Estimating Service Life for Corrugated Steel Pipe Culverts

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***Abstract*— This research category paper is a work in progress that discusses the processes used to improve the service life estimation of steel culverts under roadways in the State of California. The service life of Corrugated Steel Pipe (CSP) culverts is largely dictated by the loss of wall section of pipe arising from corrosion. This corrosion is due to chemical and electrochemical processes based on two major factors: pH levels and the resistivity of the soil.**

Service life estimates are based on several additional factors: potential for culvert abrasion, changing soil moisture, temperature conditions, soil moisture content, presence of chloride in the soil, and proximity of lakes, wetlands, or marine environments. In addition to pH and resistivity, the CSUN Caltrans Research team has added culvert thickness loss, sulfate and chloride content, total dissolved solids (TDS), salinity, and land use. The thickness reader allows the CSUN Caltrans Research team to calculate the loss of metal from the CSP culverts' nominal thickness.

The goal of this research is to improve the existing service life equations which is currently used by the California Department of Transportation and its associated test methods. To this end, modern non-destructive instrumentation is being implemented in the field to measure CSPs' thickness which is one of the key parameters under investigation throughout the State of California.

Keywords—Corrugated Steel Pipe Culvert

I. Introduction

This project will use data collected from 500 culverts along highways in the State of California to update the current equations that estimates the service life of CSPs. The techniques used for testing are a combination of procedures from Caltrans and methods gathered from other culvert corrosion research projects e.g., the Minnesota report [2][3]. Through consistent literature review and the California Department of Transportation's procedures guide, parameters affecting the CSPs are determined and tested for. From this research, the following parameters consist of: land use, soil particle size, thickness measurements, soil resistivity, soil pH, soil TDS, soil chloride content, and soil sulfate content. These parameters are collected from the field and are tested in the lab following strict protocols. The data for each of these parameters will be plotted against each other through linear regression and the equation will be formed that includes the parameters that are associated to estimate the service life of CSPs.

Currently, the Caltrans' equations used to estimate the service life of CSPs depend on pH and resistivity. The service life (SL) equation when pH values are 7.3 or greater is $1.47R^{0.41}$ where R is resistivity in ohm-cm. If pH value are less than 7.3, then the following equation is used [2]:

$$\text{SL} = 13.79[Log_{10}R - Log_{10}(2160 - 2490Log_{10}pH)] \quad (1)$$

These Caltrans' equations overestimate the culvert service life when high soil moisture and rainfall are present, as well as abrasive soils. [3] Through the course of the research, literature review has shown that resistivity is not a direct reliable indicator of the corrosiveness of soil. Resistivity less than 1000 ohm-cm indicates possible presence of high sulfate and chloride content which may indicate corroded CSPs. With these additional parameters and the further analysis of literature reviews, a more accurate service life equation may develop.

II. FIELD STRATEGY AND DATA COLLECTION

The culvert life estimation in this research are evaluated based on the following factors: pH, TDS, chloride and sulfate content, resistivity, land use, and annual rainfall. Each of these factors help evaluate the corrosiveness of the CSPs' environment, and therefore generates its duration. Given the life estimate, the culvert can be adjusted to ensure that the culvert will last a life expectancy of 75-years that the California Department of Transportation requires for new installations. These various factors are being tested in the field and lab to create a better method for estimating the culvert's life.

A. Field

The data collection method at each of the 500 sites starts with the collection of 5 lbs. of dirt in a gallon-sized zip lock bag. This soil is taken back for lab analysis which is detailed below in section II-B. After the soil is collected, the Spectrum FieldScout pH 400 Meter is used to test pH. This is done by a small ⅜ inch diameter hole, 3 inches deep below the surface of the soil and inserting the pH probe into the hole with deionized water. The pH reading is taken after 20 seconds to allow the values to stabilize. This process obtains the pH value and the temperature of the soil. Both variables affect the ability for sulfate reducing bacteria to thrive and corrode the culverts [1]. A lower value of pH and higher soil temperature provide a more ideal environment for bacteria growth and therefore a more corrosive environment. After pH and temperature are measured, soil moisture is measured using the DSMM500 Moisture Meter. This device is used to measure the moisture content in the soil by inserting the meter into the dirt alongside the culvert. High soil moisture lowers the soil resistivity, which increases the rate of corrosion. After the field soil tests are completed, the thickness loss of the culvert is then assessed.

