

Durability of Plain Galvanized Steel Drainage Pipe in South America: Criteria for Selection

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Durability of plain galvanized steel drainage pipe is associated with climate/terrain features that influence water/soil chemistry. The diverse climate/terrain features of South America provided a convenient setting for development of a regional approach to selective galvanized pipe application based generally on these features and more specifically on measured water/soil chemistry trends.

Reports of durability problems on plain galvanized culvert pipes in certain areas of South America have become a significant concern in recent years. Most of these problems have been caused by accelerated waterside corrosion of pipe inverts. Problems first appeared in Brazil in and near the Amazon Basin of northern Brazil (1). When other countries began to report durability problems, it became increasingly evident that Armco needed a reliable way to determine where plain galvanized pipe should not be used. Methods in current use in the United States have not proven to be sufficiently reliable. The present report is a condensation of the results of Armco studies in several countries of South America. A method is presented for selective use of galvanized to minimize future durability problems.

GENERAL APPROACH TO PLAIN GALVANIZED SELECTION

The application of pipe products in South America is influenced by the dependence of material durability on environmental conditions and the distribution of certain types of corrosive hostile environments over large regions of some countries. Achieving maximum utilization of a product while keeping maintenance problems at a minimum necessitates the use of an effective selection method. On the larger scale, selection involves limiting use in more hostile regions and concentrating on regions where conditions are more favorable. For reasons that will become obvious from reading the body of this report, the continent can be divided along the lines of climate and terrain into large geographical regions with different levels of environmental corrosivity toward plain galvanized pipe.

The regional approach to galvanized selection is ultimately combined with Armco studies on water/soil chemistry trends within individual regions because chemistry trends are the primary reason for durability variations. Climate and terrain features of each region are useful on a broad scale because they control water/soil chemistry, and chemistry testing defines regional trends more accurately. A specific durability esti-

mation technique based on field durability and chemistry studies has been developed and is discussed in detail by the author elsewhere in this Record. A general discussion of the regional aspect of selection and the durability estimation technique is provided here.

Ongoing water/soil testing in all regions of the continent would be valuable to ensure optimal accuracy in classifying regions according to their durability trends. Ongoing data generation will refine and adjust regional guidelines until accuracy is optimal in all respects. No Armco data are available yet for some regions, and our classification in these cases is based mainly on indirect climate/terrain data that are useful but not conclusive, so such classifications may be temporary. Additional regional water/soil testing can be accomplished on a random basis or along the routes of individual new highway projects. The latter approach has the added attraction of maximizing the prospects for good performance on individual new projects, which may be desirable on some major projects with high durability requirements.

GENERAL TECHNICAL BACKGROUND UNDERLYING SELECTION METHOD

Corrosion, an electrochemical process, and abrasion, a mechanical wear process, both contribute to galvanized pipe durability problems, but corrosion is the more important problem for any country as a whole. Corrosion problems can occur on different types of terrain, whereas important true abrasion occurs only in or near mountainous/hilly terrain where periodic movement of rock and sand at high velocity during rainfall is encountered. Galvanized selection on the basis of abrasion potential is a separate subject that will be dealt with in a future Armco report.

Factors Controlling Corrosion Behavior

Waterside Corrosion

Advanced waterside corrosion within the lower half or lower quadrant of the pipe circumference has been the more common corrosion problem observed in field inspections conducted in South America, the United States, and elsewhere (2-6). Published literature in related fields of technology indicates that several factors influence corrosion in waters. Some factors are of predominant importance, and evaluating them should permit a reasonably accurate determination of the

durability of galvanized. The most important factor is water chemistry, the essential elements of which are pH, total dissolved solids (usually denoted by conductivity or resistivity), hardness, and alkalinity. Some nonchemical factors of substantial importance include degree of agitation, temperature, and time of water contact.

Water Chemistry Hardness and alkalinity salts common to natural waters tend to form partially protective mineral scales or films that hinder corrosion of reactive metals like zinc and steel which otherwise would tend to corrode excessively (7; 8, pp. 16, 29, 32, 140; 9, pp. 160, 638; 10, p. 76; 11, p. 2.15, 2.16, 2.25). These salts, chiefly bicarbonates of calcium and magnesium, are sparingly soluble and tend to produce precipitates (primarily CaCO_3) that deposit onto corroding metal surfaces due to local surface chemical changes induced by corrosion. These salts also tend to modify metal corrosion products to encourage formation of a protective insoluble corrosion-product scale. The precipitated salts combine with modified insoluble corrosion products to form the protective scale. Soft, pure low-conductivity waters containing very little of any type of dissolved salt, including hardness/alkalinity salts, tend to be fairly corrosive because they possess no scaling tendency and they lack the buffering capacity that leads to pH lowering. Under such conditions, a less effective unmodified corrosion product scale is the main type of protection possible. The pH and the total dissolved salt content (or conductivity) are very important, partly because excessive acidity or high chloride or sulfate concentrations tend to prevent or interfere with scale formation. Acidity and chloride/sulfate salts are also inherently corrosive apart from their effects on scaling. The balance between hardness and alkalinity on one hand versus acidity and chloride/sulfate salts on the other is critical in determining whether protective scaling or excessive corrosion will occur (12; 13, p. 463).

