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EFFECTS OF CORROSION ON MILITARY FACILITIES OF THE PRESIDIO OF SAN FRANCISCO

by

Christopher Hahn

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The effects of atmospheric corrosion on military facilities at the Presidio of San Francisco induced by airborne salt fall are described. Problem areas include deterioration of galvanized sheet metal, building hardware, refrigeration and air conditioning components, and exterior electrical distribution lines. Recommendations to decrease deterioration rates are made, along with suggested revisions to Technical Manuals 5-551K and 5-680C. An information exchange mechanism between design engineers (Corps of Engineers Districts) and maintenance engineers.
(Facility Engineers) to improve facility longevity is proposed. Other measures to decrease life-cycle costs, consistent with military priorities, are also recommended.
FOREWORD

This investigation was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Design, Construction, and Operations and Maintenance Technology for Military Facilities"; Task 7, "Materials for Military Construction"; Work Unit 0U1, "Corrosion Abatement Design Criteria." The applicable OCR is 1.03.007, "Parametrics of Corrosion." The OCE Technical Monitor is Mr. E. Hunt.

The study was performed by the Engineering and Materials Division (Dr. G. R. Williamson, Chief), U.S. Army Construction Engineering Research Laboratory (CERL).

Dr. L. R. Shaffer is Technical Director of CERL, and COL J. E. Hays is Commander and Director.
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EFFECTS OF CORROSION ON MILITARY FACILITIES OF THE PRESIDIO OF SAN FRANCISCO

1 INTRODUCTION

Background

Corrosion results in a significant drain on the Army's real property resources. A study of Army and Air Force installations has indicated that 8 to 24 percent of real property maintenance expenditures are corrosion related, depending on local topography and climate. Since corrosion rates are usually quite low, problems often appear long after the facility is built. Corrosion-induced failures may be caused by (1) improper design for the particular environment, (2) use of low-cost, but high corrosion rate materials, or (3) lack of normal preventive maintenance.

This report is part of an overall study of corrosion-related problems on military installations in various climatic zones in North and South America. The Facility Engineer organization and the Area Resident Engineer organizations are being analyzed to determine predominant corrosion problem areas, and to recommend research where the state of the art is inadequate. Changes to Technical Manuals (TMs) or Guide Specifications are recommended when necessary.

Objective

The purpose of this part of the study was to analyze the deterioration of facilities and subcomponents in a temperate seacoast environment. System components having either favorable or unfavorable performance in this environment were specifically noted as being indicators of superior (and usually cost effective) or inferior construction over the long run. Maintenance or operational procedures which could increase facility life at less cost were also investigated.

Approach

The Presidio of San Francisco was selected as the study site for this environment. Supervisors of major work sections engaged in corrosion-related work were interviewed. Key engineers were contacted about maintenance and repair actions, including those accomplished in-house or by construction contract. Deteriorated components were examined, and corroded facilities and equipment were inspected. Corrosion problems were later analyzed to determine if existing technology or Army procedures could remedy the difficulty.

Mode of Technology Transfer

Results of this study impact on TM 5-551K (AF TO 40P-1-131), Plumbing and Pneumatics, and TM 5-680C, Overhead Distribution Systems. (Recommended changes to these manuals appear in Appendices A and B, respectively.) Other TMs and Guide Specifications which may be affected are TM 5-810-1, Heating, Ventilation and Air Conditioning; TM 5-670, Refrigeration, Air Conditioning, Mechanical Ventilation and Evaporative Cooling; TM 5-625, Sheet Metal; TM 5-805, Builder’s Hardware; TM 5-810-5, Plumbing; CE 251.01, Builder’s Hardware; CE 301.36, Central Refrigeration System; and CE 303.7, Aerial Electrical Distribution.
ANALYSIS OF FINDINGS

Economic Impact of Corrosion at the Presidio

The Annual Work Plan of the Presidio served as a basis for discussion with first-line supervisors about how their workers spent maintenance time. Each supervisor was asked to describe the nature of his segment of the Work Plan, and to estimate the percentage of each repair, maintenance, or replacement action that was related to metallic corrosion. Each job was evaluated by the following criteria:

1. Was the failure or deterioration of a metallic component corrosion-induced?
2. Did corrosion of a component result in damage to the building or its contents?
3. Was scale removed or scaled-up equipment replaced?
4. Was preventive maintenance, such as boiler water treatment or cathodic protection, performed to reduce corrosion losses?

