APPENDIX 14

CORROSION – ABRASION DESIGN PROCEDURE

I. CHECK FOR OLD EXISTING STRUCTURES

The most reliable information is still to be found in an old corrugated steel structure in the same location on the same watercourse. Old installations of this type are invaluable and should be the first consideration in any corrosion investigation for a proposed project. Oftentimes a little investigating upstream and downstream in the area will reveal useful installations under old roads, streets or parking lots.

Investigations of existing structures should be uniform and standardized for most useful results. The form shown in Figure 5-4 has been adopted by the National Corrugated Steel Pipe Association and is suggested for use.

II. CLASSIFY ENVIRONMENT, "NORMAL" OR "ACIDIC"

The environment, that is the natural soil and water, in the region in question may be classified by the level of hydrogen ion concentration or "pH". In many states a single classification will apply to the entire state with the exception of obvious unusual conditions such as salt water marshes, coal mining runoff and concentrated industrial effluents. In most sections of the United States the pH of the natural soil and water is fairly well established and the information available in the form of iso maps. Typical sources for this information are the U.S. Geological Survey, state departments of commerce, health and agriculture and the U.S. Soil Conservation Service.

Sites with a pH of 5.8 or more are classified as "NORMAL". Sites with a pH of less than 5.8 are classified as "ACIDIC".

III. METAL LOSS RATE

A. "NORMAL", pH = 5.8 or more

1. For ordinary installations of plain galvanized pipe, use a corrosion-abrasion rate of 0.0013 inch per year.

2. For unusually soft water installations, increase the above rate to 0.0030 inch for plain galvanized pipe as shown in Table 5-4.

TABLE 5-4
Estimated Years to Perforation on Invert of
Plain Galvanized Corrugated Steel Pipe
For NORMAL Conditions (pH ≥ 5.8)

Wall Thickness In Inches	Normal Water .0013 Inch per Year	Very Soft Water .003 Inch per Year
.064	49 years	22 years
.079	60	26
.109	84	36
.138	106	46
.168	over 100	56
.188	over 100	63
.218	over 100	73
.249	over 100	83
.280	over 100	93

B. "ACIDIC", pH less than 5.8

1. Follow the sampling and testing procedures on pages 220-223.

2. Use Chart in Figure 5-6 to estimate time to invert perforation.

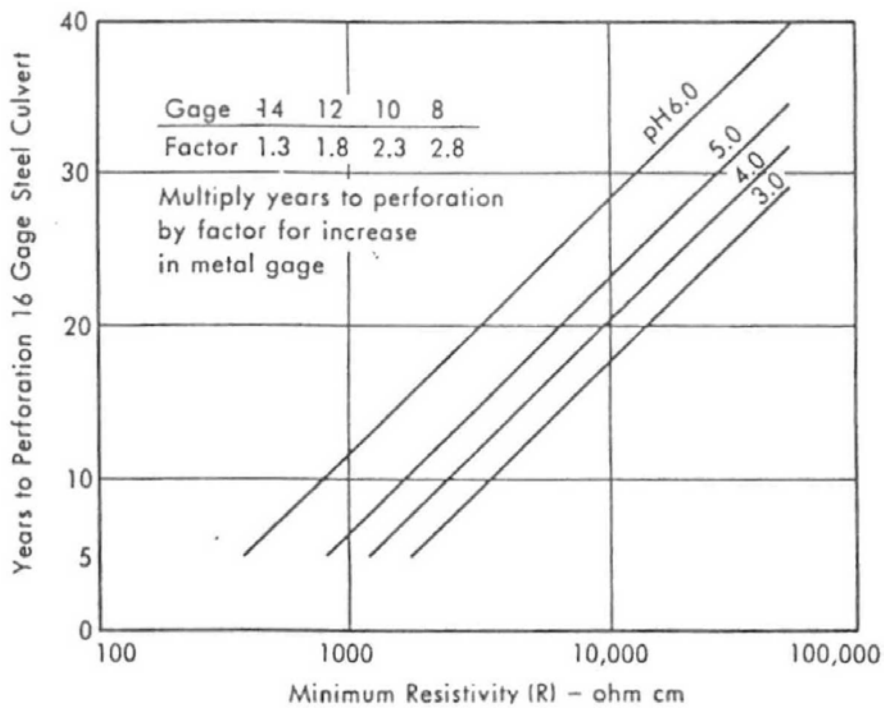

Figure 5-6
Method of Estimating Time to First Perforation for 16 Gauge Steel Pipe.
Excerpted from California Division of Highways Test Method 643-B.