Other Factors Velocity becomes a significant factor when water is sufficiently turbulent or contains enough suspended solids to promote scouring of metal surfaces, removing protective scales and producing accelerated corrosion called erosion corrosion (11, pp. 2.15, 2.16, 2.25; 14, p. 7220). Erosion corrosion is accelerated by increased water corrosivity as well as by increased velocity. Water movement serves to help aerate water and ensure high concentrations of the dissolved oxygen necessary to support corrosion (15, pp. 149, 161). Temperature becomes an important factor in waters where no useful protective scaling occurs (8, p. 16, 29, 32, 140), so temperature differences among different climates are important for nonscaling waters. Time of water contact obviously becomes a very significant factor in dry climates where most pipes are dry most of the time. It is also a very significant factor in any climate for pipes or pipe zones that are dry except for times of surface runoff during and shortly after rainfall.

Soilside Corrosion

Soilside corrosion is a complex and highly variable process, but does not usually control pipe life because, for several reasons (16, 17), typically overall soilside corrosion is much less aggressive than overall waterside corrosion (1-6).

Obviously, in soils there are no problems with abrasion or erosion corrosion, and the near-static state of soil moisture leads to reduced kinetics of overall corrosion due to reduced dissolved oxygen. In less porous soils, oxygen availability for corrosion will be low and will further ensure low overall corrosion rates (although pitting corrosion is likely to increase). In more porous soils where oxygen availability is high, protective corrosion product scales normally help ensure low overall corrosion rates (corrosion product scales are more effective on the soil side). Because of corrosion-mitigating factors like these, there is no overall dependence on CaCO_3 -type scaling for good performance as there is on the waterside. Those soilside corrosion problems that do sometimes occur are found mainly in dry climates where (a) the natural content of chloride/sulfate salts is high and (b) rainfall is inadequate to leach away soluble salts, but some groundwater moisture is present. Under these conditions, soilside corrosion will likely control pipe life because waterside flow will be infrequent. The likelihood of soilside corrosion problems is indicated reasonably well by pH/resistivity measurements.

Association of Pipe Durability with Climate and Terrain

Water/soil chemistry is controlled by climate/terrain features, and any attempt to categorize the chemistry factors that control plain galvanized pipe durability begins with a knowledge of the climate and terrain features that give rise to them (16, 18). This knowledge is immediately helpful in that it produces a basic understanding of the type and severity of problems most likely to be encountered in a given geographical region.

The most fundamental climatic feature controlling pipe durability is the total annual rainfall because it controls soil chemistry by determining the rate of leaching loss of soluble and sparingly soluble salts. The soil salt content remaining after many centuries of leaching controls the current chemistry of rainwater contacting it. Soft pure rainwater is inherently nonscaling and corrosive, but its chemistry is altered by contact with the soil. It dissolves a little soluble soil matter when it traverses the soil as surface runoff. It dissolves substantially more when it percolates through the soil a short distance and is discharged at slightly lower elevations in the form of shallow groundwater runoff (interflow). It dissolves the most when it percolates to greater depths and is slowly discharged at lower elevations. Surface runoff predominates in a stream flow during and very shortly after rainfall while any shallow groundwater runoff predominates for a longer limited time after. The groundwater runoff discharged from greater depths flows the longest and constitutes all or most of the flow of a stream existing a few days after a rainfall and all of that persisting through dry weather, so its chemistry is of primary importance. The degree and depth to which soil is leached control the chemistry of surface runoff and all groundwater runoff.

Variations in the total annual rainfall are the primary cause of the extreme variations in water and soil chemistry found in nature. At one extreme, there are corrosive soils and groundwaters rich in soluble chloride and sulfate that are found in some places in arid regions where rainfall is inadequate to leach away even highly soluble salts like these. At the other extreme, there are corrosive soft groundwater streams arising from soils that have been almost completely leached or even the sparingly soluble hardness/alkalinity salts to great

depths by prolific rainfall. In most countries, the majority of pipe sites have conditions somewhere between these two extremes and corrosion is usually less severe.

