3	3	3	3	3	3	5	3	5	4	4	4	4	4	4	3	3	3	3	3
	2	5	5	4	3	3	3	3	3	3	3	5	3	5	4	5	4	4	4	3	3	3	3	2	3
Plasticote/Epoxy	1	4	4	3	3	2	2	2	1	2	1	3	3	4	4	4	4	4	4	2	2	2	1	2	1
	2	4	4	3	3	2	2	2	2	2	2	3	3	4	4	4	4	4	4	2	2	2	1	2	2
Blackclad	1	5	5	4	3	3	3	3	4	2	0	4	4	5	4	4	4	4	4	3	1	3	0	2	2
	2	5	5	4	3	1	0	3	4	2	0	4	4	5	4	4	4	4	4	3	2	3	1	3	1
Asphalt Dipped	1	5	4	5	3	5	3	5	5	5	5	5	4	5	5	5	4	5	4	5	4	5	4	5	2
	2	5	4	5	3	5	3	5	5	5	5	5	4	5	5	5	4	5	4	5	4	5	4	5	2
Asbestos Bonded	1	5	4	5	3	5	3	5	5	5	5	5	5	5	5	5	4	5	4	5	1	5	4	5	4
	2	5	4	5	3	5	3	5	4	5	5	5	3	5	5	5	4	5	4	5	1	5	4	5	4
Kinkote Alum.	-																					5	5		
Kinkote Steel	-																					5	5		

Metal Samples in Soil Environments

Numerical values from 0 to 5 indicate severe corrosion to no visible corrosion respectively

LABORATORY TEST RESULTS

TABLE III

Sample Set		W-1		W-2		W-3		W-4		W-5		W-6		W-7		W-8		W-9		W-10		W-11		W-12	
Salt Conc.		None		250ppm Cl		500ppm Cl		1000ppm Cl		150ppm SO_4		1000ppm SO_4		2000ppm SO_4		4000ppm SO_4		250ppm Cl 150ppm SO_4		500ppm Cl 1000ppm SO_4		2000ppm Cl 4000ppm SO_4		1000ppm Cl 2000ppm SO_4	
Evaluation Period		6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo
Type I	1	5	5	5	5	4	4	5	4	5	5	5	4	5	1	2	0	4	4	4	3	2	2	2	3
	2	5	5	5	5	4	5	5	4	5	5	5	3	5	1	2	0	4	4	4	3	2	2	2	3
Type II	1	5	5	5	5	4	4	4	4	5	5	4	4	4	4	4	4	4	4	4	3	2	3	3	3
	2	5	5	5	5	4	5	4	4	5	5	4	4	4	4	4	4	4	4	4	3	2	3	3	3
Type II, C_3A	1	5	5	5	5	4	5	4	4	5	5	4	4	4	4	4	4	4	4	4	4	3	3	3	4
	2	5	5	5	5	4	5	4	4	5	5	4	4	4	4	4	4	4	4	4	4	3	3	3	4
Type V	1	5	5	5	5	5	5	4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4
	2	5	5	5	5	5	5	4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4