The initial gauge thickness is taken using the sheet metal gauge to determine the nominal thickness of the metal which is used to validate the ultrasonic thickness gauge values. This thickness is taken at the least corroded section of the culvert, usually at the 12 o'clock position. The exact thickness at the 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock are then taken using the Olympus 45MG Ultrasonic Gauge. Once this device has been calibrated with the step calibration, it is able to measure the thickness of the culvert. The culvert is sanded at these four positions to ensure a smooth surface for testing. These four positions are then measured by applying couplant gel to the sensor and placing the probe to the flat surface area of the interior of the CSPs. This gives the thickness of the remaining metal in the culvert after corrosion. The Olympus 45MG Ultrasonic Gauge is essential in collecting the thickness loss by determining the difference between the nominal and remaining metal thickness.

The Garmin Oregon 700 GPS is currently used for mapping data and to pinpoint precise location of the culverts which are inputted into ArcGIS. ArcGIS is a geographic information system that plots data on the map of California which shows the trends of each parameter.

B. Lab

The soil samples are taken back into the lab for further testing. Some parameters that are tested for are: pH, resistivity, TDS, and salinity. To test for soil resistivity, the Caltrans method, also known as the small soil-box method denoted in CTM 643 [2], is used in the lab. This method requires a weighted scale, sieve, deionized water, graduated cylinder, plastic container, and the AEMC 6471. The soil is first dried at 125°F and grounded with a pestle and mortar if necessary so that 110g of soil can be passed through a number 8 sieve. The sieved soil is mixed with 15 ml of deionized water and placed into a small size resistivity box as detailed in CTM 643[2]. If the minimum resistivity of the sample falls under 1000 ohm-cm, it is sent to the California Department of Transportation to be tested for sulfate and chloride contents by using Ion-Chromatography.

Ion-Chromatography is essential to the creation of the service life equation. Access to this resource was only possible through California Department of Transportation laboratories. The purpose of the Ion-Chromatography is to identify the levels of chloride and sulfate. 3 lbs. of soil must be sent to prepare the 5 samples necessary for calibration and measurement of the chloride and sulfate levels. Regardless of resistivity, all samples are tested for salt content, as well as pH and TDS in the CSUN soil's lab.

The ExStik II pH/Salinity/TDS Meter are used to test for pH, salinity, and TDS. The data collection process starts by first mixing 30 g of soil, passed through a number 8 sieve, with 30 ml of deionized water and stirring it for 30 seconds. The sample are left to rest for an hour so that the salts and other solids can fully dissolve into the water. Then, the ExStik II is placed into the solution and the values are recorded.

III. SITE LOCATION AND ARCGIS

Data collected is easily organized and displayed using the ArcGIS tool. The ArcGIS used Shapefiles to accurately capture common trends like pH and resistivity within different regions of California. This gives a graphical representation of the various parameters in a given area. Using this, data such as rainfall and pH from databases can be used to gain additional data to compare the corrosion to, allowing new trends to be found.

IV. SOIL PH

Soil pH affects the environment for soil bacteria. In general, the sulfate reducing bacteria found in soils thrive in lower pH environments. These bacteria convert organic detritus in the soil, in most cases mainly decomposing plant matter, and convert them into sulfates. These sulfates are highly corrosive to steel culverts. This is especially true at the steel soil boundary which is present around the culvert, and is often at the 6 o'clock position where dirt tends to accumulate. At this steel soil boundary, soil bacteria actively generate sulfates which constantly react with the steel culvert causing increased corrosion rate. Measuring the pH of the soil does not directly measure how much bacteriological activity the soil contains but does show what types of bacteria can live in the environment and how well suited the environment is for sulfate reducing bacteria. In addition, the high levels of sulfate reduction acidify the soil, so that the pH is also an indicator of how prevalent the sulfate reduction is.

V. LAND USE

Land use was classified to give an estimate of the corrosiveness of the environment as well as what corrosive conditions may be present. Different land use samples contain different kinds of content like chloride and sulfate. Separating culverts based on land use allows the team to identify locations that may contain more culvert damage. Land use was broken down into seven categories: Agricultural land, Range land, Forest land, Urban land, Wet land, and Barren land. These different land classifications have different trends in dissolved solids and moisture content which affects culvert life.

Agricultural land is defined as land which is used to produce "food or fiber" [4]. This soil contains high amounts of fertilizer in soil and runoff. Fertilizer that contains high amounts of sulfates and chlorides accelerate the corrosion of steel. In addition, most crops have ideal growth in soil with a pH below 7.0. This acidic soil generates acidic runoff which also increases the corrosion rate of the steel culverts. This is due to the increased bacteria activity in acidic environments which generate corrosive sulfates [5]. Lastly, the water used to water the crops generate higher moisture content soil and higher amounts of runoff through the culvert, causing increased corrosion, especially at the 6 o'clock position where runoff is most often in contact with the steel.