Construction contracts from FY70 through FY75 were evaluated by the same criteria. Most of the corrosion-related work is confined to maintenance and repair contracts. Only one Military Construction-Army (MCA) project during the 6 year period analyzed was corrosion-related; a sewer replacement project for $209,600.

An analysis of the Annual Work Plan revealed that plumbers, sheet metal workers, heating mechanics, and exterior electricians spend a substantial amount of time on corrosion-related jobs. In terms of the Presidio's total operating budget (excluding Camp Parks and Troop Units), about 10.5 percent of all Facility Engineer expenses are related to corrosion. Similarly, about 8.9 percent of all construction contracts (non-MCA) stem from corrosion problems. Tables 1 and 2 contain a more detailed summary of these results.

Corrosion Effects on Systems and Components and Recommended Solutions

Plumbing Systems

Deterioration of underground piping at the Presidio was caused by fairly low soil resistivity (ranges from 1,500 to 6,700 ohm-cm) and long burial times. Fixture replacement was confined to chrome-plated brass spouts and various zinc die-cast handles. The brass alloys failed because of general load-bearing section reduction caused by selective
Table 1

Summary of Facility Engineer Corrosion Costs
for the Presidio

<table>
<thead>
<tr>
<th>Work Section</th>
<th>% Corrosion-Related Work</th>
<th>Corrosion Cost ($)</th>
<th>Total Operating Cost ($)</th>
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<tbody>
<tr>
<td>Plumbing</td>
<td>55.7</td>
<td>196,649</td>
<td>353,124</td>
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<tr>
<td>Refrigeration</td>
<td>20.3</td>
<td>41,210</td>
<td>400,106</td>
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<tr>
<td>Heating Systems</td>
<td>22.5</td>
<td>59,273</td>
<td>264,000</td>
</tr>
<tr>
<td>Boiler Plant</td>
<td>23.1</td>
<td>53,432</td>
<td>230,912</td>
</tr>
<tr>
<td>Interior Electric</td>
<td>9.3</td>
<td>30,144</td>
<td>325,000</td>
</tr>
<tr>
<td>Exterior Electric</td>
<td>22.4</td>
<td>51,296</td>
<td>229,000</td>
</tr>
<tr>
<td>Water Plant</td>
<td>12.2</td>
<td>26,039</td>
<td>214,060</td>
</tr>
<tr>
<td>Woodworking</td>
<td>12.6</td>
<td>59,184</td>
<td>468,000</td>
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<tr>
<td>Metalworking</td>
<td>33.5</td>
<td>41,850</td>
<td>125,000</td>
</tr>
<tr>
<td>Painting</td>
<td>*</td>
<td>-</td>
<td>155,000</td>
</tr>
<tr>
<td>Roads and Pavements</td>
<td>0.9</td>
<td>3,510</td>
<td>390,000</td>
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<tr>
<td>Engineering Services</td>
<td>8.9**</td>
<td>56,797</td>
<td>638,175</td>
</tr>
<tr>
<td>Preventive Maintenance</td>
<td>10 (est)</td>
<td>19,000</td>
<td>190,000</td>
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<td>Hospital Support</td>
<td>4 (est)</td>
<td>12,579</td>
<td>314,496</td>
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<tr>
<td>Other Sections and</td>
<td></td>
<td>-</td>
<td>1,923,090</td>
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<tr>
<td>Supervisory Overhead</td>
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<td>6,219,963</td>
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</table>
| **Overall Corrosion % = 10.5**

\[a\] Excludes Camp Parks and troop units
\[b\] Includes labor, equipment, and materials, FY77 dollars

*All wood and masonry structures
**Derived from 6-year maintenance and repair project averages
Table 2