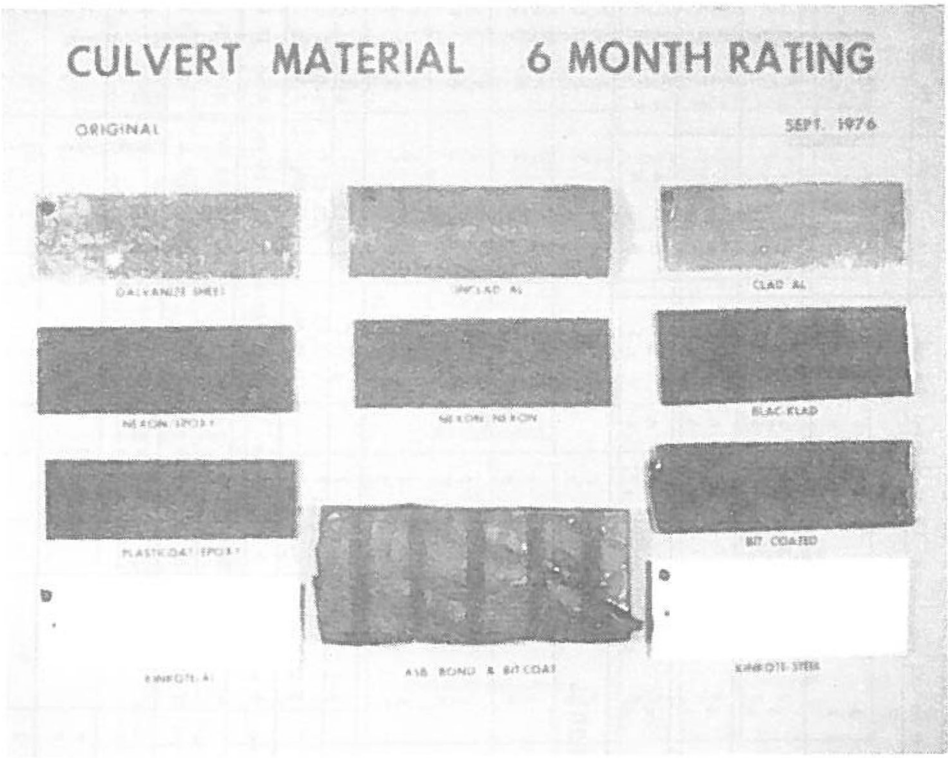
Concrete Samples in Water Environments

TABLE IV

Sample Set		S-1		S-2		S-3		S-4		S-5		S-6		S-7		S-8		S-9		S-10		S-11		S-12		S-13	
Salt Conc.		None		0.2% Cl		1.0% Cl		2.0% Cl		3.0% Cl		0.2% SO_4		0.5% SO_4		1.0% SO_4		2.0% SO_4		0.1% Cl 0.1% SO_4		1.0% Cl 0.5% SO_4		2.0% Cl 1.0% SO_4		3.0% Cl 2.0% SO_4	
Evaluation Period		6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo	6 mo	18 mo
Type I	1	5	5	5	4	4	4	3	4	3	4	3	2	2	2	2	4	1	1	4	4	4	4	2	2	1	0
	2	5	5	5	4	4	4	3	4	3	4	3	2	2	2	2	4	1	1	4	4	4	4	4	4	2	2
Type II	1	5	5	5	4	4	4	3	4	3	4	3	4	3	4	3	3	1	1	4	4	4	3	2	2	1	0
	2	5	5	5	4	4	4	3	4	3	4	3	4	3	4	3	3	1	1	4	4	4	3	2	2	1	0
Type II C_3A	1	5	5	5	4	4	4	3	4	3	4	3	4	2	4	3	2	1	1	4	3	3	3	1	2	2	1
	2	5	5	5	4	4	4	3	4	3	4	3	4	2	4	3	2	1	1	4	3	3	3	1	2	2	1
Type V	1	5	5	5	4	4	4	3	4	4	4	4	4	4	4	4	2	2	1	5	4	4	4	2	3	1	1
	2	5	5	5	4	4	4	3	4	4	4	4	4	4	4	4	3	2	1	5	4	4	4	2	3	1	1