Range land is defined as land where vegetation is "predominantly grasses, grass like plants, forbs or shrubs" [4]. This environment tends to have a moderate amount of rainfall and neutral pH. Forest land is defined as having a "tree crown areal density of 10 percent or more" [4]. This classification is first checked visually, and then confirmed using GPS data and satellite imagery. This environment has moderate to high rainfall, and a slightly acidic pH at 6-6.5.

Urban land is defined as land in which the areal density of non-industrial structures is greater than 5% structures like houses, stores, and offices. In cases which urban land is present in conjunction with another land category, the urban classifier will be added after the predominant land type classification. These environments have higher water runoff due to the watering of plants and lawns. Runoff from detergents, fertilizers, fuels, oils, and other items used in urban life are present, and may lead to decreased culvert life.

Wet land is "defined as an area in which the water table is at or near the land surface for a significant part of most years" [4]. Wet lands have high soil moisture and runoff, rapidly accelerating corrosion rate of culverts, high amounts of decomposed plant material and low soil aeration which provide an ideal environment for bacteria to thrive. These bacteria break down plant material and generate sulfates. These sulfates then leach into the water and accelerate corrosion of culverts reducing culvert life.

Barren land is defined as land near the ocean, or other saline body of water. The land around these bodies of water has high soil moisture and chloride levels due to the surrounding salt water. Both the moisture and chloride levels rapidly accelerate culvert corrosion, making these environments some of the most corrosive. This classification is appended to the main soil classification whether that be Forest land, Wet lands, etc.

VI. DATA ANALYSIS

A. Average Thickness loss

The average thickness loss is important to making the research scientific. With the comparison of the sheet metal gauge to the ultrasonic device, the average thickness loss depicts that the 6 o'clock is usually larger than the 12 o'clock position. Thus, this means that the bottom of the culverts experiences more deterioration and abrasion than the top of the culverts. Specific regions encounter different average thickness loss. Based on the data collected, Barren land regions encounter larger average thickness loss compared to other regions such as Agricultural and Range land. The pipes undergo physical, chemical, and electrochemical processes due to the land use which may contribute to the effects of the service life.

B. Service Life Equation

The goal of this project is to update the service life equations. Based on the data collected, these equations will vary according to the land use these culverts are found in. Certain parameters will be included such as resistivity, sulfates, chlorides, and etc. Other parameters that deal with the physical elements, such as abrasion will not be included in these equations; although they do play a role in the service life of culverts.

Being able to correctly predict what parameters will affect the service life of a culvert can allow various Departments of Transportation to adequately install different measures that will ensure the life expectancy of a culvert to be fulfilled. This research also aims to make sure culverts that are already installed are being updated and reinstalled if service life expectancy is reached.

Fig. 1 shows the Caltrans CTM 643 [2] service life equation for 18 Gauge steel pipe. For pH > 7.3 the data behaves exponentially, while pH < 7.3 behaves logarithmically. This trend continues as the Gauge size increases. Also, as the Gauge size increases, the trendlines are closer together. Intuitively, this shows that as the amount of steel increases, the longer it will last. This trend in pH is verified by the corrosion data collected in the field. Fig. 2 shows the increase in thickness loss as pH deviates from 7.3. This thickness loss is most prevalent at the bottom 90% of the culvert where dirt stays in constant contact.

VII. Figures and Tables

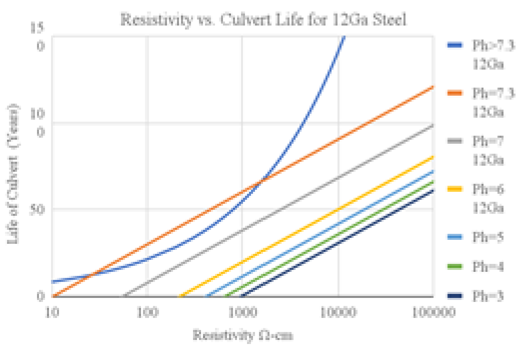

Figure 1. Caltrans service life estimates for 12 Gauge steel pipe

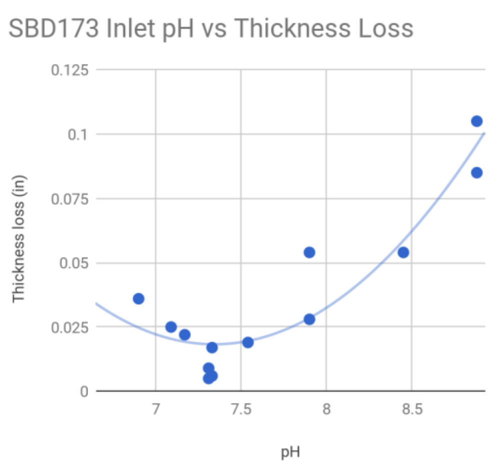

Figure 2. Graph of pH versus Corrosion showing the increased corrosion above and below 7.3 pH.

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