Corrosion-Related Project Totals (non-MCA) for the Presidio of San Francisco

<table>
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<th>Fiscal Year</th>
<th>Total Contract $ Volume</th>
<th>Corrosion-Related Value</th>
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<tr>
<td>70</td>
<td>1,840,759</td>
<td>268,146</td>
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<tr>
<td>adjusted for inflation*</td>
<td>2,959,320</td>
<td>431,088</td>
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<tr>
<td>71</td>
<td>1,436,105</td>
<td>84,755</td>
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<tr>
<td>adjusted for inflation*</td>
<td>2,085,085</td>
<td>123,056</td>
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<tr>
<td>72</td>
<td>1,926,862</td>
<td>150,936</td>
</tr>
<tr>
<td>adjusted for inflation*</td>
<td>2,444,109</td>
<td>191,453</td>
</tr>
<tr>
<td>73</td>
<td>1,230,133</td>
<td>159,058</td>
</tr>
<tr>
<td>adjusted for inflation*</td>
<td>1,428,234</td>
<td>184,672</td>
</tr>
<tr>
<td>74</td>
<td>1,139,478</td>
<td>162,602</td>
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<tr>
<td>adjusted for inflation*</td>
<td>1,231,011</td>
<td>175,663</td>
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<tr>
<td>75</td>
<td>3,076,278</td>
<td>72,882</td>
</tr>
<tr>
<td>Totals (adjusted)</td>
<td>13,224,037</td>
<td>1,178,814</td>
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</tbody>
</table>

Overall average: 8.9%

*Adjusted by comparing Engineering News-Record Construction Cost Indexes for respective years, using FY 75 (December) as a baseline. Costs are multiplied by ratio of FY 75 index to fiscal year index in question.
leaching of zinc. Zinc die-cast handles failed either from galvanic action with the brass or steel valve stem, or by intergranular attack. These failures can be abated by prohibiting zinc and beta-brass components in applications which require superior longevity. Coppers, high copper alloys, or red brasses should be used for areas experiencing dealloying of zinc.

Copper and galvanized steel were used for all aboveground pressurized piping. Although plastic piping is corrosion resistant to most waters, its use was restricted to underground waste distribution systems. Reasons cited for not using plastic pipe aboveground were (1) brittleness caused by its exposure to sunlight, (2) the high coefficient of expansion, and (3) insufficient durability during a fire. Plastics used in underground piping were acrylonitrile-butadiene styrene (ABS) and polyvinyl chloride (PVC). Personnel were concerned about the shelf life and long setting times of ABS adhesives, and ABS piping had reportedly been chewed through by rats. PVC pipe had not been penetrated.

The Repairs and Utilities TM 5-551K, was not used as a primary source of technical direction for maintenance actions. Rather, a "national" code was used, although several codes claim universal status. TM 5-810-5 requires that initial system design comply with the Uniform Plumbing Code of the International Association of Plumbing and Mechanical Officials, but TM 551K does not specify a national code for maintenance actions. The national codes should be referenced in TM 5-551K and supervisory personnel directed to obtain copies (at Government expense) of the prevalent code in their region. These "national" codes usually are more progressive than local codes and allow use of more modern materials, since they are revised annually.

Galvanized steel roofing was not extensively used throughout the installation. Because roofing is either clay tile or built-up asphalt layers on a wood base, deterioration of exterior sheet metal was confined to guttering. Aluminum gutters developed pits caused by accumulated salt fall, and plastic gutters degraded after prolonged exposure to sunlight. Many of the plastic gutters cracked when ladders were

References

placed against them, presenting a safety hazard. The galvanized guttering, whether original or replaced, was not specified with any minimal zinc thickness.* The ASTM A275 G90 Commercial Zinc Coating class should be used as a minimum (0.40 oz/sq ft [275 g/m²]) requirement. Hot-dipping of formed sheets with zinc coatings ranging from 1.15 to 2.35 oz/sq ft (351 to 717 g/m²) in the triple-spot test⁵ may be necessary for areas experiencing severe degradation, since forming sheets will cause flaking of the thick zinc coatings. The base metal should be a copper-bearing steel, 0.2 percent copper minimum.

Another problem involving metal work was the constant need to replace galvanized vent stacks. Because these vents are exposed to heated furnace exhaust gases, they have an average life span of 5 to 8 years in the salty air. A superior metal for long-life applications would be commercially pure titanium in the fully annealed condition for formability. Unlike the thin gauge galvanized steel, the titanium would resist both the oxidative effects of heated gases and chloride attack. For vent stacks requiring shorter life with less chloride exposure, TT-P-38 Ready-Mixed Aluminum Paint applied to galvanized steel is suitable for temperatures up to 300°F (149°C). For temperatures beyond 300°F (149°C), TT-P-28 Heat Resisting Aluminum Paint is indicated.