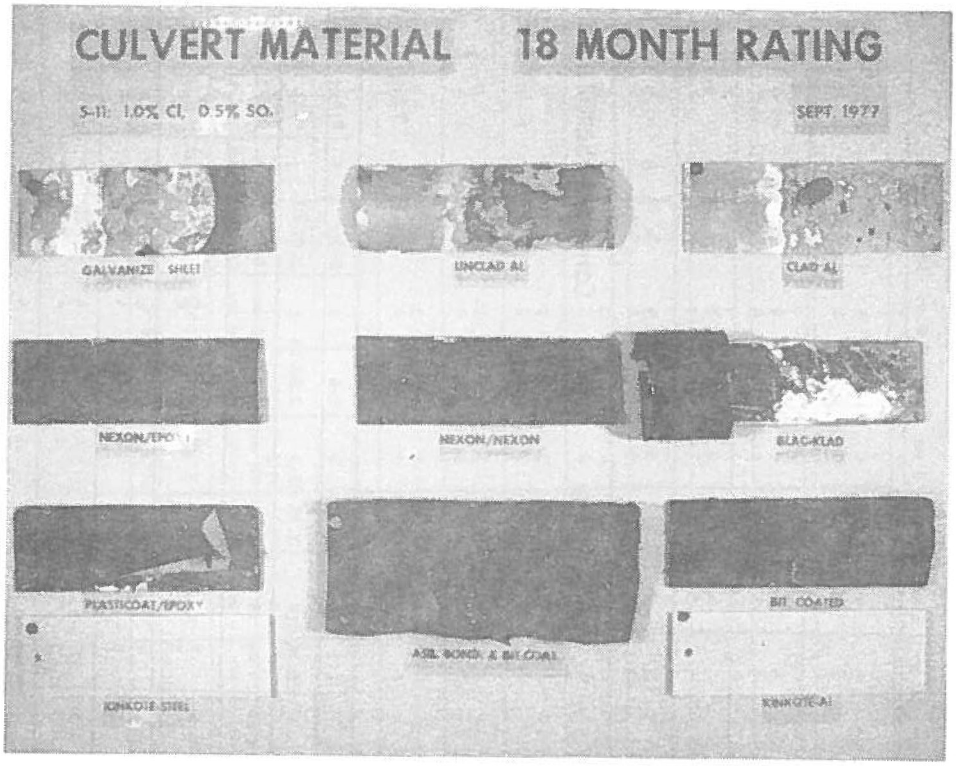
Concrete Samples in Soil Environments

Numerical values from 0 to 5 indicate severe corrosion to no visible corrosion respectively



Photograph No. 13

Original metal laboratory samples before placement into corrosive environment

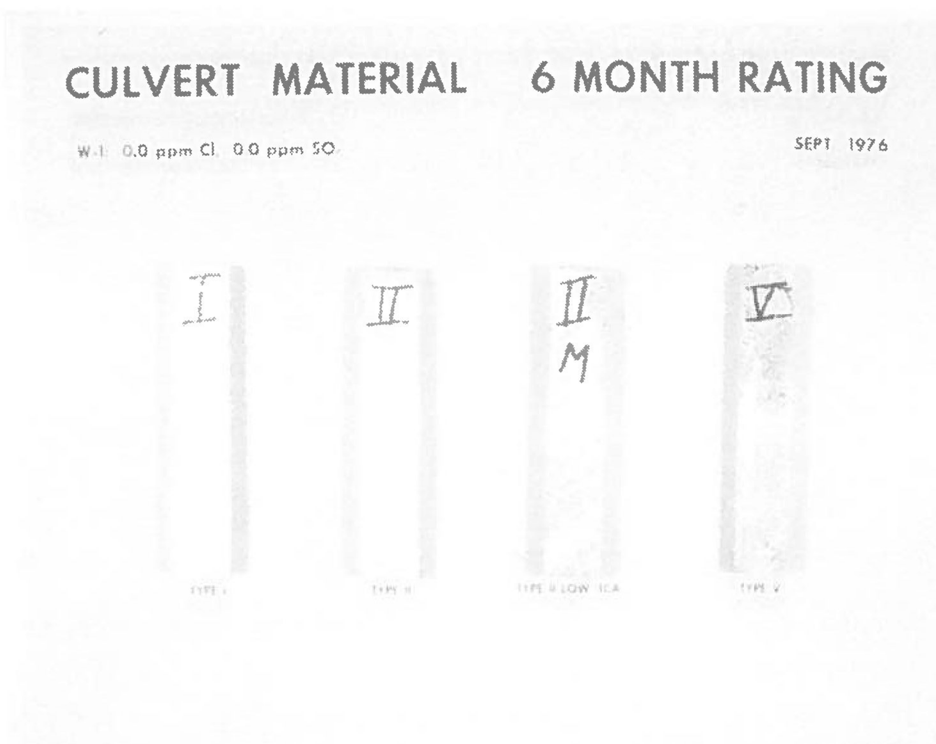


Photograph No. 14

Metal samples after 18 months in a harsh soil environment

Photograph No. 15

Metal samples after 18 months in a
harsh water environment



Photograph No. 16

Original concrete laboratory samples
No corrosion or decomposition

Photograph No. 17

Concrete samples after 18 months in a harsh water environment

Photograph No. 18

Concrete samples after 18 months in a harsh soil environment

ECONOMIC CONSIDERATIONS

A 1977 cost estimate indicates that standard galvanized, all types of concrete and aluminum are about equal in cost at $15 per lineal foot for 24 inch (61 cm) diameter pipes. The same diameter asbestos bonded asphalt dipped pipe would cost about $20 per lineal foot, and a galvanized steel asphalt dipped also would be $20 per lineal foot. The same cost estimate showed that a steel pipe of similar size with Nexon coating on one side would be an additional 20% and both sides would be an additional 30% or $18 and $19.50 respectively. Vitrified clay would cost slightly more than standard galvanized pipe. No costs are available for the other types of coatings but it is assumed that they would be similar to that of Nexon.

These costs should be considered when a corrosion resistant culvert is to be specified for a harsh environment.

CONCLUSIONS

Standard galvanized, stainless steel, concrete Type II and asbestos dipped have corroded the most in harsh field environments. These materials should not be used where high alkali and salt contents are present or where high acid water and soils are encountered.

A sample covered with Plasticote has only been in the test environment for one year and another with BLAC-KLAD for only three years. There is insufficient observation time to draw conclusions on those materials.