The controlling influence of rainfall on pipe corrosion has been demonstrated in various field studies. For example, studies by the highway departments of the states of Washington (5) and Oregon (2) revealed relatively poor plain galvanized performance in wet regions west of the Cascade Mountains and very good performance in drier eastern regions in the Cascades rainshadow. The California Department of Transportation (19) found a correlation between galvanized performance and annual rainfall and utilized environmental resistivity and pH values associated with different rainfall levels to develop a pipe life estimation method. Armco (6) found a correlation between galvanized performance and annual rainfall along the route of the Lamco Railway, in Liberia, Africa, which passes through a gradation of climatic conditions ranging from wet coastal to dry inland. In the wet, warm tropical climate of the Amazon Basin in Brazil, Armco (1) has observed severe galvanized corrosion more extensive than any problems found in drier tropical, subtropical, or temperate areas.

As noted above, rainfall influences the chemistry of soil and of the surface and groundwater runoff discharged from the soil. Temperature is also important because it influences plant growth and decomposition processes that give rise to organic and carbonic acids that increase the solubility of alkalinity/hardness salts and thus hasten salt losses by leaching. Temperature and rainfall both influence soil structure, and structure influences soil drainage and consequently influences the rate of loss of leached salts. The type of parent rock from which soil was formed is very important since calcareous rock produces considerable alkalinity and hardness while silicious rock produces considerably less. Variations in parent rock composition and consequent variations in soil type can produce abrupt changes in soil/water chemistry within a region where climatic conditions are uniform.

Ultimately the effects of rainfall, temperature, soil structure, and parent rock composition are combined and manifested in the type of soil they produce. Thus soil type provides a useful reference by which to judge prospects for the suitability of galvanized drainage pipe. In the United States, soil type has been utilized at times within individual states as a broad indicator of galvanized pipe durability (20–22). The crucial aspect of soil type is the amount of base supply, which is the source of alkalinity/hardness salts. A soil-type map that delineates the amount of base supply is very useful. Such a map illustrates the soil type in continuously wet, warm tropical regions of northern Brazil, southern Venezuela, and eastern Colombia where soil leaching is so advanced that no base supply remains and groundwater and surface runoff corrosivity is severe. In somewhat drier tropical and subtropical regions with a prolonged dry season, such as in eastern/southeastern Brazil, there is a little significant retained base supply and pipe durability is considerably better in general. Drier tropical regions, such as those in northeastern Brazil, western Ecuador and Peru, and northern/western Venezuela and Colombia, have substantial soil base supply. Mountainous tropical regions of Ecuador, Peru, Colombia, Venezuela, and Brazil have substantial base supply even in wetter climates because massive mountains and hills resist leaching longer and less rainfall is available to infiltrate and leach soil on steep terrain because more is lost as surface runoff. Wet and dry temperate regions in Argentina, Chile, and Uruguay have the greatest base sup-

ply on the continent and are the most favorable regions for galvanized application.

Total annual rainfall and storm activity are important for the amount and velocity of surface runoff they produce. When these factors are high enough, they may lead to prolonged runoff contact time and/or sufficient turbulence to accelerate corrosion notably in the pipe high-water zone or in the invert of pipe that handles only surface runoff (normally dry).

Problems Caused by Soft Pure Nonscaling Streamwater

The main cause of plain galvanized pipe corrosion in South America is the soft, pure nonscaling streamwater common to wetter climates. This problem is most severe in warmer, wetter climates of the tropics where soils have been leached to great depths by high rainfall, good drainage, and vegetation. Vegetation is important because the warm climate accelerates plant metabolism with consequent accelerated plant decomposition and generation of organic acid and CO_2 . These acids accelerate dissolution of soil hardness/alkalinity salts by increasing their solubility and thus hastening leaching loss of these vital salts. When soils are leached to great depths, all groundwater runoff will be pure and soft; and since groundwater constitutes the predominant stream flow with greatest pipe contact time, corrosion problems can be expected. The severity of corrosion is further increased by elevated water temperature and by the prevalent acidity from plant decomposition that is discharged into streams. Corrosion is also exacerbated by prolonged heavy rainfall and frequent storms that cause prolonged periods of fast-flowing high water, often leading to erosion corrosion problems in the corrosive stream water.

While soft acidic water in the warmer, wetter tropics limits the life of galvanized pipe to the extent that it is often an inadequate material, soft waters in cooler or drier temperate, subtropical, and tropical climates tend to be considerably less harsh. Lower temperatures and lesser rainfall reduce soil leaching and acidification. These conditions also reduce plant metabolism functions to the degree that acidity from plant decomposition is less prevalent, and soft waters tend to be only mildly acidic or even slightly alkaline. Groundwater in streams tends to have some significant alkalinity and hardness contents, and the result is sufficient pipe durability in softer waters to permit use of galvanized on many projects and certainly on those with limited life requirements such as culverts on secondary, tertiary, or private roads.