Building Hardware

The use of zinc-chromated steel lock hardware or an unchromated varnished steel causes a major problem at this location. Typical life of this hardware is 5 to 8 years. A similar situation exists for steel butt hinges exposed to salt air. Door closers also have a reduced life, caused mainly by internal moisture accumulation. An all-brass lock has a typical life span of 16 years at the Presidio. However, many of the so-called "all-brass" locks (passage, dead bolt, anti-jimmy) supplied by the General Services Administration (GSA) contained steel parts, especially where strength was a requisite. This can be a worse situation than one in which the components are all-steel because the manufacturer has substituted steel for critically-stressed parts. Steel corrodes at

* NOTE: CE 220.08, General Sheet Metalwork, does not permit selection of galvanized gutters. For "corrosion locations," this specification selects copper or copper-clad stainless. However, the copper-clad stainless is so thin (0.015 in. [.3310 mm]) that any discontinuities in the thin copper cladding would lead to severe pitting where salt fall occurred, such as at the Presidio.

1 to 2 mpy (0.025-0.05 mm/yr) compared with 0.021 mpy (5.25 x 10^{-4} mm/yr) for cartridge brass, not taking galvanic action into account.

Frpedvayt-Related Components

Aluminum framing for dust filtration of intake air was badly pitted, and in several cases, completely corroded through. Dust filters accumulate the salt-laden air, and eventual evaporation concentrates the salt, resulting in a very saline dew. When a new hospital complex suffered framing failure after only 2 years, Facility Engineer personnel attempted to replace the framing with austenitic stainless steel, but evidently received a ferritic or martensitic grade (personnel stated the material was magnetic). This is an example of material substitution granted by nontechnical purchasing agents. In this location, a copper-nickel alloy (67 percent Ni, 33 percent Cu) would probably sustain less pitting in creviced areas than stainless steel.

Difficulties were also reported with rapid deterioration of aluminum evaporator and condenser fins, especially when coupled to copper tubing. "Spine" fins were also severely degraded. In general, these fins could not be brushed and should be prohibited in saline exposures. All-copper fins and tubing are mandatory for this location.

Electrical Distribution Systems

The principal difficulty at this site was the high resistance caused by corrosion at aluminum conductor drop lines which lead to the main circuit-breaker panel. The aluminum service drop at the weather head apparently accumulates moisture and overheats because of section loss or shorts. Neither the manufacturer of the weather head nor the type of wire insulation is known.

Another difficulty was caused by the failure to install ground rods when cast iron water mains were replaced with plastic. This left the seemingly grounded cold water pipe in a state where current may not drain away, depending on soil moisture conditions and the depth of the steel-plastic joint.

The principal corrosion problems in these systems are corrosion of aluminum conductor/steel-reinforced (ACSR) and copper conductor splices and the deterioration of transformer cases.

Electricians at the Presidio use two types of connectors to join aluminum to copper. In the first method, a compression connector (with conductive grease) joins the aluminum to a copper pigtail, which then connects with a split bolt joining the copper cable. Split bolts are never retightened because of the danger of exceeding the flow stress where relaxation will occur; rather, they are simply replaced. The second connector is a wedge-shaped compression device which joins the cables by explosive force, requiring a powder-actuated tool. Its superiority in this environment may stem from permanent seizing induced by friction heating and extremely high compressive stresses at points of sliding impact. (See Figure 1 for details on this connector.) The use of compression-type splices in humid and saline areas should be emphasized in TM 5-680C. However, various proprietary connectors must be compared in several humid locations under monitored conditions of amperage, temperature, and dew point, before any particular connector can be endorsed.

Transformer cases require frequent repainting because of salt air and dew accumulation. In several instances, actual penetration through the case occurred. Since it is difficult to completely remove products without reducing case thickness, an economical coating system would be TT-P-615 Basic Lead Silico Chromate Primer Coating, Type I (Oil) or Type V (Oil & Alkyd), with a TT-E-522 Lustreless Phenolic Enamel, which has good resistance in humid seacoast areas. For extremely corrosive locations, use of MIL-P-38336 Inorganic Zinc Dust Primer and MIL-C-38427 Urethane or Epoxy Top Coating is indicated, although this coating system requires more careful surface preparation.

