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A Survey of the Condition of the Corrugated Metal Culverts in District 1

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16. ABSTRACT
In January 1952 the Materials and Research Department was assigned the problem of investigating and evaluating the condition of corrugated metal culverts in District I. Specifically, the scope and aims of the study may be subdivided as follows: (1) determining whether or not certain environmental conditions tend to accelerate corrosion of metal culvert pipes, (2) preparing a map of District I to indicate the areas or sections of highways where the average corrosion of culverts is marked, moderate or minor, (3) developing practical means to determine potentially corrosive areas as a guide for new construction in any area, and (4) recommending steps to repair or prevent failure in deteriorated installations.

Due to the scope of this assignment, it was decided to divide the study into two or more phases. The first phase covered in a report dated May 10, 1954, covered one method for repairing deteriorated culverts, namely the process of applying a mortar lining by the Centriline process on 8 culverts on Routes 48 and 56. The second phase reported herein covers the first two items, and those parts of the remaining items that are not separable from the first. Studies will be continued on other aspects of the problem and further reports prepared at a later date.

The volume of water flowing in the streams in District 1 made the field inspection during 1953 and 1954 feasible only in the summer and fall months. During this working period of 7 months, approximately 7,000 corrugated metal pipe culverts were inspected.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A SURVEY OF THE CONDITION OF THE CORRUGATED METAL CULVERTS IN DISTRICT I

55-13

MATERIALS & RESEARCH DEPARTMENT

STATE OF CALIFORNIA
Department of Public Works
DIVISION OF HIGHWAYS
Materials & Research Department

March 1, 1955

District I - General
Preliminary Engineering
WA1QT314
Lab. Order No. 6011

Mr. G. T. McCoy
State Highway Engineer
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A SURVEY OF

THE CONDITION OF THE CORRUGATED

METAL CULVERTS IN DISTRICT I.

Study made by - - - - - - - - - - - - - Structural Materials Section
Under General Direction of - - - - - - J. L. Beaton
Report Prepared by - - - - - - - - - - R. F. Stratfull

Very truly yours,

F. N. Hveem

F. N. HVEEM
Materials & Research Engineer

cc: Earl Withycombe
A. S. Hart
G. F. Hellesoe
J. C. Young

SYNOPSIS

In January 1952 the Materials and Research Department was assigned the problem of investigating and evaluating the condition of corrugated metal culverts in District I. Specifically, the scope and aims of the study may be subdivided as follows: (1) determining whether or not certain environmental conditions tend to accelerate corrosion of metal culvert pipes, (2) preparing a map of District I to indicate the areas or sections of highways where the average corrosion of culverts is marked, moderate or minor, (3) developing practical means to determine potentially corrosive areas as a guide for new construction in any area, and (4) recommending steps to repair or prevent failure in deteriorated installations.

Due to the scope of this assignment, it was decided to divide the study into two or more phases. The first phase covered in a report[1] dated May 10, 1954, covered one method for repairing deteriorated culverts, namely the process of applying a mortar lining by the Centriline process on 8 culverts on Routes 48 and 56. The second phase reported herein covers the first two items, and those parts of the remaining items that are not separable from the first. Studies will be continued on other aspects of the problem and further reports prepared at a later date.

The volume of water flowing in the streams in District I made the field inspection during 1953 and 1954 feasible only in the summer and fall months. During this working period of 7 months, approximately 7,000 corrugated metal pipe culverts were inspected.

The severity of corrosion evidenced in the various areas of District I is shown in the appendix by Exhibit I, "Equi-Percentage Corrosion Contour Map", and by Exhibit II, "Corrosion Area Map, District I". The specific condition of each corrugated metal pipe is recorded on field inspection sheets, copies of which are filed with District I and Headquarters Maintenance Department. The originals are filed with the Materials and Research Department.

Specific recommendations developed from an analysis of the data collected during this survey are included in Chapter VII of this report.

The results of this survey show that it definitely is possible to define areas as to their corrosion potentiality. The results also suggest that rapid survey methods can be developed to do this on a statewide basis.

The majority of the metal corrosion in culverts throughout District I occurred in the invert and was usually due to aggressive water. In most cases of accelerated failure of the culvert metal the culprit was the groundwater flowing on a continuous basis and emanating from organic reducing soils.

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I. INTRODUCTION

For many years Engineers in District I have been concerned about the increasing evidence of an apparently rapid rate of metal culvert deterioration due to corrosion. However, it has not been physically possible for the District to adequately maintain a progressive condition record on all metal culverts. With the information that the District was able to accumulate, they were unable to determine definitely whether or not abnormally "corrosive areas" existed. Consequently, when a culvert actually failed, expedient replacements and emergency repairs were required. These replacements and repairs were accompanied by the excessive costs associated with emergency work.

The need for a more comprehensive survey was emphasized by a report, forwarded in 1950 by the District Engineer, covering a hasty survey of all the culverts within a portion of I-HUM-1-I, J, which showed a high percentage to be in poor condition. This survey was made by the District following the completion of a construction project on HUM-1-J where it was necessary to expend $30,000 to replace one culvert that had been planned for extension. After the contract was awarded, close inspection showed that this existing pipe had collapsed and could not be used.

In an endeavor to assist the District in this problem, Mr. Earl Withycombe, Assistant State Highway Engineer, requested the Materials and Research Department to make a complete condition survey of all of the corrugated metal culverts in the District, so that the magnitude of the maintenance and replacement program could be estimated and considered, economy-wise, in the over-all highway planning program.

A preliminary survey of the culverts in District I, made by Headquarters Laboratory before starting the detailed inspection, indicated that culvert corrosion is most pronounced in the invert, and is confined primarily to the width covered by low water flow. This observation suggested that corrosive products from the soils in the watershed areas were the agents primarily responsible. It seemed pertinent, therefore, to adopt some simple type of watershed description that could be related to corrosion studies which have been undertaken by agencies such as the National Bureau of Standards, the American Gas Association, and others. From an analysis of the current research reports on corrosion, it was decided that the soil classification considerations affecting corrosion in District I would be: whether the soil was primarily organic or inorganic, and whether it had good or poor aeration.

Due to the existence of many watersheds containing organic reducing soils throughout District I, the work of Starkey and Wight[2] concerning anaerobic corrosion seemed of special significance. This work gave evidence that a soil which is non-aerated and which contains organic matter would support anaerobic bacteria. An extreme example of this soil type is swampland. The anaerobic bacteria form hydrogen sulfide. The hydrogen sulfide may be oxidized to form sulfurous and sulfuric acids, which are highly corrosive. While the scope of our survey as covered in this report is limited, there is no doubt that this factor is definitely important.

Alkalis and other minerals were not considered special overall problems in District I; however, in certain cases they were noted.

Salt air exposure has been believed to be a major contributing medium to the corrosion of metal pipes in the coastal area. The effect of such exposure is noted in this report as atmospheric attack.

The decision to identify the nature of the watersheds and the physical environment of the streams has proven to be well worthwhile, as is brought out in the body of the report.

Broadly speaking, the results of this survey show that roughly 26 percent of the watersheds drained by metal pipes in District I can be classified as producing highly corrosive waters; 37 percent moderately corrosive; and 37 percent relatively non-corrosive.

