

## Chapter 5 Coating System Selection

### 5-1. Introduction

*a.* A systematic approach to coating selection for new construction and maintenance painting is described in this chapter. The first section details the criteria for selecting a coating system based on the service environment(s), surface preparation requirements, and options for coating application. Other considerations such as VOC concerns, coating cost, supplier recommendations, ease of application, and maintainability are discussed.

*b.* After a coating system is selected, alternative methods of surface preparation and application are explored. Special sections are devoted to the advantages/disadvantages of shop versus field cleaning/painting, difficult to coat areas, and the use of cathodic protection alternatives in those areas. The balance of this chapter is devoted to reviewing existing systems, candidate maintenance, and new coating systems options for given USACE structures service environments. Also, special concerns or cautions associated with these coating system choices are discussed.

### 5-2. Criteria for Selecting a Coating System

No single coating or coating system can satisfy every service condition or environment that may be encountered in a given civil works facility. Selecting candidate coating systems for an exposure environment depends on identifying and understanding how each of the environments impact various coatings. For example, chlorinated rubber or vinyl coatings, which are thermoplastics, would not be used in locations subjected to high heat or strong solvents because they would quickly dissolve or soften. If alkyd enamels were used in an environment with, for example, caustic conditions, they would soften, swell, and quickly disbond as a result of saponification. Chemistry, experience, and the coating system performance history have illustrated these facts. The Paint Systems and Painting Schedule section of CWGS 09940 and the Supplementary Application Instructions contained therein show paint systems that will provide satisfactory, cost-effective performance based on given service environments. Characteristics of the environment that the coating system will encounter must be well identified. Once the environmental exposure has been properly determined, the process to select coatings systems that have a known history and track record of successful use in these identified environments may begin.

*a. Identifying the service environment(s).* Exposure environments that have the greatest impact on coatings and

coating systems performance will be described briefly here. Picking the correct coating for painting projects might be described as a process of elimination rather than one of selection. Probably the most important step in coating selection is to evaluate the conditions under which the coating must perform. This cannot be a superficial evaluation but must consider all the conditions that may exist. Even small and seemingly irrelevant factors may affect coating system performance. In most situations, a combination of two or more service environments act together to create a hostile environment. Chapter 4 provides detailed information on the environmental resistance qualities of various generic coating types and should prove valuable when used in conjunction with this chapter.

(1) Temperature extremes. Most applied coating systems are subject to temperature variances within their applied environments. For the most part, these fluctuations are moderate (normal atmosphere fluctuations). Even normal atmospheric temperature variations have an effect on coating performance (i.e., piling studies performed by USACE show a significantly higher rate of coating failure on pilings off the coast of South Florida than in the Cape Cod area. Additionally, in many instances, unique processes or system operations may generate adverse (cold or hot) temperatures outside the normal. Extreme cold or heat can cause brittleness, poor impact resistance, shrinkage, or loss of adhesion and may alter the corrosion-prevention characteristics of the coating system. High temperatures also tend to aggravate the corrosivity of the environment severely (i.e., many acids become increasingly aggressive with temperature increases). Curing mechanisms involved with conventional coatings frequently are temperature dependent. With high heat, the curing process may occur too rapidly or, conversely, in cold temperatures curing may not occur at all. Coatings to be applied in extremely cold environments must have excellent adhesion, resiliency, and plasticity. Likely candidates for heat-resistant coatings are those modified with silicone and/or metal flake (i.e., aluminum, stainless steel). Some inorganic, zinc-rich coatings can be applied at temperatures as cold as -18 °C (0 °F) and provide excellent corrosion protection in the extreme cold.

(2) High humidity. High humidity frequently is accompanied by condensation. Consequently, such a continuously wet, heavily moisture laden environment is often considered to be in a state of constant immersion. A water molecule is extremely small and can pass through the molecular network of even the most moisture-resistant protective films. Each coating and resin type has a unique moisture vapor transfer rate. Obvious coatings for such continuously moist environments should exhibit low moisture vapor permeability (MVP) and water absorption

rates. Industry practice generally has found that, the lower the moisture vapor transfer rate, the better corrosion protection the coating provides. Commonly used coatings with typically low moisture vapor transfer rates are formulations of two-part epoxies, vinyls, coal tars, and respective modifications of these coatings. Coatings pigmented with metallic or glass flake have been found to improve moisture resistance and lower the MVP rate of some coatings.