Leakage of raw water from heat exchangers was thought to contaminate boiler condensate. Conductivity should be tested periodically to determine if such a condition exists. Conductivity monitoring might be considered for new construction at key system locations. Inability to treat the water for low pressure boilers was also reported, as was damage to sodium silico fluoride injectors used for fluoridation of
drinking water. A suggested alloy for these injectors is Monel 200* (67 percent nickel, 31.5 percent copper, 1.25 percent iron), which has good resistance to any hydrofluoric acid (HF) which may form. Another alternative is AISI 316, which has good resistance to hydrofluosilicic acid (H$_2$SiF$_6$), although pitting may develop. 


3 FACILITY LIFE-CYCLE MAINTAINABILITY

Certain organizational impediments to effective corrosion control found at the Presidio were also typical of problems encountered at other Army installations.

Maintainability of Construction

The District Engineer is responsible for the timely completion of a Military Construction project, keeping a close watch on cost growth, whereas the Facility Engineer is more concerned with maintainability. These goals may not necessarily be convergent. A continual, positive interplay must exist between the District and Facility Engineers so that new construction does not repeat the errors of the past. Both short- and long-term information regarding facility maintainability problems discovered after acceptance can significantly contribute toward improved construction. Long-term feedback is particularly important since corrosion problems often surface many years after the facility has been in use.

Both the Army and the Air Force have various short-term construction deficiency reporting mechanisms, but there is no life-cycle deficiency reporting system at present. A life-cycle reporting system proposed by the Directorate of Facilities Engineering (DAEN-FEM), OCE, suggests that recommendations for facility improvements be forwarded to major commands rather than the District. However, corrosion is a region-specific phenomenon, and therefore is better controlled through ongoing dialogue between the District and Facility Engineers. This dialogue could be accomplished by having the Facility Engineer submit an annual consolidated installation summary of facility maintainability trends (regardless of facility age) to the District, with information copies to OCE and major commands.

The advantages of a regional life-cycle reporting system are multiple, especially for corrosion problems. A regional system avoids universal adoption of specific materials, products, or procedures (minimizes manufacturer endorsement problems). A cost comparison of alternate materials could be taken into account, since prices vary depending on source of manufacture and shipping rates. Historical precedents for specification of a successful material would be provided for a particular region, and would be grounds for rejection of other materials because of their documented failure in certain applications.

12DAEN-FEM message dated 012106Z Dec 76; Subj: Interim Change, AR 420-10: Construction Improvement Recommendation.
Material Substitutions and Intended Facility Life

The superior material for a given application is one that has sufficient corrosion resistance which complements its mechanical or other required properties. However, other materials may be substituted during procurement, especially when acquisition price is the determining factor, and not the corrosion rate or long-term cost. This is particularly applicable to bench stock replacement items which are not subject to rigid material specifications. Although the lot-priced item seems equivalent and apparently less expensive, over the long run these components may have to be replaced several times, involving installation and procurement costs. Since corrosion rates vary with location, determining the cost effectiveness of replacement component parts may take several years. This can be accomplished by noting demand levels for various items over the years, or studying specific high replacement items in designated buildings, and noting differences in lifetimes of parts of generic equivalence.

Inferior materials are often used on buildings and structures which are kept long beyond their intended lifetime. In many cases, there is no rigid disposal schedule. If intended facility life is short, there is reluctance to use a superior material. This attitude persists because of the advanced physical age of many Army facilities. However, if labor force levels are reduced in the future, components must have a longer life since personnel may not be available to replace the shorter-life component.
1. The Facility Engineer of the Presidio allocates about 10.5 percent of his resources to corrosion-related work, including preventive maintenance, repair, and replacement actions.

2. Approximately 8.9 percent of all non-MCA Presidio maintenance and repair contracts are the result of corrosion. This percentage was obtained by adjusting prior year corrosion costs for inflation, adding them, and then dividing by total adjusted maintenance and repair contract values for the 6-year period analyzed.

3. Underground piping and potable water distribution systems incurred substantial losses. Atmospheric deterioration of exterior metal components was due to airborne salt fall.

4. Dealloying of thin-wall brass fixtures and failures of zinc die cast handles were common occurrences.

5. Although galvanized steel was used extensively, no attention was paid to zinc coating thickness specification.

6. Coated steel locks and hinges required frequent replacement because of corrosion. This problem was compounded by the inability to obtain the required all-brass components from GSA.

7. Aluminum condenser and evaporator fins deteriorated rapidly, decreasing heat transfer efficiency. Pitting, crevicing, and generalized attack occurred, especially with aluminum fins on copper tubing.