II. THEORY OF CORROSION

A. Mechanism of Corrosion.

There are many factors that affect the rate of corrosion of iron or steel in water. The corrosion of ferrous metal in substantially pure water and air can be chemically expressed as:

$$Fe + 2H^{+} \rightleftarrows Fe^{++} + 2H$$

It is common knowledge that two different metals can set up a galvanic corrosion cell. For example, when zinc and copper are immersed in an electrolyte and electrically connected they will become anode and cathode respectively. When these two metals are electrically connected through a galvanometer, a current will be measured, and the zinc will disintegrate. In other words, a battery is formed. It is also true that differences in the electrolyte, such as chemical concentration or differential aeration, will cause anodic and cathodic areas to be set up on a single piece of metal.

By partly immersing specimens of plain carbon steel and also iron in water, and using three independent methods of measurements, Evans and Hoar[3,4], measured the quantity of electric current flowing between anodic and cathodic areas, and obtained a direct correlation between the current flowing and the weight of metal dissolved. Others, Brown and Mears[5], also Evans and Thornhill[6], obtained the same correlation between current quantity and weight of metal dissolved. The anodic and cathodic areas on the same piece of metal are caused by non-uniformities which exist in all metals.

As summarized by Speller[7], "It may now be regarded as established that in substantially all cases of corrosion in the presence of water the driving force of the corrosion reaction between metal and environment is electrochemical. The magnitude of this electrochemical potential, which varies with the environment and the metal, determines the tendency of the reaction to proceed, whereas the rate of corrosion is determined mainly by the resistance to the continued progress of the reaction set up by certain of the corrosion by-products".

B. Pertinent Factors Influencing the Rate of Corrosion.

During the course of the culvert inspection a number of observations were made concerning factors affecting the rate of corrosion. Those factors considered to be especially significant were recorded. These were: evidence of extreme water hardness, which was indicated by a calcareous deposit in the culvert invert; rust formation, which was recorded as to its particular type, i.e., tubercle, flake, powder, etc.; and the evidence of hydrogen sulfide in the watershed soil.

The influence of these significant factors on the accelerated corrosion of metal culverts is discussed in the following paragraphs:

1. Influence of Water Hardness.

Water undersaturated with calcium carbonate is likely to corrode a metal pipe, and waters saturated with calcium carbonate are in general relatively harmless.[4]

The water issuing from a chalk or limestone formation will usually, although not invariably, be in equilibrium with calcium carbonate, i.e., will be non-aggressive.

With very soft waters, rain water and some mineral spring water, the attack on a metal pipe is likely to continue indefinitely.

In areas of heavy rainfall, with a quick runoff over saturated ground containing calcium, the likelihood of the water becoming saturated with calcium is small. However, if the rate of runoff is slow enough, the water will become saturated with calcium and tend to deposit a calcareous layer in the culvert. Conversely, if the runoff is quick, any removal of a calcareous deposit in the culvert will depend on the relative frequency of water undersaturated and oversaturated with calcium.

The majority of waters used for public supply purposes contain a considerable amount of calcium carbonate, which is kept in solution as calcium bi-carbonate by the presence of carbon dioxide. If the excess of carbon dioxide present is just sufficient to keep the calcium carbonate in solution, any incipient corrosion will produce a rise in the pH value at the cathodic regions and will consequently lead to the precipitation of calcium carbonate. This will divert the cathodic reaction elsewhere, so that after a time the whole interior surface of the pipe will have become covered with a layer of calcium carbonate.

In the presence of sufficient oxygen, this layer of calcium carbonate will interact with iron salts forming under its surface a clinging form of ferric oxide rust. For many waters, this layer will be more protective when oxygen is present in large quantities, because the rust will then be formed very close to the metal.

2. Influence of Rust.

In natural waters, the precipitated rust usually carries down some compounds containing lime, magnesia and silica, together with other insoluble material from the water. These substances have considerable influence on the structure and density of the rust coating on the metal surface. A loose, non-adherent coating under ordinary conditions, may accelerate the rate of corrosion ; a uniformly dense and adherent coating may form an effective corrosion barrier and reduce the rate considerably.

3. Influence of Hydrogen Sulfide.

"Hydrogen sulfide when present in water makes the water acid and causes rapid corrosion, even in the absence of oxygen. It is mostly found in soils that contain anaerobic bacteria, in water contaminated with sewerage, or in mineral water. In the presence of oxygen, sulfuric acid may be formed as a reaction product[7]".

III. SURVEY METHODS EMPLOYED IN THIS STUDY OF CULVERT PIPES.

A. Method of Inspection.

1. Comparison of original metal lost.

In order to work with any reasonable speed in the cramped and poorly accessible spaces found in culverts, it was necessary to devise some quick, even though approximate, method of evaluating metal loss.

In estimating the relative metal loss of the culverts, the penetration or rebound of a prospector's pick striking the culvert was "transposed" in terms of percentage of original metal lost. The penetration or rebound from the blow of the pick was compared to similar metal of known thickness. Considering the inevitable variation of metal loss that exists in culverts, this method seems to give reasonably accurate indications.

2. Physical Factors.

The physical factors tabulated in the survey included: height of fill over the culvert, asphalt coating conditions, rust type, location and extent of metal deterioration, presence of ground water, etc. A more detailed explanation of the physical factors obtained and a sample culvert inspection record sheet are included as Exhibit VII in the appendix.

3. Soil Properties.

Starkey and Wight[2], in a report to the American Gas Association in 1945, determined that the corrosion rate of steel was greater in soils containing anaerobic bacteria than when the bacteria were absent.

Since the time allotted to this culvert survey of District I would not permit complete chemical and electrical tests of the soils and waters, the following definitions of soil characteristics, based on visual inspection, were used so that the information could be correlated to work by Starkey and Wight[2] and others .

a. Reducing Soils:

1. Have poor soil aeration.
2. Poor water drainage resulting in waterlogged soil.
3. Usually a black or mottled gray in appearance.
4. An odor of hydrogen sulfide (H_2S) perceived.
5. Usually have evidence of the presence of anaerobic bacteria.

b. Oxidizing soils:

1. Well drained in an agricultural sense. *

2. Usually light in color.

c. Inorganic:

1. Soil has little or no organic or vegetable matter in its composition.

d. Organic:

1. Soil has organic matter or vegetation.

It was decided after consideration of the above four definitions that the watershed soils could be described under four broad headings for the purposes of this report:

1. Organic Reducing

2. Organic Oxidizing

3. Inorganic Reducing

4. Inorganic Oxidizing

This scheme of watershed description was used in the culvert survey. Soils classified as inorganic reducing were not found in District I, which explains their absence in the charts and tables following.

4. Culvert Service Life.

The culvert corrosion rate was determined by two steps. The first was the determination of the culvert metal loss. The second was relating the culvert metal loss to years of service.

There were two steps used in determining the years of service for a particular culvert. The first step was to obtain the culvert installation date from the construction plans. The second step consisted of contacting the highway maintenance crews and obtaining the dates of culvert replacements as they were "remembered". In some cases, where no construction plans were available, the culvert installation dates were obtained from the maintenance crews, and, if possible, checked with dated bridges or culverts.

* Note: Light porous soil through which water drains rapidly.

IV. RESULTS OF SURVEY

A. Corrosion Rates.

Other factors being equal, the rate of culvert corrosion will be a function of water immersion time. However, the chemical compositions of stream or runoff waters is a variable depending upon many factors. Some of these factors include air pollution, and the solubility of the chemicals in the soils from which these waters drain.