Problems Caused by Excessive Free CO_2 and Higher Conductivity Combined

Another important type of durability problem with plain galvanized occurs in waters of appreciable free CO_2 (carbonic acid) and higher conductivity. Such waters are found in areas of moderately wet tropical, subtropical, and temperate regions where rainfall is not sufficient to cause complete soil leaching or in wetter regions where mineral-rich soils have resisted complete leaching longer. In waters of such areas, sometimes much of the natural alkalinity reacts with and is consumed by organic acidity from decomposition of abundant vegetation while CO_2 from decomposition increases because it does not

react with HCO_3^- alkalinity. Alkalinity is essential for scaling control of corrosion, and replacement of beneficial alkalinity with detrimental acid reaction salts combined with the influence of increased CO_2 and sustained higher conductivity can cause severe general and pitting attack of pipe inverts. Excessive free CO_2 suppresses scaling and directly accelerates corrosion, and the combined effect of excess CO_2 and higher conductivity can be very severe. Slow flowing streams in areas with somewhat impeded drainage are more likely to be rich in free CO_2 because higher velocity greatly aerates the water and drives off CO_2 (8).

Problems Caused by Sulfuric Acid

Occasional problems with inorganic sulfuric acid occur in areas with mine or outcropping drainage.

Problems Caused by Extreme High Conductivity Due to Salinity

In very dry or arid climates, plain galvanized pipe generally performs very well because water flow is generally brief and infrequent. Flowing or stagnant highly saline groundwater, high in conductivity due to high chloride/sulfate salinity, can cause problems at some pipe sites. Soilside corrosion problems can occur where the soil is rich in chloride/sulfate salts, although high pH and limited soil moisture availability tend to control such corrosion. Highly saline waters and soils occur mainly in arid regions where no salt leaching loss occurs. Of course, highly saline seawater or estuary water is a problem wherever it is found, and galvanized should not be installed wherever contact with such water is likely.

Problems Caused by Erosion Corrosion

Erosion corrosion is induced by increased water corrosivity as well as by increased velocity because protective scales that form in corrosive waters are less tenacious and are more easily removed or interfered with. In this writer's experience, erosion corrosion problems are usually associated with surface runoff due to the combined effect of its higher velocity and appreciable corrosivity from lesser scaling salt content, which under certain conditions are troublesome despite limited pipe contact time. Such problems occur in the pipe high-water zone or in the invert on pipes that are normally dry where soft turbulent surface runoff exerts its influence. Groundwater runoff normally does not induce erosion corrosion due to its limited velocity and lower corrosivity, and this is true even in mountainous/hilly terrain where velocity can be substantial but groundwater scaling tendencies are normally appreciable. Groundwater runoff of moderate velocity can induce erosion corrosion when water corrosivity is very high, as is the case with soft acidic waters of some wet tropical regions.

COATING/PAVEMENT PROTECTION FOR CORRUGATED STEEL PIPE IN HOSTILE REGIONS

The writer has had considerable experience with certain kinds of coating/pavement materials that improve the durability of

corrugated steel pipe to permit its use in streams of hostile regions, but some of these materials are not currently available in South America. Thick hot-dip asphalt mastic coatings add substantially to the service life of plain galvanized pipe in warmer climates (4, 6). Thick asphalt or concrete pavement is effective in combating abrasion and adds considerably to the service life of plain galvanized in many corrosive streams (4, 16). A thick bitumen coating mechanically bonded to a galvanized substrate through a fiber mat partially embedded in the zinc coating provides good protection against severe corrosive streams and soils (16, 23). Aluminized steel (Type 2) has superior resistance to the corrosive effects of dissolved oxygen, CO_2 , organic acid, and water turbulence that cause most of the problems on plain galvanized (24). Epoxy-coated steel has a field history of good performance in highly corrosive waters (25, 26), and field tests and experience on a fusion-bonded epoxy-powder coating in Brazil and the United States show good results in corrosive waters (results may be published later).