8. The corrosion of aluminum conductors joined to copper caused difficulties for electricians.

9. Formal mechanisms to provide feedback between the design agency and the inheriting maintenance organization on long-term corrosion-related deficiencies do not exist.
5 RECOMMENDATIONS

1. Closer controls should be placed on stocking the proper replacement parts for specific buildings, especially considering intended lifetime. It is not recommended that the best alloy always be used, but rather that a superior alloy or material be designated only for buildings that will require long-term service. This implies stocking multiple types of a generic item.

2. It is recommended that life-cycle cost rather than initial cost be considered. The life-cycle cost can be roughly indicated by watching demand levels on specific replacement parts over a period of years.

3. A facility deficiency reporting system which feeds long-term system life information back to the District from the Facility Engineer should be considered for adoption. This will permit formal dialogue between construction and maintenance forces, and will provide the District with design information regarding facility maintainability.

4. Several sections of TM 5-551K (AF TO 40P-1-1-31) and TM 5-680C should be revised in accordance with the recommended changes listed in Appendices A and B.
APPENDIX A:

RECOMMENDED CHANGES TO TM 5-551K
1. 4-1 4-1a(1) 6  
Delete "where liquids may corrode or". Add: "For handling acidic corrosives, high silicon (14%) cast iron should be used. For strong caustics under pressure, use monel or nickel-bearing austenitic stainless steels." REASON: Unless a rigorous cost analysis and provisions to replace the cast iron pipe are made, high silicon cast iron has marked corrosion resistance to strong acids compared to gray cast iron. It will handle most alkaline well, except for stress corrosion cracking due to caustic embrittlement. The nickel-base alloys and higher nickel austenitic stainless steels will tolerate high causticity under stress.

2. 4-8 4-18  
Add: Place asterisks on ground joint union caption and flange union caption. Add to Figure 4-18 description: "Also available with dielectric gaskets and bolt sleeves for coupling dissimilar metals; similarly, dielectric ground joint unions are also manufactured." REASON: Availability of this fitting variation should be made known to decrease galvanic corrosion of pipe junctions in corrosive media.

3. 4-16 4-23b 3  
Delete "will not rust, rot or corrode." Insert "is not corroded by most natural and treated waters. Some plastics are susceptible to degradation by certain strong acids, organic solvents and sunlight. They are also subject to embrittlement at freezing temperatures." REASON: Statement is too general and misleading to the uniformed reader regarding limitations of generic plastics. Plastic-like metals, are environment-sensitive and should not be thought of as a cure-all for corrosion problems. There are circumstances where plastics will "rot and corrode."

*Reference to line numbers within the paragraph is included.
**RECOMMENDED CHANGES TO PUBLICATIONS AND BLANK FORMS**

For use of this form, see AR 350-1, the Issuance agency in the US Army Adjutant General Center.

TO: Issuance agency of a particular publication

From: Army Adjutant General Center

(continuation)

**PART I - ALL PUBLICATIONS EXCEPT PUBLICATION NO. 156 AND EXTERNAL PUBBLICATIONS**

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<td>Add as a note to Table 12-4: &quot;Water velocities above 7 feet per second in copper piping may result in internal erosion corrosion damage.&quot;</td>
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<td>5.</td>
<td>12-3</td>
<td>12-5c</td>
<td>10</td>
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<td></td>
<td>Add to para C: &quot;For buried sections of gas piping that have cathodic protection applied, protected areas may require water jumpers to maintain continuity, bypassing the higher resistance Dresser coupling.&quot;</td>
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</tr>
</tbody>
</table>
| 6.       | 10-8     | 10-8      |          |            |           | REASON: This paragraph requires complete revision. Several corrosion mechanisms are incompletely explained and other forms of corrosion that plumbers encounter (besides galvanic and general attack) are not mentioned. There are more ways of combating corrosion than the two methods listed. The explanation of galvanic corrosion on the basis of different electrical conductivity is confusing. Galvanic difference usually stems from inherent metallic stability or formation of adherent surface films. For example, titanium has poor IACS conductivity, but has far superior performance in salt water than iron (a fair electrical conductor). The description of corrosion as a etching process in piping may hold for the deallaying of brass, but in most cases the iron forms an insoluble corrosion product. Oxygen content, pH, and velocity effects are not discussed. Impressed-current cathodic protection, superior alloy section and liner materials are not mentioned as additional preventive methods. SUGGESTED REVISION: "a. Corrosion is the degradation of a material or alloy by its environment. Plumbers replace large quantities of pipe because of corrosion, especially in buried and above ground water supply piping. Several forms of corrosion are encountered by plumbers besides uniform attack, which results in thinning of pipe walls."