It is an exceptional occurrence when all the culverts in adjacent watersheds have the same corrosion rate. However, it is quite likely that a reasonable percentage of culverts in adjacent watersheds will have a similar corrosion rate. The "Corrosion Area" map was prepared with this knowledge, and reflects the service life to be expected of a substantial number of 16 gage galvanized metal culverts in each of the areas indicated.

This "service life" is an expression of probability that a substantial number of culverts in the localized area will not exceed the service life indicated. Hence, the risk of costly replacement is reflected by the Corrosion Area map, but it does not necessarily mean that all culverts in a given area will have the service life shown.

On the attached "Map", the apparent rate of corrosion decreases with distance from the sea coast. Since this study did not include complete analysis of the factors affecting corrosion, the significance of this in relation to salt air or annual rainfall is not known. It was found, in the culvert survey, that the outer galvanized areas of the culverts exposed to sun and air rarely showed signs of corrosion in less than 20 years. However, this was not true if the culvert was exposed to direct sea spray or water immersion. Attached is Exhibit VI, which is a typical comparison of culvert corrosion rates on I-MEN-56-A and I-MEN-16-A. Work charts of this type were made for all the sections of the highways and used to make the corrosion area map.

B. Watershed Soils and Accelerated Corrosion.

The chemical composition of runoff waters can be altered by soluble chemicals in the soils. This factor of chemical alteration of runoff waters was recorded by observing any apparent chemical action taking place in the soil. For example: soil with an odor of hydrogen sulfide, caused by a chemical reaction, was recorded as organic reducing.

The following discussion offers evidence that the indirect action of anaerobic bacteria, or at least the presence of organic reducing soils, is one of the causes of accelerated corrosion of metal culverts.

The corrosion rate of metal culverts on Route 56 is marked, when compared to the corrosion rate of the culverts on Route 16. Therefore, the physical factors noted during the inspection of the culverts on Routes I-MEN-56 and I-MEN, LAK-16 were mathematically analyzed to determine the relationship between environment and accelerated corrosion.

In comparing the presence of ground water on Route 56 and Route 16 it was found that approximately 58% of the culverts on Route 56 had year round ground water flow as compared with only 2% for Route 16.

A comparison of the watershed soil types for the two routes shows that 35% of the watersheds on Route 56 were made up of organic reducing soils, and only 1% of the watersheds on Route 16 involved soils of this type. The predominate "watershed soil" along Route 16 was "inorganic oxidizing".

The average life for more than 75% of the galvanized culverts on Route 16 is estimated to be 30 years or greater, while on Route 56 the life is estimated to be 20 years or less. This observation seems to indicate that organic reducing watersheds are more corrosive to galvanized metal culverts than are inorganic oxidizing watersheds. However, definite and completely supportable conclusions must await a more thorough environmental study.

In any collection of data that show a rather wide range of values, there is always the possibility of chance, accounting for the variations. Therefore, in order to determine whether a soil type was a significant factor, the relationship between watershed soil types and the condition of culverts was statistically analyzed.

The total number of culverts in each soil group area was tabulated and then segregated into degrees of deterioration referenced to each soil classification.

The analysis indicates that the difference in percent of corroded culverts in various soil classifications due to random variation was less than 0.01, or the chance that the corrosion rates of the culverts were affected by random variation alone is less than 1 out of 100.

As there were only 10 culverts on Route 56 which were classified as having inorganic oxidizing soil, data from Route 48 was added to permit a better mathematical spread of soil types.

In comparing the soil classifications and corroded culverts on Routes 56 and 48, the following relationships were found:

The probability that the difference between the percent of corroded culverts in inorganic oxidizing and organic oxidizing soils is due to random variation is .14 or 14 out of 100 culverts. The probability that the difference between the percent of corroded culverts in inorganic oxidizing and organic reducing soils is due to random variation is .09, or 9 out of 100 culverts.

These figures indicate that for these locations of culverts the watershed soil type will have a substantial influence on the corrosion rate, and the variations cannot be attributed to chance alone.

C. Effect of Corrosion on Culverts.

It was observed during the survey that culvert failure usually occurred in the invert. In some cases the invert of the culvert at both ends was completely perforated, while the invert in the middle of the culvert was not. In certain other cases the invert in the middle of the culvert would be perforated, and the ends would be in good condition. Extreme care had to be taken during the culvert inspection to inspect the center of the culvert, wherever possible.

There were also a number of cases in which the section of the culvert invert which was continually submerged was in good condition, but the area at the edges of the water flow in the culvert which was alternately wet and dry would be perforated. In the culvert survey this area of attack was called the area of "splash".

Evidence from other studies, although not observed during this survey, indicates that accelerated corrosion of a metal culvert will occur from the soil side when the structure is placed in peat, or some other such highly aggressive soil, in which case the failure may be in any location around the circumference of the pipe.

As it is general engineering practice in District I to place relatively clean backfill of inorganic material around a culvert, it seems probable that any severe exterior corrosion of a culvert in this area would be caused only by the percolation of corrosive ground or runoff water into the backfill.

D. Observations on Specific Routes.

A listing of environmental factors affecting corrosion pertinent to each section of highway is included as Exhibit IV in the appendix.

V. DISCUSSION

A. Culvert Corrosion and Repair.

There are many causes for the corrosion of the culverts in District I. However, a very rough indication of the corrosion potential for a watershed can be made visually. If there is evidence of limestone, chalk, or other calcareous substances in the watershed, the likelihood that the culvert will suffer severe corrosion may be slight. Conversely, if the watershed offers no evidence of calcareous earth deposits and has an organic reducing watershed soil type, the potential for a severe corrosion rate is great.

As the culvert survey indicated that the watershed runoff is often responsible for the more corrosive environment, some method of culvert invert protection should be undertaken, especially when the watershed runoff appears to have a high corrosion potential. This protection could be in the form of asphalt or concrete paving. However, in the case of concrete paving, it might be well to wait until the galvanizing has deteriorated, as the high pH of the localized concrete environment may cause an uneconomic service life of the galvanizing[4,7].

Attached is Exhibit V, "Suggested Temporary Culvert Repair Methods, District I". This chart shows three current methods of culvert repair used by the District, and a recommended procedure for using a bituminous corrosion seal in highly corrosive areas.

One method of culvert repair that has economic advantages is the Centrilining[1] process. This process, of which a sample installation was observed during this culvert survey, entails the placing of an approximately 1" thick cement mortar coating, which covers the entire inside surface of the culvert. This method was found to be economically feasible when a culvert replacement would require trenching through approximately 9' or more of fill. The Centrilining process would also have economic culvert repair advantages over replacement in kind under lower fill heights when the highway is subject to heavy traffic. This method of repair is also indicated on Exhibit V.

The relative merits of asphalt dipping, asbestos bonding, asphalt paving, and other means of metal culvert corrosion protection have not been completely evaluated on a comparative life or survival basis nor has the use of concrete pipe. However, it has been observed that the above methods of metal culvert protection all help extend culvert life and sufficient data was collected to make a rough estimate. Attempts will be made to evaluate more closely such protective coatings and treatments in future studies.

There was some indication noted of concrete deterioration in several old concrete pipe installations in organic reducing soils. This condition was not extensive; however, it does indicate that environmental consideration must also be given to concrete as well as metal culvert installations.

The culvert study in District I strongly supports the opinion that chemical and electrical tests of the watershed waters would give advance information on corrosion potential.

B. Economic Effect of Recommendations.

Some idea of the magnitude of the metal culvert replacement or repair problem in District I may be derived from the following Table I showing the present estimated remaining service life of the existing metal pipes.

