HR-2001

# EVALUATION OF STAINLESS STEEL CULVERT PIPE
# in
# Mahaska County, Iowa

## 1.0 INTRODUCTION

Corrosion of culvert pipe in Iowa in general is not a serious problem. However, it is potentially significant in some local areas. An opportunity to make a limited durability study of stainless steel pipe was presented when a local fabricating company expressed interest in a cooperative field experiment. The potential of stainless steel pipe is to reduce maintenance costs that are incurred through replacement and upkeep. A new stainless steel material, Allegheny Metal MF-1, was used in a partial fabrication demonstration and later these demonstration sections were delivered to the selected field site for placement.

## 2.0 PURPOSE

The purpose of this field experiment is to study the ~~durability~~ performance of MF-1 stainless steel culvert pipe compared to galvanized steel pipe.

This report is a description of the selection of and general conditions existing at the installation site, with an attempt to indicate whether the use of stainless steel pipes in Iowa is justified from an economic standpoint.

## 3.0 DESCRIPTION OF MATERIALS

The Allegheny-Ludlum Steel Corporation reports[5][a] the typical composition of the MF-1 as follows:

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a Superscripts refer to references at end of report.

## TABLE I

### Typical Chemical Composition, Percentages

| Alloy | C | Mn | Si | Cr | Ni | Ti | Fe |
|---|---|---|---|---|---|---|---|
| MF-1 | 0.04 | 0.50 | 0.40 | 11.00 | 0.20 | 0.50 | Balance |

Because this study is to be a direct comparison study, one section of galvanized corrugated metal pipe of the same dimensions as one of the stainless steel sections was purchased and installed in the same manner as the stainless steel, see figure 1.

Table two below lists the dimensions and type of sections installed.

## TABLE II

| Material | Pipe Diameter (in.) | Pipe Length (ft.) | Degree of Bend (Deg.) |
|---|---|---|---|
| MF-1 | 15 | 20 | - |
| MF-1 | 15 | 14 | - |
| MF-1 | 15 | - | 14 |
| Galvanized Steel | 15 | 20 | - |

Note, in figure 1, that the $14^{o}$ stainless steel elbow is placed on the downstream end of the upstream pipe. This elbow section is a potential problem. The weld used to attach the elbow to the 14 foot pipe section caused a local discoloration and scalding tending to expose the weld area to potential corrosive action, see figure 2.

A second item to be noted on the stainless steel pipe was the apparent formation of ~~interior rust spots~~ at the extreme ends of the 14' and 20' pipe sections, see figure 3. This condition was quite noticeable and should be carefully observed in future inspections.

Figure 2 Welded Elbow

## 4.0 SELECTION AND DESCRIPTION OF FIELD TEST SITE

According to the Allegheny-Ludlum Steel Corporation, producers of the stainless steel, MF-1 is highly resistant to the corrosive action of soils and various effluents which have a PH range of 2-10. These credentials prompted the selection of a test site, by the Design Department, on Iowa Primary Road 92 in Mahaska County. In particular, Section 15 of Garfield Township (T75W-R16W) at Sta. 197+00 42.5' right and left.

This site was selected because of the relatively high corrosive action of local "mine water"[b] which is present in the area and because a 3' x 4' reinforced concrete box culvert is already in place at this location.

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b "mine water" is water which has run across the open coal mining areas of the region.

In 1954 or 1955, when the 3' x 4' x 87' reinforced concrete box culvert was constructed, the wearing surface was coated with a bituminous material. In the ensuing 12 or 13 years the bituminous material has scaled and flaked off, see figure 4. The deterioration of the bituminous coating is evident in the bottom of the culvert, however along the edges it is still in tact. This fact has lead observers to believe that the flaking and wearing of the material is due to the turbulant action of the water and not the corrosiveness of the water. A pH test performed on the mine water run off was between 5 and 6. (The pH of a near by stream was 6).