**TYPED NAME, GRADE OR TITLE**

**TELEPHONE EXCHANGE AND NUMBER**

**SIGNATURE**

**DA FORM 2028 REPLACES DA FORM 24-10 DEC 1966 WHICH WILL BE USED**

21
These other forms of corrosion are (1) galvanic attack, (2) pitting, (3) crevice corrosion, (4) erosion corrosion, (5) dealloying, (6) intergranular corrosion and (7) stress corrosion.

(1) The uniform corrosion of steel increases when the amount of oxygen, the temperature, and the acidity increase. Since most potable water is not highly acidic, pH less than 4 would be found mostly in undrinkable process water.

(2) Galvanic attack occurs when two different metals are mated by threads or flanges. The severity of the corrosion depends on how the two metals behave in water or soils. How long a dissimilar joint will last can be roughly predicted by a galvanic series. The greater the separation of each metal on the series, the more likely galvanic corrosion will take place. A rough galvanic series for common plumbing alloys is as follows:

inactive metals: Gold, silver, Titanium, Stainless steels (austenitic), Nickel alloys, Bronzes, Copper and brass, Tin, Lead, Cast iron, Mild steel, Aluminum alloys, Cadmium, Zinc

active metals: Magnesium

This is avoided by dielectric fittings or by changing materials.
(3) Pitting occurs when corrosion takes place in a small area, and the surrounding area is not corroded. This may be caused by the inherent tendency of the alloy to pit in certain corrosives, or by contaminants that may settle, inducing pits. Stainless steels, magnesium, aluminum, and zinc tend to pit. Since it is usually more difficult to change environment, it is best to substitute a material that does not pit.

(4) Crevice corrosion occurs when conditions in the piping system are not uniform, usually caused by the piping design. Gaskets are common places where oxygen is partially excluded, but water is not. Gaskets with a wicking action (porous) often suffer crevice corrosion. Improperly welded seams which do not completely seal out moisture are also susceptible.

(5) Erosion corrosion occurs when the velocity of the water exceeds a certain critical value. The metal cannot replace its protective film because it is being swept away. Copper is especially susceptible to erosion corrosion. Recommended ways to stop the gully-like attack of erosion corrosion are to reduce pressure, increase pipe diameter or eliminate sharp bends. Substitution of steel may be necessary.

(6) Delamination is a form of corrosion that is usually found in brass or cast iron. In brass alloys, the zinc leaches out leaving a weak spongy copper (dezincification). For gray cast iron, the iron (ferrite) corrodes out, leaving just graphite (graphitization). To prevent dezincification, use of brasses with more than 70% copper should reduce the problem. Neither ductile nor malleable iron will suffer graphitization like gray cast iron.
### RECOMMENDED CHANGES TO PUBLICATIONS AND BLANK FORMS

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<thead>
<tr>
<th>ITEM NO</th>
<th>PAGE NO</th>
<th>PAGES COUNTER</th>
<th>PAGE COUNTER</th>
<th>DATE</th>
<th>REASON</th>
<th>RECOMMENDED CHANGES</th>
</tr>
</thead>
</table>

**PART II: ALL PUBLICATIONS AND BLANK FORMS**

- **IM 5-155 (AF 10-40P-1-171)**
  - **DATE:** 1/31/71
  - **REASON:** Changes requested.

**RECOMMENDED CHANGES (CONTINUED)**

1. **However, it is desirable in situations where a
corrosion resistance similar to that of brass**

2. **Intergranular corrosion is a problem
equipped by structures. For instance, if handles or
drain covers are made of cast iron, they
corode this way, becoming brittle. Stainless
alloys are susceptible to corrosion from within
the microscopic network of grains, which can
cause eventual rupture. Stainless steels are
preferable alloys for such cases.**

3. **Stress corrosion cracking is caused by the
action of a specific corrosive agent on metal
when piping is under pressure. Although it is
usually seen in brass containing tin, it is also
can in contact with strong acids. Not all metals
behave the same when subject to pre-stressed
corrosives; some are more resistant than others.
Stress-corrosion cracking takes place slowly,
quickly, from several days to a few weeks, and
result with engineering personnel if you want
to avoid this form of corrosion to be a problem.**