TABLE I

PRESENT ESTIMATED REMAINING SERVICE LIFE

Remaining Service Life	% Total (7,000 Pipes)	* Estimated Replacement Cost
5 years or less	14%	$1,180,000
5 to 20	10%	840,000
20 to 30	12%	1,010,000
30 or more	64%	5,380,000

* Based on the assumption that the average metal pipe in District I is 100' long, 24" in diameter, and is under 10' of fill.

The percentage values shown are based on the approximate total of 7,000 metal pipes. The remaining service life was estimated from a projection of the present apparent rate of corrosion.

Another method for describing the magnitude of the corrosion problem in District I is depicted on Exhibit I in the appendix, "Equi-Percentage Corrosion Contour Map". This chart was developed by computing the percentage of culverts in critical condition in each highway section, then contour lines were connected to points in the various highway sections having an equal percentage of culverts in critical condition.

This Exhibit I may be used to distribute culvert replacement or repair funds by establishing a priority for each highway section. This priority could be based upon the percentage of critical culverts in each highway section.

Tables II and III following show the approximate increased service life and economic effect that may be expected through the use of the minimum protective procedures listed on Exhibit III in the appendix. In Table II the increase in service life is the average additional service life that can be expected if instead of a plain galvanized corrugated metal pipe a galvanized metal pipe, protected as indicated on Exhibit III, is used in the corrosion area indicated. Table III shows the savings that will accrue if such practice is followed.

TABLE II

SERVICE LIFE EFFECT OF MINIMUM PROTECTIVE MEASURES

Corrosion Area	Average Service Life Increase
Highly Corrosive	120%
Moderately Corrosive	15%
Non-Corrosive	5%
All	50%

TABLE III

ECONOMIC EFFECT OF MINIMUM PROTECTIVE MEASURES

Corrosion Area	Corrosion Cost Savings Due to Increased Service Life
Highly Corrosive	55%
Moderately Corrosive	11%
Non-Corrosive	2%
All	30%

VI . SUMMARY

The present condition of each metal pipe culvert in District I is listed on the culvert inspection sheets. Complete sets of these sheets are on file in the District, Headquarters Maintenance Department, and the Materials and Research Department.

The present magnitude of the culvert corrosion problem in District I is summarized on Exhibit I, "Equi-Percentage Corrosion Contour Map" in the appendix.

As a guide for future planning, a corrosion area map of District I is attached, Exhibit II. The map is not an indication of the present condition of the 7,000 metal culverts in District I, but is rather an indication of the expected rate of corrosion of an adequate number of unprotected 16 gage galvanized corrugated metal pipes so as to indicate the economic influence of the area. This is based on a projection of the data collected during this survey.

Exhibit III, "Recommended Minimum Corrosion Protection for Metal Culverts to Obtain an Estimated 20 Years or Greater Service Life", should be used in conjunction with the Corrosion Area Map.

As previously stated, the primary position of deterioration of corrugated metal pipe culverts in District I is in the invert, and is due to aggressive waters. Observation indicates that, where necessary, additional protection provided in the invert of the pipe should result in a service life of the metal culverts which will more nearly correspond to that of the road.

It is suggested that where invert paving is used, it should extend for a distance on both sides of the culvert flow line to a horizontal height equal to one third (1/3) of the diameter of the pipe. Also, when a culvert which is located in a highly corrosive area is being repaired with a concrete paved invert, the backfill soil which contacts the concrete should be sealed with a bituminous seal. This procedure will delay accelerated corrosion of the culvert metal at the concrete to metal junction, and is depicted on Exhibit V, "Suggested Temporary Culvert Repair Methods, District I."

VII. RECOMMENDATIONS

It is recommended that:

1. The Equi-Percentage Corrosion Contour Map, Exhibit I, be used as a guide in the planning of a District I metal culvert replacement program.

2. The Corrosion Area Map, Exhibit II, and the accompanying minimum protection chart, Exhibit III, be used as a guide for future design of District I drainage.

3. The factors listed in Exhibit IV may be used as a guide during the preliminary design of drainage culverts in the District.

4. Exhibit V, Suggested Temporary Culvert Repair Methods, be used as a guide for future maintenance repairs to existing culverts.

5. For locations involving costly metal culvert installations in areas of suspected extreme corrosion rates and where replacement or repair of the culvert during the lifetime of the highway would not be practical, a preliminary electro-chemical corrosion survey be performed so as to provide the most economical installation.

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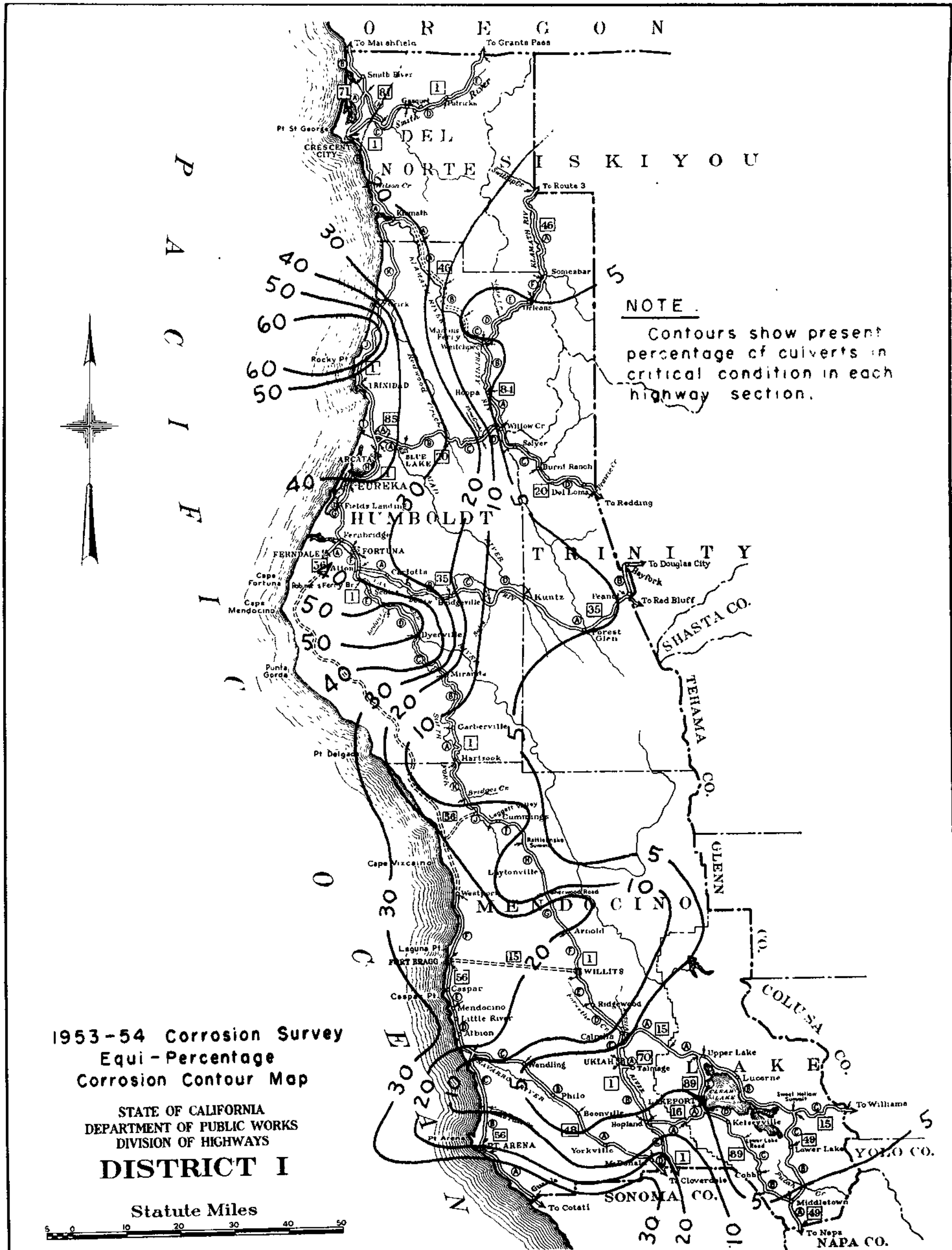