4.1 Local Water Flow Conditions

Water flows in the culvert only during periods of run off. However, at the time of installation, water was flowing in the culvert ditch because of a recent 1½" rain in the area.

Total rainfall in this area is about 33 inches per year[4] or approximately 100 acre-ft. per year. Assuming a velocity of 2.8 fps in the bot culvert and that the bot culvert will run 1.5 inches deep, an estimate of the time, $t_e$, to drain the area can be determined from the following equation,

$$t_e = \frac{V_w}{v A_{effective}}$$

where: $t_e$ = Time to drain the area, unit time

~~L = Length of the barrel, ft.~~

$V_w$ = Total volume of water, cu. ft.

$A_{effective}$ = Effective area of barrel, ft² (box culvert)

~~$D_o$ = Depth of barrel, ft.~~

v = Velocity of flow, ft/unit time

~~$V_B$ = Volume of barrel, cu. ft.~~

~~$D_F$ = Depth of flow in barrel, ft.~~

Substitution of the proper values in this equation will yield a total flow time of 4.74 days per year. This means that only 1.30% of the time water is actually flowing in the ditch. (See Appendix A for calculations).

The data are based on the assumption of no infiltration. If a runoff coefficient of 0.5 had been used, this would reduce the flow to approximately 2.4 day/year or .65% of the time.

4.2 Local Soil Conditions

The state of Iowa has 90% of its land area covered by 5 of the 36 great soil groups,[2] see figure 5. The Brunizens[c] make up the largest segment followed by the Grey-Brown Podzolic soils, the Planosols, the Wiesenbodens (also referred to as Humic Grey Soils) and the Alluvial soils. The Lithosols and Bogsoils make up the other 10%.

The Brunizens are characterized by a pH range of 3.4 to 8.1. The Wiesenbodens have a pH range of 5.3 to 8.0, while the Grey-

Brown Podzolic soils have a pH range of [illegible]. Finally the [illegible]

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c The term "Brunizen" is proposed by Simonson, Rieken, and Smith as a substitute for "Prairie Soil" which is used throughout the U.S.

Brown Podzolic soils have a pH range of 3.8 - 6.4. Finally the Planosols have a range of 3.9 - 6.0.

The Grey-Brown Podsolic and Planosols are the soils which show tendencies to be highly corrosive. The existance of the different soil types is shown in Figure 5.

Figure 5 was sketched by using the soil maps of Iowa and Minnesota.[1] Figure 6 indicates the soil areas that are potentially the most corrosive. The area along the Mississippi extends northward into Minnesota and is comparable to Area II of that state.

## 5.0 ECONOMIC CONSIDERATIONS

In discussing the selection of different types of materials to be used by the ISHC in culvert construction, the life of the structure must be assumed. The life of a culvert depends to a great extent on its location within the state. Figure 5 shows the area of the state that has existing soil conditions that will yield a culvert "in service life" of 50 plus years. The worst conditions exist in the southeastern regions of the state, where highly corrosive "mine water" has caused some pipes to corrode in a mush shorter period of time than 50 years. In this area, corrugated metal pipe has an approximate life expectancy of 25 years. [redacted] The life of a concrete pipe is expected to be longer due to the availability of protective coatings. The design life of concrete culverts will be assumed to be 50 years[3].

## 5.1 Annual Cost Analysis

Some assumptions must be made before beginning a cost analysis. In this report the following assumptions were made: (1) an interest rate on investments of 4% will not change over the next 50 years; (2) construction costs will not change appreciably over the next 50 years, (3) 178' pipe under a 5' fill on an interstate project is a typical installation.