(3) Immersion. Immersion service coatings are exposed to water solutions ranging from highly pure deionized water to water containing high concentrations of various chemicals, acids, or alkali solutions. Specific immersion linings may be subject to the effects of storage of petroleum or solvents. Primarily though, water is the main exposure element in immersions. Coatings for immersion service must exhibit good adhesion, moisture resistance, vapor transfer, ionic penetration, cathodic disbondment, osmosis, and variances in temperature. Examples of coatings that traditionally have performed well in immersion are: coal tar epoxies (CTE), vinyls, untopcoated zinc-rich coatings, and modifications of epoxy coatings.

(4) Oxidizing-reduction. Oxidizing environments—such as atmospheric service or areas of ozone generation and strong oxidizing agents such as bleach or nitric acid—are more common than reduction environments. Most coatings are more susceptible to oxidation than to reduction. Oxidation may cause coating film brittleness and loss of cohesive strength; a common example of this is an old, weathered alkyd that can oxidize to an almost powdery state after many years. Generic coating types that historically have performed well in oxidizing environments are: CTEs, chlorinated rubber, and formulations of epoxies and polyurethanes.

(5) Extreme pH. Extremes of pH, such as strong acid or alkaline environments, can have a dramatic effect on coatings systems selection. The degree of impermeability of the chosen coating to the environment is of primary importance. The coating film essentially must be inert to prevent a reaction with the environment or permeation of the solution into the coating film. Alkali resistance is vitally important to a primer coating. Chemical reactions that take place in the corrosion process produce strong alkaline products that are deposited on the substrate. Subsequently, any primer that is not resistant to these by-products will have a tendency to fail because of cathodic disbondment. This failure can result in additional undercutting of the coating and the spreading of underfilm corrosion. Substrates such as concrete typically have a high alkalinity; therefore, a coating system chosen for a concrete substrate also must exhibit good alkaline resistance. Formulations of coatings that have a good history of performance in extreme

pH environments are vinyls, chlorinated rubbers, and epoxy modifications. However, alkyd or oil-containing coatings tend to have a poor resistance to alkalinity and should not be used in such an environment.

(6) Solvent exposure. The function of solvents in coating formulation in relation to the application properties of the coating is well known. However, solvents often become an exposure environment to the dry-cured coating system. The effects of the solvent on the coating system generally will vary by solvent type and the resistance of the generic type of coating that has been applied. There are numerous types of solvents. Typical solvents frequently can be classified into two categories: hydrocarbons and oxygenated solvents. A less important group of solvents are called the terpenes. Hydrocarbons are so named because their molecules contain only hydrogen and carbon atoms. The molecules of oxygenated solvents also contain oxygen atoms. But some commonly used oxygenated solvents may contain atoms of other chemical elements such as nitrogen. Hydrocarbon solvents more commonly are found than oxygenated solvents. Oxygenated solvents and hydrocarbon solvents frequently are blended for use in lacquers, catalyzed coatings, and synthetic resins solutions. As with many other exposures, a high degree of impermeability is necessary for the coatings to resist solvents. The coating system chosen must not be dissolved or softened by the solvent in the exposure environment. For example, USACE vinyl systems are resistant to solvents of the aliphatic variety and most often can tolerate spills from aromatic hydrocarbons. However, the stronger oxygenated solvents will readily attack, soften, and dissolve the vinyl film. Therefore, it is necessary to make a good system selection because the binder may be dissolved easily and softened by various levels of solvency strength. Historically, two-component highly crosslinked coatings, such as formulations of epoxy and urethane coatings, have exhibited good solvent resistance. Therefore, the blend and type of solvent in the exposure environment should be identified so the appropriate coating system can be chosen. When all pertinent factors have been identified, coating manufacturers can be consulted for system recommendations. The major manufacturers of high performance protective coatings have an excellent understanding of the temperature and chemical exposure limitations of their products. In fact, many publish tables of chemical resistance for various coatings and include some of this information in technical product data sheets. Specific facility coatings histories, manufacturers' performance history, and published coating system service life data are particularly helpful. When searching for such information, the exposure environment must be accurately assessed to select only those coating systems with a high probability of success and/or a proven track record. When a process is new and the exposure environment is uncertain, field test patches of candidate products can be applied in