OREGON
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NAPA CO.
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NOTE.
Contours show present percentage of culverts in critical condition in each highway section.
1953-54 Corrosion Survey
Equi-Percentage
Corrosion Contour Map
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
DISTRICT I
Statute Miles
Crescent City
Klamath
Orleans
Hoopa
Trinidad
Arcata
Eureka
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Ferndale
Garberville
Laytonville
Westport
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Mendocino
Ukiah
Lakeport
Pt Arena

MATERIALS AND RESEARCH DEPARTMENT

CORROSION AREA MAP

EXHIBIT II

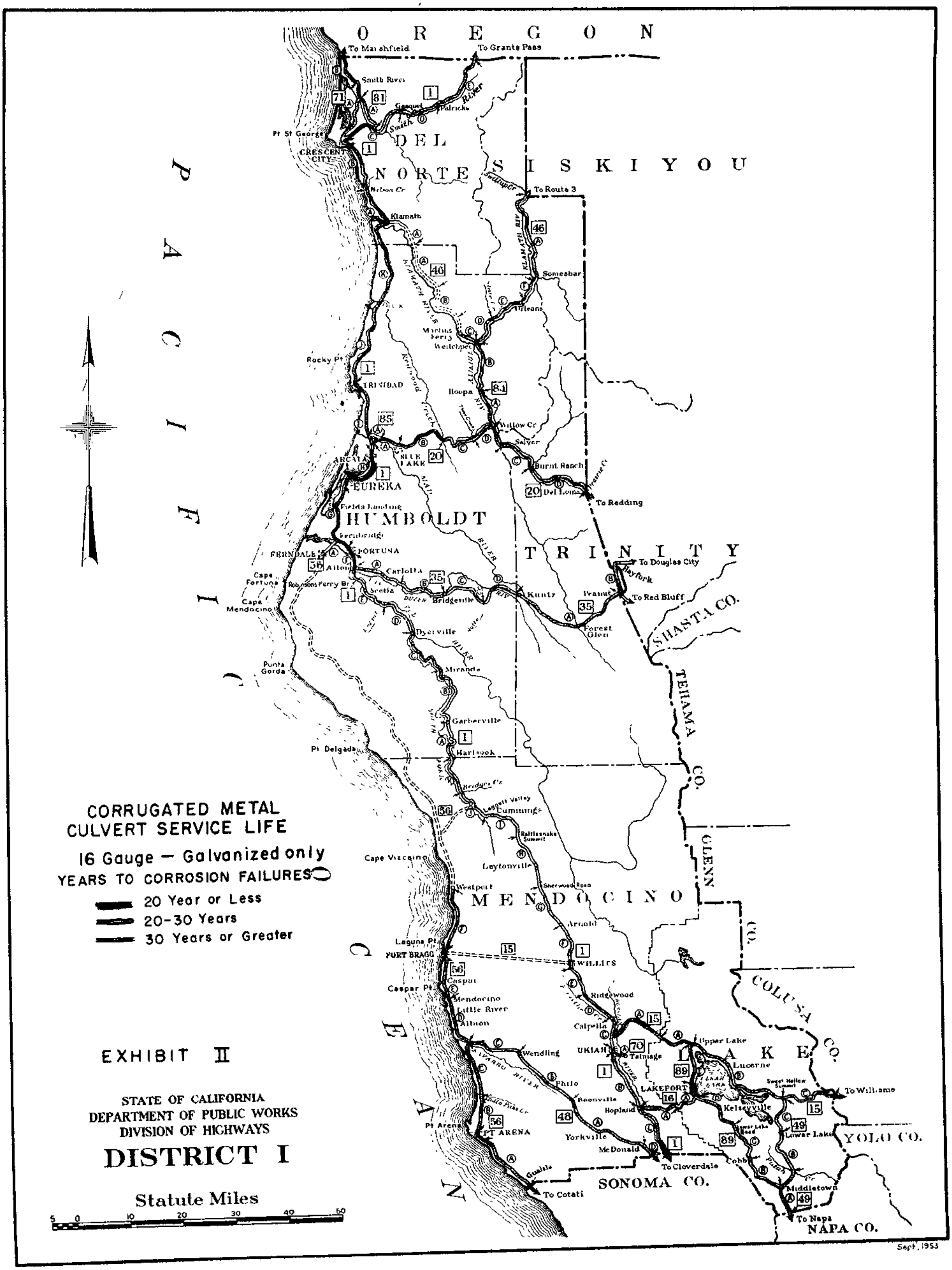


Exhibit III

RECOMMENDED MINIMUM CORROSION PROTECTION FOR METAL CULVERTS

CORROSION AREA (Refer to Corrosion Map, Exhibit I)	SOIL CLASSIFICATION					
	ORGANIC REDUCING		ORGANIC OXIDIZING		INORGANIC OXIDIZING	
	Continuous Flow	Periodic Flow	Continuous Flow	Periodic Flow	Continuous Flow	Periodic Flow
HIGHLY CORROSIVE (Orange Area)	* Asphalt Dip Paved Invert	* Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert
MODERATELY CORROSIVE (Green Area)	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Galvanize Only	Asphalt Dip Paved Invert	Galvanize Only
RELATIVELY NON CORROSIVE (Blue Area)	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Asphalt Dip Paved Invert	Galvanize Only	Asphalt Dip Paved Invert	Galvanize Only

* Bituminous Asphalt Product Used Shall Comply with Headquarters Recommended Specification of November 18, 1954.

EXHIBIT IV

OBSERVATIONS ON SPECIFIC ROUTES.

A. Coastal Location: (Routes 1, 56, 71 between Gualala and Oregon)

1. General physical conditions observed to accompany accelerated corrosion.

   a. Hydrogen sulfide perceived in watershed soil type.

   b. Clay or silt soil in watershed.

   c. Formation of flake or tubercle type of rust.

   d. Continuous ground water flow.

   e. Presence of salt water spray or tidal water.

2. Physical conditions observed to accompany less severe corrosion rates.

   a. Watershed has sandy or granular type of soil.

   b. Soil is a light reddish brown in color and well drained.

   c. With ground water flow, invert is silted with sandy type soil.

   d. Culvert carries pavement runoff only.

B. "Inland" Locations: (Routes 1, 48, 35).

1. Physical conditions observed to accompany accelerated corrosion.

   a. Hydrogen sulfide perceived in areas of ponded water.

   b. The culvert invert is silted.

   c. Silt in culvert is removed through maintenance.

   d. Watershed is overgrown with ferns and lush vegetation.

   e. Ground water flow.

2. Physical conditions observed to accompany less severe corrosion rates.

   a. Culvert has self-cleaning gradient.

   b. No ground water flow.

C. Watershed soil types.

1. "Organic watershed" and soils.