IV. PROTECTIVE COATINGS AND PAVING

A. ASPHALT COATED ONLY (no pavement)

Asphalt coatings are quite useful in protecting pipe under many circumstances. Such coating is very effective on the pipe exterior. In those applications in which the exterior of the pipe determines its life, such coatings add approximately 25 years. Arid regions represent a typical environment in which pipe exteriors can determine pipe life.

The usefulness of coatings alone on the pipe interior is limited. Abrasive flow may remove the coating in the invert. New York observed approximately 10 years of added life for coatings alone while California found a 6-year addition. It is recommended that coatings (without invert paving) only be used for:

1. Protection of pipe *exteriors*. Add 25 years.

2. Pipe *interiors* in non-abrasive flows, free of ice action. Add 6 to 10 years.

B. ASPHALT COATING AND PAVING

Asphalt coating and invert-paving affords a much higher degree of interior protection to pipe than asphalt coating alone. For factory-made pipe, the poured asphalt pavement protects the critical invert area with a resilient mass. There is a limit to the performance of such paving as it is not suitable for very severe erosion situations such as those in which the bottom is torn out of normal structures in a season or two.

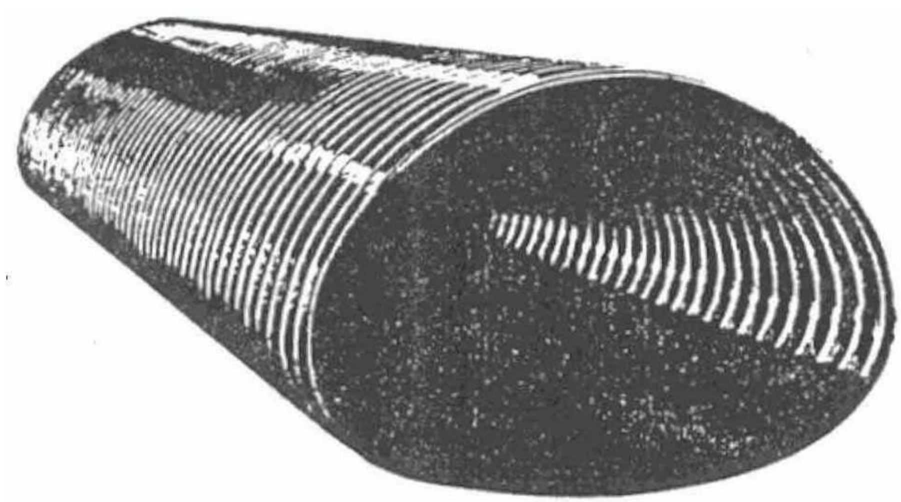

Figure 5-7
A thick pavement covers the bottom of the pipe or pipe-arch to a minimum depth of 1/8 inch. Such pavement protects against abrasion and the impact of gravel and boulders

California found up to 15 years of added life for asphalt pavements. However, this was based on a small number of installations, and most of these installations represented highly abrasive flow conditions and/or steep slopes. On the other hand, in New York, pavements extended pipe life "beyond practical limits of design life." It seems obvious that engineering judgment must be exercised in evaluating paving and assigning some number of years of life for it. The following guideline is recommended:

Table 5-5

Years of Life Added to Structures with Asphalt Paved Invert

Slope of Pipe	Abrasion	Added Years
Less than 1%	Mild	35
	Significant	25
1% - 2%	Mild	30
	Significant	20
3% - 4%	Mild	25
	Significant	20
Greater than 4%	Mild	20
	Significant	15

V. CULVERT GRADE STAINLESS STEEL, TYPE 409

Sites of aggressive corrosion and abrasion are potential applications for this relatively new type steel pipe. Using the corrosion design methods previously described or those published by the American Concrete Institute for rigid pipe may indicate prohibitively short service life. In these cases the first cost becomes much less significant than for normal applications. Typical sites or applications are listed here.