Transite, plastic, aluminum and concrete Type V and Type II low C_3A seem to be the most resistant to highly corrosive conditions. Concrete made with Type V cement is the most resistant of concrete materials to alkali conditions. It should be noted that all types of concrete will not be equally resistant and that the several types installed at Fruita and Olathe have been under observation for three years. More time is required to determine the most corrosion resistant type.

Results from the laboratory and field tests are not compatible in all cases bacause of fluctuating pH values and salt concentrations. Field test sights fluctuate from season to season because of the amount of water present and variable flow rates. Laboratory environments changed slightly as some salts chemically combined with culvert materials.

These salts were not replaced therefore concenteations declined slightly as materials corroded. Some other inconsistencies can be noted but are considered to be insignificant.

RECOMMENDATIONS

Concrete pipe made with Type II or Type V cement should be substituted in moderate to high alkaline or acidic environments.

The drainage ditch, at the Straight Creek site, upstream from the inlet of the concrete cross culvert, could be lined with crushed limestone and powdered lime. The seepage water flowing through and over this lime would become more nearly neutral in pH value. The life of the concrete culvert would then be substantially lengthened because of a reduced etching action of acid.

When and if it becomes necessary to replace this concrete culvert or any other culvert in an acidic environment, it is recommended that a small vitrified clay or plastic pipe be placed at a lower elevation than, or upstream of the inlet of the new culvert. The small pipe would carry the corrosive seep water and the larger standard pipe will carry diluted storm runoff water.

IMPLEMENTATION

Implementation of the results of these experiments has been and will continue to be a continuous and dynamic process. Specifications and special provisions have been implemented on the basis of field and laboratory experiences and the recommendations of the Culvert Corrosion Committee.

The recommendations in this report are for consideration by the Culvert Corrosion Committee and appropriate revisions could be made in the specifications.

Future evaluations of new materials and the few materials still in test environments will be handled in a similar manner.

FUTURE NEEDS

Plasticote and BLAC-KLAD materials should be evaluated after a few more years of exposure in their extreme test environments. Some of the types of concrete pipe also require more time to determine the most corrosion resistant. These and any other new materials should be evaluated and reported on by the Product Evaluation Procedure.

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

66-1 Final Report - Denver SE Pavement Study I 25-3(20)
66-2 Interim Reports on the Experimental Base Project At Ordway, Colorado #1
66-3 Interim Report on the Clifton-Highline Canal Experimental Project I 70-1(14)33 #1
66-4 Final Report on Statistical Research Project - Quality Control Study on Asphalt Pavement
66-5 Final Report on the Automatic "Icy Road" Sign Study
66-6 Interim Report on Crawford-South Experimental Project S 0125(9) #1
66-7 Final Report on the Strasburg E & W Pavement Study I 70-4(30)
66-8 ASCE Report on High Altitude Multiple Vehicle Emission Tests
66-9 Final Report on Photo and Engineering Geology Along Interstate Route 70 from Dotsero to Rifle, Colorado
66-10 Interim Report on the Reflective Traffic Bead Study #1
66-11 Rock Slope Stability in the Precambrian Metamorphic Rocks of the Front Range, Colorado

67-1 Interim Report on Experimental Base Project at Ordway, Colorado #2
67-2 Second Interim Report on Crawford-South Experimental Project S 0125(9)
67-3 Interim Report on Clifton-Highline Canal Experimental Project I 70-1(14)33 #2
67-4 Reflective Traffic Bead Study #2
67-5 Density-Temperature-Roller Data from Asphalt Paving Projects in Colorado
67-6 Skid Resistance in Colorado
67-7 Swelling Soils Study at Cedar Point, Colorado
67-8 Lime Shaft and Lime Till Stabilization of Subgrades on Colorado Highways
67-9 Embankment Construction Without Moisture-Density Control
67-10 Study of Preformed Open Cell Neoprene Joint Sealer
67-11 Dielectric Measurements of Asphalt Content
67-12 Revision of Colorado CHLOE Profilometer
67-13 Performance of Box Beam Guard Rail Having Vertical Post Mounted in Sand
67-14 Scaling on Concrete Bridge Decks

68-1 Rock Rippability Study
68-2 Equilibrium Moisture and Density Study of Subgrades in Colorado
68-3 Grooving of Concrete Pavement Surfaces in Colorado to Prevent Hydroplaning
68-4 A Statistical Study of Rock Slopes in Jointed Gneiss with Reference to Highway Rock Slope Design
68-5 Reflective Traffic Bead Study -Interim #3
68-6 Use of a Microwave Oven for Rapid Drying of Aggregate Samples
68-7 Means for Measuring Surface Smoothness
68-8 Culvert Performance at Test Sites in Colorado
68-9 Colorado's Reflective Bead Study
68-10 Dielectric Measurements of Asphalt Content - Final Report