It was observed generally that in a predominant number of cases accelerated corrosion of metal culverts occurred in watersheds having organic reducing soils. This fact was observed in the coastal, redwood and interior regions.

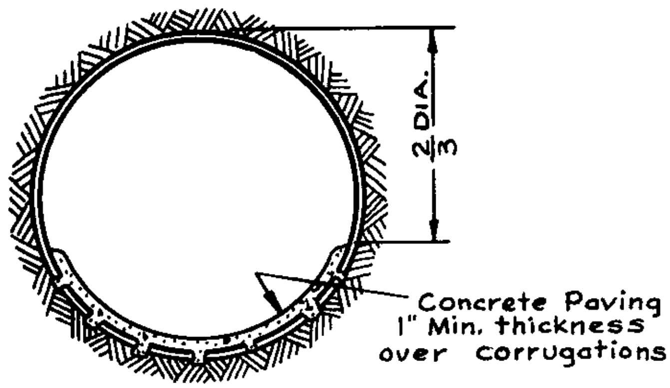
It was also observed that some culverts in the organic oxidizing soils had nearly the same corrosion rate as those in organic reducing soils. Since the propagation of anaerobic bacteria depends on moisture and the exclusion of oxygen[6], it is apparent that some consideration of the soil aeration and drainage would give an indication of the intermittent presence of the anaerobic bacteria in the organic oxidizing soils.

In many cases of accelerated culvert corrosion rates, the cause may not be an environment such as the organic reducing soils. It may be that there are insufficient chemicals in the waters to cause a protective film of corrosion products to be deposited.

As previously mentioned, calcium carbonate has been widely recognized by public utility companies as a mechanism for inhibiting internal corrosion of steel water mains. When a water supply system has been found to have insufficient calcium carbonate to deposit a protective film of corrosion products, calcium is artificially added for this purpose.

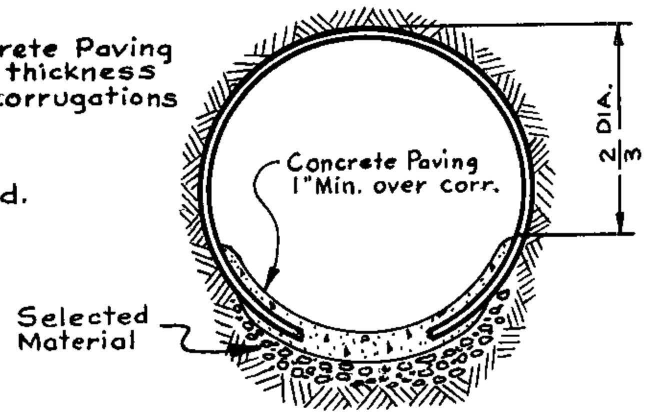
Although this system for corrosion inhibition may be impractical for highway culverts, the fundamental test for the calcium balance of the water can be made to determine its corrosion potential.

SUGGESTED TEMPORARY CULVERT REPAIR METHODS



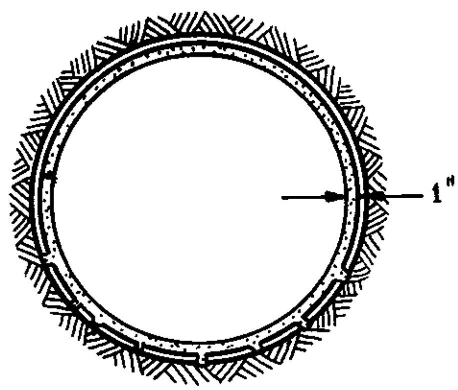
METHOD - A

Used when earth fill is stabilized.



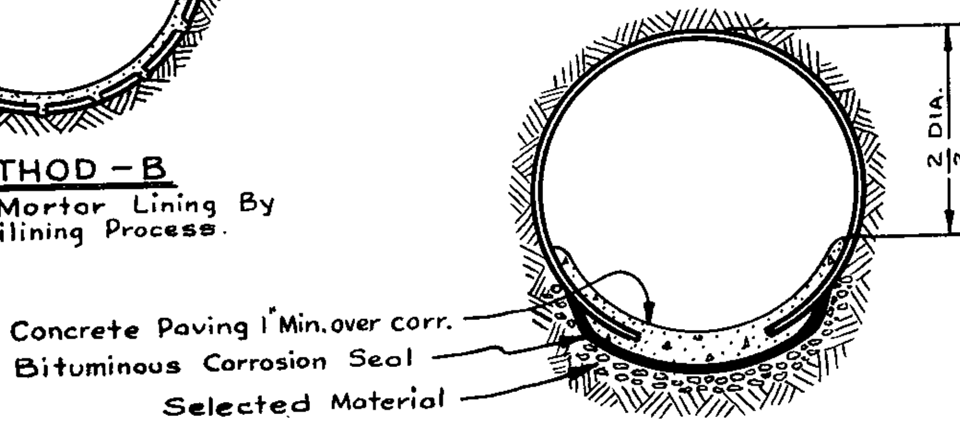
METHOD - C

Used when earth fill has not stabilized.



METHOD - B

Cement Mortor Lining By Centrilining Process.