### Corrugated Metal Pipe

Length x construction cost (1967) = Total initial cost

178' x $5.83[c]/lineal ft. = $1,037.74

Principal x (crf - 4% - 50 yrs.) = Annual cost
(crf - 4% - 50 yrs.) = 0.04655020

1,037.74 (0.04655020) = $48.31

### Replacement Costs

(1) Remove and Replace pavement
30 Syd. x $20/sy = $600

(2) Excavation and Removal of existing pipe
178' x $2.50/lineal foot = $445

(3) Detour in Median (including temporary surfacing) 2,500 Cy x $.50/CY = $1,250

(4) New Pipe
178' x $5.83 = 1,037.74
Total...3,332.74

Annual cost of $3,332.74 invested 25 years from now = principal x present worth factor x capital recovery factor.

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c based on average cost for the first 9 mo. of 1967.

(pwf' - 4% - 25) = 0.26223370
(crf - 4% - 50) = 0.04655020
Annual Cost = 3,332.74 (0.26223370) (0.046555020) = $40.68

Total Annual Cost = $48.31 + $40.68 = $88.99

Concrete Culvert Pipe

178' x 7.03 (1967 average) = $1,251.34

Annual cost = 1,251.34 (crf. 4% - 50 years) = 1.251.34 (0.04655020)
= 58.25

Stainless Steel Pipe

178' x 14.37[d]

= 2,557.86

Annual Cost = 2,557.86 (crf. - 4% - 50 years)
= 2,557.86 (0.04655020)
= 119.07

These costs reflect the high annual costs associated with the stainless steel pipe. Comparatively, they amount to, 33¢/lineal foot for concrete pipe, 50¢/lineal foot for corrugated metal pipe and 67¢/lineal foot for stainless steel pipe.

## 6.0 CONCLUDING REMARKS

There are a few comments that should be made in regard to some statements contained in this report. The values of the pH of the water flowing in the stream bed was determined with a wide band litmus paper which depended entirely on somewhat gross color comparisons.

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d Price per foot figured on the basis of $.29/lb quoted by Mr. Thorpe at the fabrication on 12 April 1967 plus the installation cost of galvanized pipe. (See Appendix B for Calculations.)

There is no definite correlation between pH of local water and pH of local soil. There have been no pH tests performed on the local soil. Therefore, the local soil pH is unknown. Many variables are associated with corrosion studies in pipes that have as yet, not been correlated in this study.[6] These include the hydrogen ion concentration, electric potential, degree of saturation with calcium carbonate, flow velocity, and factors such as grade of inlet, and grade of culvert. Some type of a study will have to accompany this installation to indicate the condition of other culverts in the general area. Without this data, proper analysis of the stainless steel pipes, cannot be complete.

In the economic analysis, the design life of the pipes contains many variables. The life of the concrete and galvanized pipes was predicted from the data available. The only available data on stainless steel pipe infers that they have a theoretical life of infinity.

At present, the policy on culvert pipes in Iowa is to use concrete culverts under roadways, and it is left up to the contractor to select the type of pipe he wants to use for entrance pipes. Therefore, at present, stainless steel pipes could be placed at entrance locations only. Even though the life of the stainless steel pipe is infinite, the life of these entrances is not. It is rather hard to believe that the entrances and possibly the roadway would not be re-worked, if not reconstructed, in 50 years. This is how the 50 year life for the stainless steel pipe was assumed.

When one looks at the data pertaining to flow in section 4.1, it is obvious that no large quantities of water flow through the test pipes in an average year. With a more judicious study, it is conceivable that a more desirable location could have been selected, and therefore more meaningful data extracted.

## 7.0 PLAN OF EVALUATION

The continuing plan of study of these pipes consists of periodic visual observations with short written reports to be submitted by the observer. The velocity of the water will be checked, along with the pH of the water. These observations will continue for an undertermined period of time.

## 8.0 REFERENCES


1. Durability Design Method for Galvanized Steel Pipe in Minnesota, Minnesota Members of Nations Corrugated Pipe Association, Spring, 1967.

2. "Understanding Iowa Soils", Simonson, Riecken, Smith 1952.

3. Report on Limited Condition Survey of Galvanized Corrugated Metal and Concrete Pipe Drainage Structures, unpublished internal report, Materials Department Report R-164, by DeYoung, Stewart, Boring.