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

69-1 Treatment of Swelling Soils, West of Agate, Colorado
69-2 The Whitewater Experimental Project - First Interim Report
69-3 Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
69-4 Pavement Marking Materials Tested in Colorado
69-5 Study of Preformed Open Cell Neoprene Joint Sealer for Use in Transverse Weakened Plane Sawed Joints - Final Report
69-6 Use of Microwave Oven for Rapid Drying of Aggregate Samples - Final Report
69-7 Follow Up Report, Colorado's Reflective Bead Study
69-8 Rock Rippability Study - Final Report
69-9 Ordway Experimental Project, Post Construction Field Measurements - Interim Report

70-1 State-of-the-Art - Automatic Controls on Construction Equipment
70-2 Action Program to Promote Highway Safety
70-3 Reflective Traffic Bead Study - Final Report
70-4 Asphalt Membrane Project at Elk Springs - First Interim Report
70-5 Evaluation of Colorado's Flexible Pavement Base Design Methods - Final Report
70-6 The Effect of Vibration on the Durability of Concrete Pavement - First Interim Report
70-7 Crawford - South Experimental Project S 0125(9) - Third Interim Report
70-8 The Whitewater Experimental Project: An Instrumented Roadway Test Section to Study Hydrogenesis - Final Report
70-9 Clifton-Highline Canal Experimental Project - Third Interim Report

71-1 The Effect of Good Vibration on the Durability of Concrete Pavement #2
71-2 Effect of Vibration on Durability of Concrete
71-3 Lighted Deer Crossing Signs and Vehicular Speed

72-1 Reflection Cracking in Bituminous Overlays - Interim Report
72-2 Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
72-3 Skid Testing in Colorado
72-4 Development of Dwarf Ground Cover for Erosion Control in Colorado
72-5 Corrugated Metal Arch Barrier, Phase 1, Scale Model Study
72-6 Styrofoam Highway Insulation on Colorado Mountain Passes
72-7 Colorado Tunnel Ventilation Study - Interim Report
72-8 Effectiveness of Absorptive Form Liner for Horizontal Surfaces
72-9 Partially Beaded Centerline Markings
72-10 Field Study of Erosion Control Agents in Colorado
72-11 Soil Modification Highway Projects in Colorado
72-12 Calibration of Colorado's Texturemeter - Final Report
72-13 Air Pollution at High Altitude Construction Sites

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

73-1 Thermoplastics - Performance in Denver
73-2 The Ordway Colorado Experimental Base Project
73-3 Noise Levels Associated with Plant Mix Seals
73-4 Accelerated Concrete Strength Study
73-5 Colorado Tunnel Ventilation Study
73-6 Clifton-Highline Canal Experimental Report
73-7 Seibert Experimental Project

74-1 Implementation Package for Swelling Soils in Colorado
74-2 Embankments With and Without Moisture Density Control

75-1 Erosion Control and Revegetation on Vail Pass
75-2 The Effects of Vibration on Durability of Concrete Pavement
75-3 Infrared Heating to Prevent Preferential Icing on Concrete Box Girder Bridges
75-4 Asphalt Membrane Project at Elk Springs, Colorado
75-5 Treatment of Swelling Soils - West of Agate, Colorado, Project I 70-4(48)347

76-1 Examination of Noise Prediction Methods
76-2 Bridge Deck Deterioration in Colorado
76-3 Absorptive Form Liner and Burlap and Cement and Sand to Assist Bridge Deck Cure
76-4 Low Profile Markers for Wet/Night Visibility
76-5 Erosion Control and Revegetation on Vail Pass
76-6 Reflection Cracking in Bituminous Overlays
76-7 Skid Number-Speed Gradient in Colorado
76-8 The Use of Filter Cloth to Prevent Clogging of Underdrains

77-1 Performance of a Multiplate Steel Arch Near Penrose
77-2 Crawford-South - Colorado's First Full Length Lime Stabilization Project
77-3 Performance of Special Curing Agents and Water Reducing Agents on Concrete Pavements in Colorado
77-4 Nuclear Testing for Density Control of Concrete Pavement
77-5 Highway Lighting to Prevent Deer-Auto Accidents
77-6 Rate of Deterioriation in Concrete Bridge Decks in Colorado