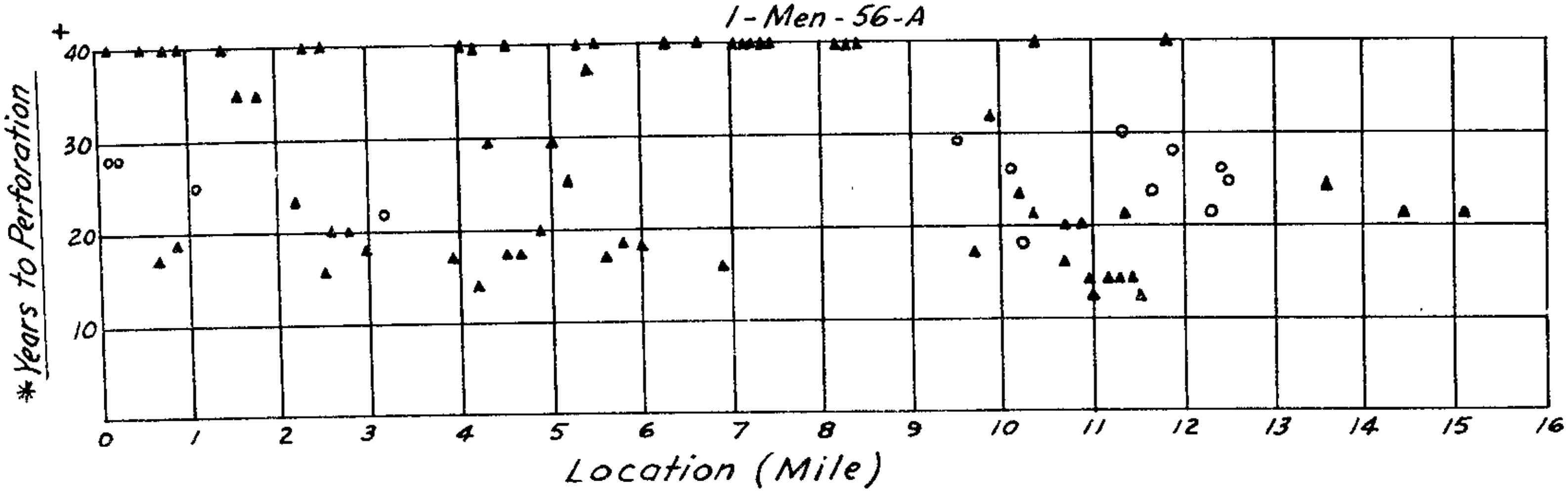


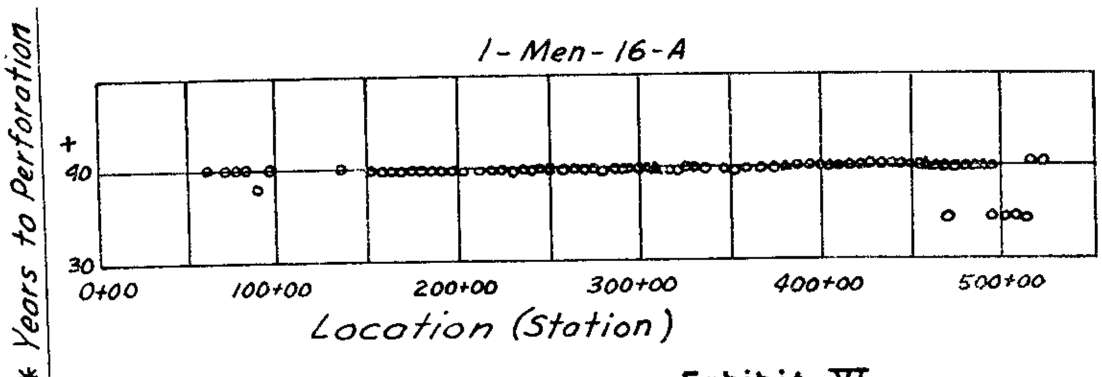
METHOD - D

Recommended Practice when earth fill is not stabilized and runoff is highly corrosive.

Culvert Corrosion Rates

A Typical Comparison of Culvert Corrosion Rates Used for Corrosion Area Designation





NOTE: No culvert with less than 10 yrs. service was included

o = Galvanized C.M.P.
▲ = Asphalt Dip C.M.P.
* - Calculated from estimated metal loss at time of inspection
+ - Culverts with calculated life in excess of 40 yrs. plotted on 40 year ordinate.

Exhibit VI

STATE OF CALIFORNIA
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPT.

CULVERT INSPECTION INSTRUCTIONS

Procedure for filling out Form T-620-53 Rev.

The physical condition of a culvert is determined from the reaction or penetration of a prospector's pick to the metal surface and is described in % of original metal thickness lost.

The inspection report is to be filled out in such a manner that an engineer in the office can visualize the physical condition of a culvert in the field.

The following terminology is to be used on the inspection report to describe the varying culvert conditions.

INLET SECTION

Column	Abbreviation	Definition and Procedure
Type	Gal.	Galvanized C.M.P.
	A.D.	Asphalt dip C.M.P.
	A.B.	Asbestos bonded C.M.P.
	A.P.I.	Asphalt paved invert
	C.P.I.	Concrete paved invert
	R.C.P.	Reinforced concrete pipe
	P.C.P.	Plain concrete pipe
	R.C.B.	Reinforced concrete box
	P.C.B.	Plain concrete box
Installed 19__		The year the culvert was installed shall be inserted in this column.
	M.	Date of culvert installation not checked on plans. Installation date obtained from Maintenance foreman or other verbal source. Example: 25M - culvert installed in 1925, date obtained from maintenance forces.
Cond. Length		Designates the length in feet of culvert inspected visually or by test.
	A	Air
	W	Water
	V	Visual
		Example: A3 - the inlet or outlet section of the culvert projects 3' beyond the fill. The outside bottom section normally in contact with soil is in contact with air.
Silt Depth		Depth of silt designated in inches above the culvert invert.
Upstream ridge		The upstream face of a corrugation.

Column	Abbreviation	Definition and Procedure
	G	General
	P	Pit
	0 thru 10(x)	Describes metal loss in terms of % of original metal thickness. 1 = 10%, 2 = 20%, X = 100%
	0 thru 10(x)	Describes total area in %. 1 = 10%, 2 = 20%, X = 100%
		Example: 6P9 - 60% of the corrosion area has pits to a depth of 90% of the original metal thickness.
Splash	See upstream ridge	Area inside culvert where normal flow of water fluctuates or splashes most often.
Air		Designates corrosion area not in contact with soil or flowing water.
	O	Outside
	I	Inside
	0 thru 10(x)	1 = 10%, 2 = 20%, X = 100%
		Example: O1 designates that the outside section of culvert (section most likely to get direct sunlight) has lost 10% of its original metal thickness.
Soil		Designates the culvert section in contact with earth backfill.
Abrasion	0 thru 10(x)	1 = 10%, 5 = 50%, X = 100% A numeral in this column is the inspector's opinion of how much of the culvert metal loss is caused by abrasion.
Rust Type	Flake	Hard, adherent stratified rust flakes. Usually a black or a dark colored layer of rust adjacent to the metal surface.
	Fine powder	Relatively smooth to the touch, about the consistency of cement. Usually found with soil contact. Generally light in color.
	Coarse powder	Granular, relatively adherent. Usually found in atmospheric corrosion. Color varies from light to dark reddish brown.
	Tubercle	Generally are hard nodules of rust. Usually has a dark or black colored rust layer adjacent to metal surface. Usually found in areas subject to runoff water or sea water attack. Sometimes gelatinous in appearance. Indicates pitting of metal.

Column	Abbreviation	Definition or example
	W	Water
	H	Splash
	S	Soil
	A	Air
	O	Outside
	I	Inside
Asphalt Coating		Location of condition of asphalt coating is the same as rust type location.
Fill Shoulder		Height in feet from the crown of the culvert to the highway shoulder.
Metal Gage		This is the standard sheet metal thickness of the culvert steel.
Waterway		The adequacy of the waterway is determined by visual observation and/or statements by maintenance forces. If the roadway floods because the culvert is inadequate, designate the reason.
	W	Waterway
	S	Silt
	D	Debris
	P	Profile of road