A. ACID MINE WATER DRAINAGE

Conventional concrete and metal pipes have in some instances shown a life of less than a year in acid mine water drainage. However, test installations of culvert-grade stainless steel, placed in 1966, have under these conditions shown no observable corrosion. There is every reason to believe that an indefinite service life may be assigned.

B. SALT WATER

This environment has proved most severe for conventional pipe materials. After three years of exposure to tidal salt water, culvert-grade stainless steel pipe is still in excellent condition with only superficial staining but no loss of metal.'

C. ABRASION

Stainless steel, type 409, has been thoroughly tested for pipe line transmission of coal slurries and other highly abrasive materials. In this service it has provided many times the life of other pipe line materials. Culvert test pipes of this stainless steel installed under highly abrasive conditions have shown virtually no metal loss over a period of years.

For these three conditions – acid mine water drainage, salt water and abrasive flow – culvert grade stainless steel pipe can be a sound economic choice even though the first cost may be as much as three times that of galvanized steel pipe. Structural design should be based on minimum thickness required, as in Chapter 3. The service life is provided by the premium material, stainless steel. It defeats the economic purpose to also increase thickness beyond the structural requirement.

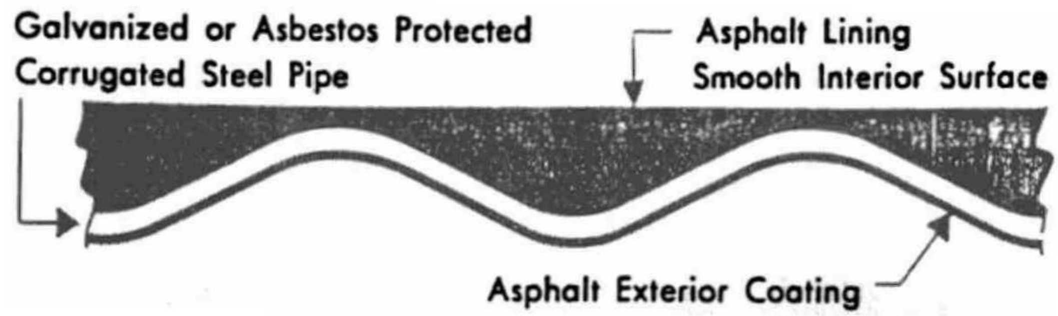

Figure 5-8
Cross Section of Bituminous Spun Lining Over the
Complete Interior Periphery of Corrugated Steel Pipe

VI. "DESIGN LIFE"

The foregoing parameters may be applied to the minimum structural design obtained in Chapter 3 to determine the average number of years before perforation may be expected in the pipe invert. This figure establishes the length of time the structure is likely to operate without material maintenance. After that it is likely to operate without material maintenance. After that it is quite possible to extend the useful life of the structure with a field-applied pavement or lining.

What is the required "time to invert perforation" of a particular structure? Logically it is quite variable, being a matter of economic comparisons of initial cost and interest on investment versus repair costs at future dates. However, it is common practice to establish a standard DESIGN LIFE for drainage structures commensurate with the importance of the facility.

The term DESIGN LIFE refers to the period of service without major repairs. For example, the Federal Highway Administration requires a 50-year design life for Interstate Highways and this applies also to the culverts. Most state highway departments have comparable requirements for their highest level of construction. For less important installations a shorter design life is acceptable.

It is important to recognize that the structure does not crumble and collapse at the end of its DESIGN LIFE. This merely marks the estimated average time without repair costs.

VII. SELECTION OF FINAL PIPE DESIGN

From the appropriate chart (Table 5-4 or Figure 5-6), check the "time to invert perforation" for the pipe wall thickness required for structural design. If this equals or exceeds the established DESIGN LIFE for the structure, the minimum structural thickness is satisfactory for the final design.

If the time to perforation is less than DESIGN LIFE, there are several solutions possible. The most economical one is usually the most desirable. To find this, follow the procedure outlined below. Do not fall into the easy trap of arbitrarily increasing the metal thickness.