DEVELOPMENT OF A GALVANIZED PIPE SELECTION METHOD

The selection process for plain galvanized steel pipe is based on dividing the continent into regions on the basis of soil type and then further characterizing each region according to average annual rainfall and average annual storm activity. These combined factors determine in a general way the surface runoff corrosivity trends of each region, and these trends are sufficient to characterize pipe corrosion behavior in the high-water zone and in the invert on pipes that are normally dry. Even for pipes that are normally dry, waterside corrosion normally controls pipe durability in all but drier climates (<500–600 mm/year). While corrosion by surface runoff is normally controlled adequately by the relatively brief pipe contact time, some conditions can lead to problems. Obviously, leached acidic types of soil can produce very soft and somewhat acidic runoff of high potential corrosivity, and high annual rainfall can increase contact time substantially. Furthermore, high storm activity can produce enough velocity and turbulence to induce erosion corrosion problems.

Soil type and annual rainfall also control soil/groundwater chemistry trends within a region, but because of prolonged contact time, more specific chemistry data are needed to characterize durability trends more accurately. In drier climates with less than 500 to 600 mm/year rainfall, soil resistivity and pH will be of primary importance whereas in wetter climates, groundwater pH, resistivity, alkalinity, and hardness are the primary factors. When testing has established water or soil chemistry trends, different regions can then be ranked according to their potential for durability problems.

RECOMMENDED REGIONAL GUIDELINES FOR GALVANIZED APPLICATION

Recommendations on where to concentrate on galvanized application and where to limit it are based on the writers' best knowledge of field performance and environmental conditions and are subject to change as field experience broadens. Regions are listed below in a descending order of preference for concentration of galvanized application corresponding to the order

of increasing possibility of corrosion problems. The order may change a little as more data become available. Regions in categories A, B, and C are the most favorable for galvanized application with regard to corrosion potential, and the need for additional water/soil testing on the local project level is minimal, being limited to some major projects with high durability requirements. Regions in the intermediate categories D and E are favorable, but there is a greater need for water testing on the local project level. All regions in the relatively low category F are there largely because of a lack of data, and when data become available any or all of these regions could rise to categories E, D, C, B, or A. In regions in categories G and H, galvanized application should be limited on the basis of the potential for corrosion problems. It is important to realize that limited application will apply to certain other regions on the basis of abrasion potential once abrasion studies are completed.

Limited application of galvanized in hostile regions refers primarily to limiting use of plain galvanized on projects with high durability requirements. General use of plain galvanized could still apply on some projects or types of sites without high durability requirements, such as secondary or tertiary roadways and driveway culverts. On projects with high durability requirements, sites with streams having prolonged flow are the major concern. Plain galvanized may be satisfactory for sites that are normally dry. At sites with flowing streams in hostile regions, plain galvanized can often be used in structural-plate arches and in the upper half of structural-plate pipes and pipe arches. In streams of marginally hostile regions, galvanized can sometimes be used throughout larger full structural-plate pipes and pipe arches because some larger streams with substantial dry weather flow velocity are less corrosive due to enhanced aeration and very low free CO₂ content (testing of water at each individual site is justified by the large economic investment). Obviously, plain galvanized can be used in any region for projects involving only soil exposure such as structural-plate highway/street/railway underpasses and some tunnel liners.

Category A. Durability, as indicated by data and climate/terrain features, is best in the following regions:

1. Chile—All regions except as noted in C and F.
2. Argentina—All regions except as noted in E and F.
3. Uruguay—All regions.

Category B. Galvanized will have wide application, as indicated by data and climate/terrain features, but soft water and CO₂/conductivity problems are possible in some areas.

1. Northern and western Colombia and Venezuela (out to limits of Andes and Costa Mountains)—All drier regions (<1500 mm/yr), all temperate/cool high altitude areas.

2. Northeast Brazil—All drier areas (<1500 mm/yr) in provinces of Ceara, Bahia, Piaui, Pernambuco, Paraiba, Rio Grande do Norte, Sergipe, and Alagoa except as noted in G (little data available but favorable climate over large areas of this region).

3. Ecuador and Peru—All drier regions (<1500 mm/yr), all temperate/cool high altitude areas.

Category C. Galvanized will have wide application, but as indicated by limited data and climate/terrain features, some soft water or CO₂/conductivity problems are likely in some areas.

1. Southern part of eastern Brazil—Provinces of Rio Grande do Sol, Santa Catarina, Parana, Sao Paulo, Rio de Janeiro, and Mato Grosso do Sul.

2. Southwest Bolivia and eastern Paraguay—All drier regions (<1500 mm/yr), except as in F (no data but favorable climate and terrain).

3. Portions of eastern Brazil—Drier areas (<1500 mm/yr): provinces of Goias and Minas Gerais.

4. Portions of southern Chile—Wetter areas (>1500 mm/yr), except as noted in F.

Category D. Galvanized should have substantial application, but data are limited and climate/terrain should produce soft water or CO₂/conductivity problems in some areas.