EARTH TYPE

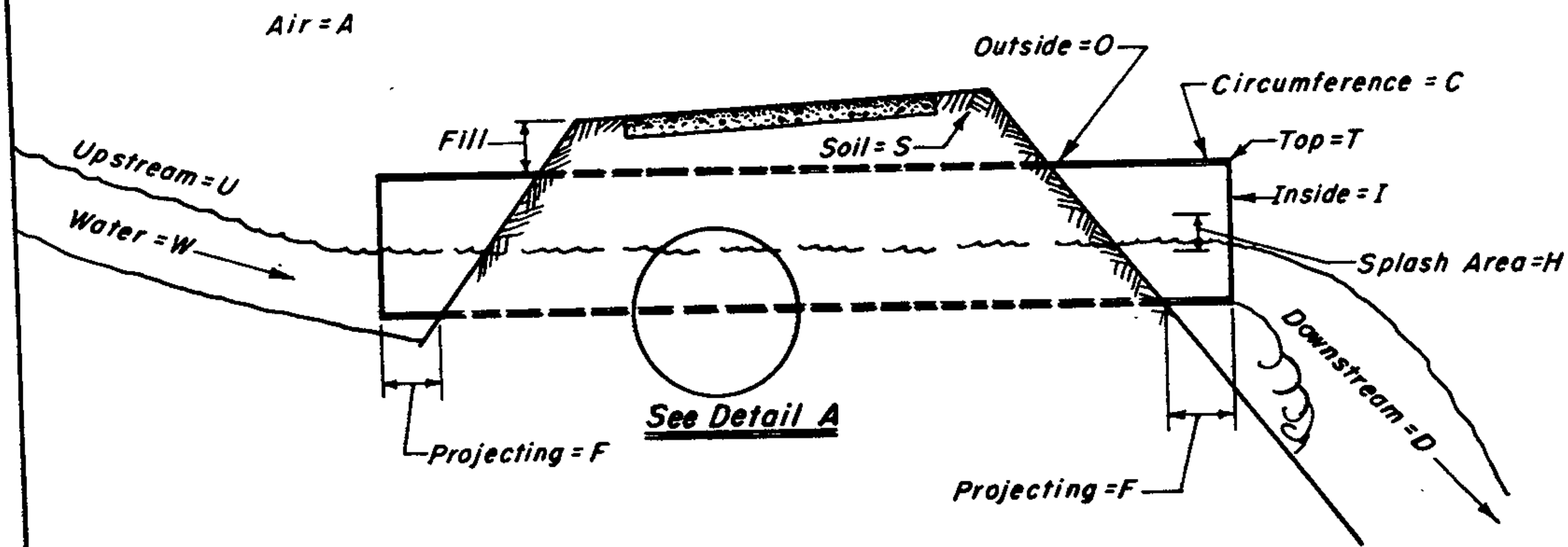
Organic	Watershed has more than 50% of land area covered by vegetation.
Inorganic	Watershed has less than 50% of land area covered by vegetation.
Reducing	Generally the soil is dark or mottled gray and black in color. Very often an odor similar to decomposing sewerage (H_2S) is perceived when moist soil is exposed a few inches below the surface.
Oxidizing	Land is well drained in an agricultural sense. Generally a light colored soil.

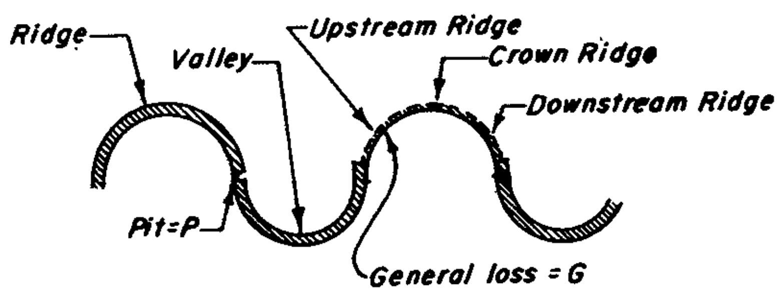
Examples:

1. Inorganic Oxidizing: May be sand dunes, or rocky watersheds with little topsoil or vegetation.

2. Organic Reducing: May be marshland or watersheds similar to those found on the coast. Odor of H_2S perceived.

MATERIALS & RESEARCH DEPARTMENT
CULVERT INSPECTION TERMINOLOGY





Detail A

Schematic drawing of section through pipe corrugations.

REFERENCE FOR
CULVERT INSPECTION RECORD
FORMS No. T-620-53 & T-620-53 Rev.

Exhibit VIII

STATE OF CALIFORNIA

MATERIALS AND RESEARCH DEPARTMENT
CULVERT INSPECTION RECORD

DIVISION OF HIGHWAYS

DIST. I CO. Hum RTE. 1 SEC. N INSPECTOR Smith DATE 5-5-54

			Existing Culvert																														
			Inlet Section									Center Section										Outlet Section											
							Metal Loss									Metal Loss										Metal Loss							
							Water.									Water.										Water.							
Mile	Station	Size & Length	Type	Installed 19__	Cond. Length	Silt Depth	UpStrm Ridge	Crown Ridge	DnStrm Ridge	Valley	Splash	Type	Installed 19__	Cond. Length	Silt Depth	UpStrm Ridge	Crown Ridge	DnStrm Ridge	Valley	Splash	Type	Installed 19__	Cond. Length	Silt Depth	UpStrm Ridge	Crown Ridge	DnStrm Ridge	Valley	Splash				
	799+22	15" x 70'	Gal	25	8	0	G9	GX	G9	G9	-	Gal	25	V48	0	G9	GX	G9	G9	-	18" ADXT	35	14	0	G5	G5	G5	G5	-				
	802+93	18" x 60'	Gal	25	6	0	G8	G7	G6	G6	-	Gal	25	V43	0	G8	G7	G6	G6	-	ADXT	35	1	4"	G5	G5	G5	G5	-				
							3Px	3Px	6P7	4P9	-					3Px	3Px	6P9	4P9	-													
	803+00	12" x 40'	Gal	25	8	0	G6	G6	G7	G6	-	Gal	25	V25	0	G6	G6	G7	G6	-	Gal	25	2	6"	G4	G4	G4	G4	G7				
							3Px	3Px	6P8	4P9	-					3Px	3Px	6P8	4P9	-					3Px	3Px	6P8	4P9	-				
	921+85	18" x 70'	Gal	25	A3	0	G7	G7	G7	G7	-																						
							5P9	5P9	5P9	5P9	-																						
			Gal	25	3-6	0	G5	G5	G4	G4	-	Gal	25	V61	0	G5	G5	G4	G4	-	Gal	25	W3	0	G8	G8	G7	G9	-				
							6Px	5P8	3P8	4P7	-					6Px	5P8	3P8	4P7	-					6Px	5Px	3Px	4Px	-				
	922+50	24" x 60'	ADAPI	35	4	0	G0	G0	G0	G0	-	ADAPI	35	V52	0	G0	G0	G0	G0	-	ADAPI	35	4	0	G0	G0	G0	G0	-				
	922+75	30" x 50'	Gal CPI	25	10	0	GX	GX	GX	GX	GX	RCB	15	30	0						ADAPI	35	10	0	G0	G0	G0	G0	-				

Form No. T-620-53-Rev.

Mile Station	Metal Loss: Air	Metal Loss: Soil	Abrasion: Yes	Abrasion: No	Ground Water: Yes	Ground Water: No	Rust Type Location: Flake	Rust Type Location: Fine Pwdr	Rust Type Location: Coarse Pwdr	Rust Type Location: Tubercle	Asphalt Coating: Excellent	Asphalt Coating: Cracking	Asphalt Coating: Chipping	Asphalt Coating: Deteriorated	Fill Shldr: Inlet	Fill Shldr: Outlet	Metal Gauge	Earth Type: Organic	Earth Type: Inorganic	Earth Type: Oxidizing	Earth Type: Reducing	Water Way: Adequate	Water Way: Inadequate	Previous Culvert: Installed 19__	Previous Culvert: Type	REMARKS (Predominant cause of metal loss,etc)
799+32	9/10	2	2			✓	W	S	OA						8	12	16	✓		✓		✓				Air/Soil rated for galv.
799+32	60	1	2				W	S			IA		OA	SW			16									" / " " " AD-XT
802+93	9/10	2	2			✓	W	S	OA	W					6	15	16	✓		✓		✓				" / " " " galv.
802+93	60	1	2				W	S		W		IA	OA	SW			16									
803+00	9/10	2		✓		✓	WH	S	OA	W					1	3	16	✓		✓			D			
921+85	9/10	2		✓		✓	WS	S	OA	W					10	11	16	✓		✓		✓				
922+50	60	1		✓	✓						W	IA	OA	S	15	17	14	✓		✓		✓				
922+75	9/10	2	S		✓		H	S	OA						20	30	12	✓		✓			W			Air/Soil rated for CPIXT
922+75	60	1						S			W	IA	OA	S			12									" / " " " API-XT