4. **Several methods are available at the
plumber's discretion to solve corrosion problems.
He may choose the material during replacement
of the piping to one more suited for the environment.
He may alter the configuration (but not interfering
with operation) i.e. increasing the diameter
or changing bend severity. If expansion joint
being drawn into the system, he may exclude it.
I recommend that the piping changed at its source. In
drinking water is involved, changes must not have
any detrimental effects on public health.**

---

**TYPE NAME/ GRADE OR TITLE:**

**TELEPHONE NUMBER:**

**DATE:**

**RECOMMENDED CHANGES:**

**SIGNATURE:**

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**DA FORM 2028**

REPLACES DA FORM 2028 DECEMBER 1970 WHICH WILL BE USED
10. Recommended changes to publications and blank forms

<table>
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<tr>
<td>7</td>
<td>10-9</td>
<td>10-Bc(1)</td>
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Lined with inert or protective coatings, like teflon, or zinc, may be used. For lines that are buried, he should verify whether cathodic protection is being applied. This includes the replacement of magnesium anodes in water heaters, and the operation of both sacrificial (magnesium or zinc) and impressed-current (rectifier) cathodic protection systems on buried mains and laterals.


Add: "Severe scaling in a water main should be reported to main water plant personnel. Thin unbroken scale is beneficial and prevents corrosion by forming a protective layer."

APPENDIX B:

RECOMMENDED CHANGES TO TM 5-680C
**RECOMMENDED CHANGES TO PUBLICATIONS AND BLANK FORMS**

For use of this form, see AR 101-1, the proponent agency is the US Army Adjutant General Center.

<table>
<thead>
<tr>
<th>COMMANDANT</th>
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<tbody>
<tr>
<td>US Army Construction Engineering Research Laboratory</td>
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<td>20 Jun 1972</td>
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**PART I - ALL PUBLICATIONS, FORMS, SHEETS AND BLANK FORMS**

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<tr>
<td>TH 5-GBC</td>
<td>Sup 63</td>
<td>Overhead Distribution System</td>
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**INSERT THE FOLLOWING AFTER THE PROPOSITION**

"Powder-actuated compression connectors which have comparable performance are also available (see Figure 56)." REASON: Superior performance of this type of connector has been reported by field personnel. Such connectors perform markedly better than split bolts in humid or marine areas.

**ADD NEW PARAGRAPH**

"Compression connectors are recommended for splicing and tapping in humid or marine regions. It is critical that the junction, especially if aluminum is being connected, have sufficient anti-oxidant conductive grease to exclude moisture, dew, or salt accumulation. Many splices have pre-filled grease containers which uniformly seal the junction upon compression, whereas others require the electrician to coat mating surfaces with antioxidant grease before tightening the joint."

**REPLACE SPLIT BOLT PHOTOGRAPH WITH PHOTOGRAPH OF PNEUMATIC WEDGE CONNECTOR**

---

**TYPED NAME, GRADE OR TITLE**

CHRISTOPHER HANIA
Corrosion Metallurgist

**RECOMMENDED CHANGES AND ACTION**

(217) 354-6611, Ext 216

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Note: This list represents the distribution centers for CEML.
Facility Inquiries

AMC
Aberdeen Proving Ground, MD
Army Medical Logistics

Burlington Army Ammunition Plant, VT

Corpus Christi Army Depot, TX

Ft Bragg, NC

Ft Drum, NY

Ft Sam Houston, TX

Shortage Decrease, CA

United States Military Reserve, TX

FOR
Army Tel., Omaha Section, NE

Ft McPherson, GA

Ft Lewis, WA

Ft Bragg, NC

Presidio of San Francisco, CA

HHC
Ft Gordon, GA

Ft Myer, VA

HHC
Ft Bragg Military Police, NC

Sunny Point Military Police Terminal, NC

SPMDC
Ft Jackson, SC

Ft McPherson, GA

Ft Benning, GA

Ft Lee, VA

Ft Dev, VA

Ft Gordon, GA

Ft Sam Houston, TX

USMLE
Ft Bliss, TX

USMC
Marine Corps Base, Quantico, VA

US Army Medical Center, TX
Hahin, Christopher


24 p. : ill. ; 27 cm. (Interim report -- Construction Engineering Research Laboratory ; M-254).