1. Ecuador and Peru—Wet regions (>1500 mm/yr), except as noted in F.

2. Northern and western Colombia and Venezuela—Wet regions (>1500 mm/yr), except as noted in G.

Category E. Galvanized should have substantial application, but some serious CO₂/conductivity problems in some areas are indicated by data and climate/terrain features.

1. Brazilian provinces of Acre, Rondonia, and Mato Grosso.

2. Argentina in province of Entre Rios and possibly in areas of other nearby provinces.

Category F. Galvanized may have wide or at least useful application, but there are not enough field data to use for guidance, and climatic/terrain conditions could cause severe soft water, CO₂/conductivity, or salinity problems. It would be best to limit application of galvanized or to conduct local project testing until more comprehensive data indicate otherwise.

1. Portions of eastern and northeastern Brazil—including provinces of Espirito Santo and Maranhao and all areas in other provinces (categories B and C) having >1500 mm/year rainfall.

2. Northern and western Colombia and Venezuela, southern Chile, eastern Peru, and parts of Ecuador—extreme wet areas where rainfall is >2000 mm/year.

3. Bolivia—all areas outside southwest and salt flats in southwest.

4. Northern and western Venezuela for a limited distance beyond the Andes and Costa Mountains—provinces of Delta Amacuro, Monagas, Anzoategui, Guarico, Cojedes, Portuguesa, and Barinas.

5. Argentina and western Paraguay—Gran Chaco region and salt flats in northwestern Argentina.

Category G. Galvanized may have useful application, but in some regions, limited data reveal probable widespread soft water, salinity, or CO₂/conductivity problems; and in other regions, unfavorable climate/terrain conditions are likely to cause severe widespread soft water problems. Galvanized application should be limited except where local project testing indicates otherwise.

1. Entire countries of Surinam, Guyana, and French Guiana.

2. Northeastern Brazil—eastern coastal areas in provinces of Bahia, Sergipe, Alagoa, Pernambuco, Paraiba, and Rio Grande do Norte.

Category H. In these regions, widespread severe soft water problems are indicated by field data and experience. Galvanized application is limited.

1. Northern Brazil, southern Venezuela and eastern Colombia—all of the Amazon valley and most of its very large watershed, all of the Guiana highlands of Venezuela, and much of the Llanos of Venezuela and Colombia. This area includes the provinces of Para, Amapa, Roraima, and most of Amazonas in Brazil and at least the provinces of Amazonas, Bolivar, and Apure in Venezuela. In Colombia, all areas east of the mountains should be considered suspect for the present. Most of these regions of category H are not highly populated, but there are significant existing or potential highway systems in them all.

DEVELOPMENT OF SPECIFIC DURABILITY ESTIMATION TECHNIQUE

The ranking of regions and the accurate designation of regional durability trends are based on the use of a specific durability estimation technique, which is described briefly below.

Current U.S. Technique

The durability estimation technique that has been the most useful in providing specific characterization of environmental corrosivity in the United States is the California Chart, although in its earlier form it is generally overly conservative and under some circumstances is overly liberal as discussed by the author elsewhere in this Record. This technique relates pipe durability to the pH and resistivity of either the waterside or the soilside environment (19). This approach is proper for the soilside environment for which pH and resistivity are generally the most important factors controlling durability of galvanized culvert pipe. However, it is not entirely adequate for the more complicated waterside environment which causes most problems. The most important problem with the California Chart is that it ignores the crucial effect of water scaling on corrosion behavior. In doing so, the earlier chart form gives results that are overly conservative in the significantly hard and alkaline scaling waters predominant in most countries and results that are overly liberal in the soft nonscaling or slightly scaling waters common to certain areas of some countries. In hard water, scaling reduces the overall corrosion rate of a pipe to a considerably lower level than that suggested by the chart; in soft water, inadequate scaling allows corrosion to exceed the level suggested by the chart. The estimates are sometimes conservative or liberal by a factor of 2 or more judging by Armco field data as shown by the author elsewhere in this Record.

Durability estimation accuracy could be greatly improved by the use of a more comprehensive waterside technique that relates durability to all of the critical controlling factors, including CO_2 , alkalinity, and hardness, as well as resistivity and pH. Armco has addressed this need, and the result is a modified type of California Chart for depicting waterside corrosion behavior based on Armco field data.

Development of a More Comprehensive Waterside Durability Estimation Technique

Armco has developed a waterside estimation technique based on the combined effects of CO_2 , conductivity, total alkalinity,

and total hardness that eliminates the conservatism/liberalism trends of the California Chart and delineates the chemistry trends that control galvanized use. The effect of temperature is also included so that the technique can be applied in different climates. The detailed derivation of the technique is too lengthy to be included here but has been discussed by the author elsewhere in this Record.