A. Check the possible alternatives required for hydraulic design. That is, possible size differences, applicable to invert paved or fully paved pipe. Clearly, if paving also assists in hydraulic requirements, it should be chosen to provide the added years required.

B. Consider the erosion factor at the site. If it is significant, again paving will be a logical first choice solution.

C. If a structural plate pipe is involved, additional metal thickness of the invert plate is normally the most economical solution.

D. For standard corrugated steel pipe, use this guideline: The combination of least metal thickness and invert paving that provides the required "time to perforation" will be the most economical solution.

EXAMPLE 1

From Chapter 3, "Structural Design", Example No. 1, a 48" culvert under 60' of fill required a wall thickness of 0.064" in either a $2^{2}/_{3}$" x ½" or 3" x 1" corrugation. Assume the following corrosion-abrasion conditions for this installation:

Environment: In this whole general area, the pH of soil and water is above 5.8. However, the water is very soft.
Slope of Pipe: S = 0.008 ft. per ft.
Abrasion: Silty bedload, no sharp, abrasive detritus.
General: Midwestern area, hilly, average rainfall

SOLUTION

1. No old existing structures available
2. Environment classifies as “Normal”
3. Metal Loss Rate: For very soft water, from Table 5-4, a loss rate of .003 iin. Per year will apply.
4. Coatings and Paving: Add 6 years for asphalt coating alone. From Table 5-05 add 35 years for coating and paving for mild abrasion and less than 1T slope.
5. Design Life: Culvert under Interstate Highway. Requires 50 years without major repair.
6. Selection of Final Design: From Table 5-4, .064” wall = 22 yrs.
.138” wall = 46 yrs.

   Alternatives:
   1. .064” wall + coating and paving = 22 + 35 = 57 yrs.
   2. .138” wall + coating = 46 + 6 = 52 yrs

   Select .064” wall, coated and paved, as most economical solution.

EXAMPLE 2

From Chapter 3, Example 2, a 120” diam. Pipe in 3” x 1” or 6” x 2” corrugation under 65’ of fill requires 0.168” wall thickness. Assume the following corrosion-abrasion design factors:

Environment: pH of soil and water is 5.0 in this area.
Slope of Pipe: S = 0.015 ft. per ft.
Abrasion: Small fractured rock and sharp sand bedload plus evidence of abrasion.
General: Mountainous area; heavy rainfall

SOLUTION:

1. No existing steel structures on same water course. Ten-year old concrete box upstream shows significant abrasion in invert.
2. Site classifies as “Acidic”
3. Metal Loss Rate:
   a. Soil resistity at site measured 4500 ohm-cm
   b. From Figure 5-6, time to perforation for .064” thickness = 18 years, Metal Thickness factor for 0.168” is 2.8. Years for 0.168” = 2.8 x 18 = 50.4 years.
4. Coating and paving. Asphalt paving not available in 120” pipe. Asphalt coating not recommended for interior protection in abrasive conditions.
5. Design Life. Major highway, requires 50 years.
6. Final Design: The structural design thickness of 0.168” provides the required design life. However, the evidence of significant abrasion indicates added invert protection. Recommend heavy invert plat of 0.218” thickness for 6” x 2” structural plat pipe or field-installed concrete pavement for a 3” x 1” pipe.

VIII. SUMMARY

The tools are available for confident design of galvanized corrugated steel structures for corrosive and abrasive effects. Moderan comprehensive investigations in such states as California, New York, Washington, Minnesota and Kansas are the basis for the recommended design procedure presented.

IX. MAINTENANCE

The following quotation is taken from the U.S. Soil Conservation Design Manual: "All structures need maintenance for satisfactory operation and to prolong their life, thereby reducing replacement cost. Owners should be urged to inspect structures at least once annually and at other opportune times. Cracks that develop should be sealed, protective coatings applied where needed, and modifications, riprap, or repairs made where and when they are necessary. Often a small repair job will prevent a large repair job, or even complete failure, later on. Debris or obstructions at the inlet or outlet of structures should be removed immediately."

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