4. "Magnitude and Frequency of Iowa Floods", Schwob, Bulletin Number 28, Iowa Highway Research Board.

5. "Why Stainless Steel Culverts?" Allegheny Ludlum Steel Corporation.

6. "Durability of Corrugated Metal Culverts", state of New York Department of Transportation, Research Report 66-5, Nov-1967.

## APPENDIX A

### Computation of Flow Time

$t_{e} = \frac{LV_W DQ}{vV_B D_F}$ (AREA) % Area actually flow assumed =

$Vw = \frac{33 \text{ in./year}}{12 \text{ in./ft.}} \times 36 \text{ acres} \times 43{,}560 \frac{\text{ft.}^2}{\text{acre}}$

$= \left(431{,}244 \frac{\text{cu. ft.}}{\text{YR}}\right)(1 \text{ YR}) = 431{,}244 \text{ ft}^3$

Area $= \pi d^2/4 = (\pi)(1.25)^2/4 = 1.22 \text{ ft}^2$

~~$V_B = 3 \times 4 \times 87 = 1044$ cu. ft.~~

$V_{assumed} = 2.8$ ft/sec.

~~$t_e = \frac{87}{2.8} \times \frac{431,244}{1,044} \times \frac{4}{1.5/12} \times \frac{1}{3600} \times \frac{1}{29}$~~

= 4.74 days

% of time water flowing $= \frac{4.74}{365} \times 100 = 1.30\%$

assume it runs clear full

$t_e = \frac{431{,}244 \text{ ft}^3}{(2.8 \frac{ft}{sec})(1.22 \text{ ft}^2)} = \frac{}{3.416}$ Sec. 126,242 Sec

12 for R.C.B.

now assume only .365 eff area

~~60 sec~~ $\left(\frac{1 \text{ min}}{60 \text{ Sec}}\right)\left(\frac{1 \text{ hr}}{60 \text{ min}}\right)\left(\frac{1 \text{ Day}}{24 \text{ hr}}\right)\left(\frac{1 \text{ Yr}}{365 \text{ days}}\right)$

$36 \times 10^2 \times .24 \times 10^2$

$t_e = 4.75$ days

$(3600)(24)$

$= 8.64 \times 10^4$ Sec/day

$\frac{126242 \text{ Sec}}{8.64 \times 10^4} = 1.5$ days

$\left(\frac{1 \text{ Day}}{8.64 \times 10^4 \text{ Sec}}\right)$ thru pipe

## APPENDIX B

Assume a pipe of one ft. length, 24 inch diameter, and 12 gage size.

24 inch, 12 gage weights 39.6 lbs./ft.[5]
at $.29/lb.
    cost = 39.6 ($0.29) = $11.48

weight of 24 inch, 12 gage CMP
    = 29.4 lbs./ft.
cost = 29.4 lbs./ft. ($0.10/lb.)[e] = 2.94

construction costs (1967) for CMP
    = $5.83/ft.

∴ installation = 5.83 - 2.94
    = 2.89/ft.

construction cost for stainless steel will be
    = $11.48 + $2.89
    = $14.37/ft.

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e $.10/lb was quoted by Mr. Thorpe for CMP same time as the price of $0.29 for the Stainless Steel.

$\frac{1.5 \text{ inches deep}}{12} = ft = .125\,ft$

$(3')(.125\,ft) = .375\,ft^2$


or ~~.375 ft² / ...~~ = AREA EFFECTIVE

$$te = \frac{431,244}{(2.8)(.375\,ft^2 \text{ eff area})} = \frac{431,244\,ft^3}{1.05\,\frac{ft^3}{sec}} = 410,708\,sec$$

$$\begin{array}{r} ^{3}\\ 2.8 \\ \times .4 \\ \hline 1.12 \end{array}$$

$$\frac{41,0708\,sec}{8.64 \times 10^4\,\frac{sec}{day}} = 4.75\,day$$

# RELATIVE SERVICE LIFE OF VARIOUS GAGES OF CORRUGATED METAL PIPE

Lighter gage corrugated metal pipe than that required in current, standard gage-fill height tables is being advocated by some steel companies in their current advertising campaigns. Use of these lighter gages, they say, is made possible by using either the 3" x 1" corrugation (instead of the more common 2⅔" x ½" corrugation) or the ring compression theory of design for the 2⅔" x ½" corrugation.