The technique is based largely on the interaction of alkalinity, hardness, and acidity which controls the scaling tendency. Alkalinity is primarily in the form of HCO_3^- (bicarbonate), which is consumed by reaction with organic acids from plant decomposition to produce corrosive reaction products. Plant decomposition is the prevalent primary source of natural acidity, but of course inorganic acidity found in acid mine water areas would also consume alkalinity. If alkalinity is totally consumed, as it is in some tropical regions, the water becomes too corrosive to permit use of plain galvanized or other more common pipe materials. Plant decomposition also produces CO_2 , which combines with water to form corrosive carbonic acid; but CO_2 does not consume HCO_3^- because CO_2 is part of the essential reaction by which HCO_3^- is formed from CaCO_3 in soil and rock. Indeed, a little excess unreacted or free CO_2 is necessary to stabilize HCO_3^- in solution, but any excess free CO_2 above this small amount reduces the scaling tendency and increases water corrosivity. In any natural water with some significant alkalinity remaining after reaction with organic acid, CO_2 is the remaining form of acidity influencing the pH and the scaling tendency. The interaction of free CO_2 , alkalinity, and hardness controls the basic scaling tendency in any water where the use of plain galvanized can be recommended. Alkalinity and hardness encourage scaling; free CO_2 discourages it. Thus, a scaling tendency expression in which alkalinity and hardness concentrations are positive factors and the free CO_2 concentration is a negative factor is easily developed.

The effectiveness of scaling is also influenced by corrosive salts such as chloride and sulfate. In scaling waters, excessive concentrations of such salts interfere with or prevent adequate scale formation and in nonscaling CO_2 -rich waters they add to the corrosive effect of CO_2 . The interaction of scaling tendency (positive or negative) and corrosive salts is the primary control of pipe corrosion behavior. An Armco graph for estimation of durability based on this interaction is illustrated in nonspecific form in Figure 1.

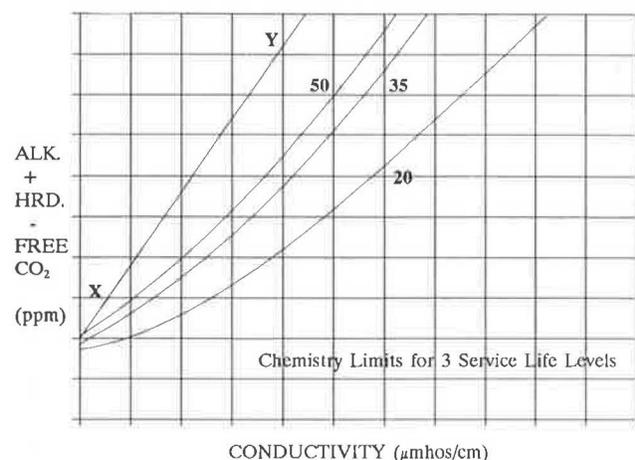


FIGURE 1 Modified California Chart.

In the use of the graph, diagonal line XY represents the condition in which all the conductivity is due to protective scaling salts and corrosion is minimal. At all points to the right of or below XY, corrosive salts and CO₂ are present and corrosivity increases with increasing distance from XY. The free CO₂ is calculated from the pH and alkalinity, so the effect of pH on corrosion is included because specifying the alkalinity and free CO₂ specifies the pH. The proportion of scaling and corrosive salts in the conductivity is specified because corrosive salts constitute the balance of conductivity once scaling salts are specified. The technique can be described as a modified California Chart in which the effect of pH on water corrosivity has been corrected to include the effect of scaling tendency and the effect of conductivity has been corrected to specify the proportion of scaling and corrosive salts.

Limitations of the Estimation Graph

Influence of Seasonal Water Chemistry Variations

The estimation graph is based on one-time water testing. Seasonal variations in stream chemistry (primarily acidity) that can have a limited effect on graph accuracy. For optimal accuracy it would be necessary to determine mean or average dry-weather chemistry parameters by testing at different seasons, but this would not be practical. The best compromise is to conduct one-time testing in dry summer weather when groundwater acidification is greatest so that regions are characterized according to worst-case or near-worst-case conditions. Each region will have relatively stable basic water chemistry characteristics due to stable general features of climate, soil, and terrain. Favorable regions or areas with hard or modestly hard water will be evident as will unfavorable ones where soft acidic water, high CO₂/conductivity water, or high salinity water is present.

Influence of Water Flow Characteristics

The modified graph applies best to pipe handling streams with persistent groundwater flow. For conditions of nonpersistent flow, pipe life is adequately defined by climate/terrain features alone as discussed below.

Pipes in Persistent Flowing Streams Under certain conditions, periodic surface runoff can induce erosion corrosion or other accelerated corrosion in the high-water zone that causes pipe life to deviate from the graph estimate. Corrosion behavior in the high-water zone is related to the type of soil in the watershed because surface runoff chemistry is related in a crude fashion to soil chemistry. Stream flow during rainfall contains a small proportion of groundwater with its leached soil salts, and even surface runoff contains some soluble matter leached from the soil. In the writer's experience in wet, tropical South America, in areas where the soils are leached and acidic and the surface runoff is soft and acidic, perforation in the high-water zone can be expected to occur frequently in less than 15 years on 14-gauge galvanized, whereas in areas with unleached alkaline soils, the same degree of perforation can be expected to be delayed for at least 25 to 30 years and

usually much longer. It is important to realize that in using the modified graph, the possibility of premature interfering corrosion in the high-water zone is greater for a 50-year service life expectancy than it is for 35- or 20-year expectancies.

In predicting performance well beyond 25 to 30 years, increasing consideration should be given to parameters that influence surface runoff chemistry, contact time, and velocity. On the regional scale, these parameters include primarily soil type, annual rainfall, and storm activity. On the local project scale, certain other factors are sometimes significant, and these are as described below. On the local level, watershed slope and size can be important under certain conditions. On or near steep terrain, the effect of high velocity of surface runoff is usually counteracted by that of the brief pipe contact time resulting from rapid drainage, but under certain conditions, turbulence or contact time are excessive. On flat terrain, the effect of reduced velocity tends to counteract that of the increased contact time; but in a very large watershed, contact time may be excessive.

1. Early problems (less than 25 years) are possible in the high- and low-water zones on pipes located on flat terrain near the base of steep terrain due to turbulence resulting from velocity and directional changes upon encountering flatter terrain abruptly. Problems increase in severity with increasing annual rainfall, but have been observed even in relatively dry climate (as low as 900 mm/yr).

2. Early problems can occur in a larger watershed on steep mountainous terrain or even on moderately sloped or gently sloped terrain when there are hills or mountains nearby in the watershed because both contact time and velocity in the high-water zone are significant under such conditions. But so far, early problems of this type in less than 25 years have been observed only in wetter climates (>1500 mm/yr) on soil types with very soft surface runoff.

3. Occasional later problems (beyond 25 to 30 years) are possible in alkaline soil regions on flatter terrain at large, wide streams with substantial dry weather flow because these conditions are indicative of a very large watershed and long contact time in the high-water zone.

Pipes That Are Normally Dry Pipes that have no developed drainage channel have flow only during rainfall and for a limited time after, but service life is controlled by waterside corrosion except in dry climates. Such pipes obviously experience contact only with surface runoff, and performance will be similar to that of the high-water zone on pipes with persistent stream flow and will be controlled by similar factors. Again surface runoff chemistry, contact time, and velocity are controlling factors, but contact time tends to be short because small watershed size is a basic cause of temporary flow. Acidic leached soils, high annual rainfall, and velocity-induced turbulence are the most troublesome factors, and problems are most important in wet tropical climates with considerable storm activity.

Pipes in Prevalent Stagnant Water Stagnant water in poorly developed or undeveloped drainage channels is associated with small watersheds, and corrosion in the high-water zone

tends to be comparable to that occurring in the invert of pipes that are normally dry. Stagnant water chemistry should not be used with the estimation graph to characterize regional durability trends because usually the water contains more free CO₂ than flowing water and yet is less corrosive due to low dissolved oxygen.

Galvanized Durability Estimation in Soil Environments

In dry climates, most pipes are dry most of the time, and soilside corrosion controls pipe durability, so use of the California Chart on the basis of soil resistivity and pH should give useful though conservative estimates of galvanized durability (except at occasional sites with groundwater flow). The chart could also be used in any climate on projects involving only soil exposure, such as highway underpasses or tunnel liners. It could also be used in any climate for pipes having effective long-term invert pavement protection. First perforation time upon which chart estimates are based does not mark the limit of pipe service life, and the American Iron and Steel Institute has proposed a modification of the California Chart that may reflect actual service life in soils more realistically (27, p. 222). Their modification is based on National Bureau of Standards soil test results (28) that indicate that overall metal weight loss at the time of first perforation is only about 13 percent in soils. The modification predicates a service life based on about twice this much metal loss, so its use would tend to compensate for severe conservatism arising in dry climate soils of low moisture content.

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