This advertising claims that substantial first cost savings are realized by use of the lighter gage metal, but before you count these savings you should ask: How long should the pipe last? Will the lighter gage metal furnish the service life requirements?

Obviously the service life of the pipe will be shortened by use of the lighter gage metal – by how much?

In their "Method for Estimating the Service Life of Metal Culverts, Test Method No. Calif. 643-B" the California Department of Public Works, Division of Highways, sets forth a method for estimating corrugated metal pipe culvert service life by measuring the electrical resistivity and pH of the surrounding soil. Curves have been developed based on studies of more than 12,000 culverts in the past 35 years to estimate this service life.

The following Gage Factor Table is used to estimate the relative expected service life for different metal gages:

| Gage | 16 | 14 | 12 | 10 | 8 | 6 | 2 | 0 | 000 |
|---|---|---|---|---|---|---|---|---|---|
| Factor | 1.0 | 1.3 | 1.8 | 2.3 | 2.8 | 3.3 | 4.3 | 5.0 | 6.0 |

Example: If the curves indicate a service life of 10 years for 16-gage corrugated metal pipe, 12-gage pipe will last 1.8 as long or 18 years.

While these Gage Factors relate the service life expectancy to 16-gage metal, the following table (derived from the above table) makes it possible to compare the expected service life directly for all gages of corrugated metal pipe.

So, in considering the required service life of a corrugated metal pipe in its intended environment, the engineer may specify a heavier gage pipe than the 3" x 1" corrugation or the ring compression theory may indicate – and find it much cheaper in the long run. Of course, if real permanence is required, he will choose concrete pipe.

## GAGE FACTOR TABLE SHOWING COMPARATIVE SERVICE LIFE FOR DIFFERENT GAGES OF CORRUGATED METAL PIPE

| GAGE | 16 | 14 | 12 | 10 | 8 | 6 | 2 | 0 | 000 |
|---|---|---|---|---|---|---|---|---|---|
| FACTOR — 16 ga. | 1.0 | 1.3 | 1.8 | 2.3 | 2.8 | 3.3 | 4.3 | 5.0 | 6.0 |
| 14 ga. | .8 | 1.0 | 1.4 | 1.8 | 2.2 | 2.5 | 3.3 | 3.8 | 4.6 |
| 12 ga. | .6 | .7 | 1.0 | 1.3 | 1.6 | 1.8 | 2.4 | 2.8 | 3.3 |
| 10 ga. | .44 | .6 | .8 | 1.0 | 1.2 | 1.4 | 1.9 | 2.2 | 2.6 |
| 8 ga. | .36 | .5 | .6 | .8 | 1.0 | 1.2 | 1.5 | 1.8 | 2.1 |
| 6 ga. | .3 | .4 | .5 | .7 | .8 | 1.0 | 1.3 | 1.5 | 1.8 |
| 2 ga. | .23 | .3 | .4 | .5 | .7 | .8 | 1.0 | 1.2 | 1.4 |
| 0 ga. | .2 | .26 | .36 | .46 | .56 | .7 | .9 | 1.0 | 1.2 |
| 000 ga. | .16 | .2 | .3 | .4 | .46 | .55 | .7 | .8 | 1.0 |

**EXAMPLE:** If you read on the 12-gage line, the expected service life of 16-gage metal is only 0.6 as long as that for 12-gage while for 6-gage it is 1.8 longer.