that environment and evaluated. If a new environment can be identified and simulated, screening and testing of candidate materials can be performed by qualified laboratories using specially designed test apparatus. However, the key to success for any situation rests with thorough, accurate identification of the exposure environment.

(a) Hydrocarbons. There are two types of hydrocarbon solvents: aliphatic and aromatic. Special blends of these solvents have been developed to form solvents called semi-aromatics. Aliphatic and aromatic hydrocarbons differ in the way in which the carbon atoms are connected in the molecule. This characteristic structural difference leads to a sharp difference in the chemical and toxicological properties. The aromatic hydrocarbons are the stronger solvents for coating film formers. They also are more irritating to humans in both liquid and vapor forms. Typical aromatic hydrocarbons are: benzene, toluene, and xylene. Typical aliphatic hydrocarbons are: hexane, heptane, and odorless mineral spirits. Ordinary mineral spirits are mostly aliphatic hydrocarbons. Aromatic and aliphatic hydrocarbons generally are derived from heat distillation of petroleum products. They generally are found as a blend of aliphatic and aromatic components and are readily available in an extensive range of solvent strengths and evaporation rates.

(b) Oxygenated solvents. Oxygenated solvents are manufactured by a variety of processes. Those most commonly known of these solvents are: alcohols, ethers, ketones, and glycol-ethers. Typically, there may be a blend or combination of these solvents in the exposure environment. Examples of alcohol solvents are: methanol, ethanol, isopropanol, and butanol. Examples of ether solvents are: ethyl acetate, isopropyl acetate, butyl acetate, and butyl cellusolve acetate. Examples of ketones are: acetone, methyl ethyl chloride, methyl isobutyl ketone, and cyclohexanone. Examples of glycol-ethers are: cellusolve and butyl cellusolve.

(c) Terpene solvents. These solvents are derived from the sap of pine trees; examples are terpene, dipentene, and pine oil.

(7) Wet/dry cycling. Alternate wet and dry cycling, such as that associated with atmosphere and weather, may have a significant effect on the performance of a coating system. Coating subject to wet and dry cycling must exhibit strong adhesion, low moisture vapor transfer rates, and good corrosion and undercutting resistance. Although a significant number of coatings will perform satisfactorily in a cycling environment, coating system selection mainly will depend on other in-service elements that impact this environment.

(8) Thermal cycling. Thermal cycling naturally generates the forces of expansion and contraction. For a coating system to provide maximum protection to the substrate, it must have the ability to expand and contract with the substrate. For the most part, thermal cycling is associated with normal atmospheric weathering. For example, a metallic substrate may heat up rapidly when exposed to the sunlight; however, when the sun sets or if it becomes cloudy, the temperature can rapidly decrease. Such stresses must be withstood by the coating system without loss of adhesion or checking and cracking. Acrylics, vinyls, and inorganic zinc coatings have proven exceptionally resistant to fluctuations in temperature.

(9) Ultraviolet exposure. Resistance to ultraviolet (UV) radiation is extremely important. Sunlight can rapidly degrade a coating and will cause a complete loss of film integrity, resulting in chalking, loss of gloss, fading, and brittleness in a rather short period of time. Such degradation may result in an aesthetically unacceptable coating appearance. Specific generic coating types exhibit better resistance to UV light than others. For example, a two-component epoxy coating will chalk rather rapidly under exposure to UV light, but formulations of acrylic aliphatic polyurethanes remain stable on UV light exposure. Inherent in most alkyd and oil-based products is poor resistance to UV exposure, which results in chalking, loss of gloss, and loss of color. However, modifications with silicone (i.e., silicone alkyds) can greatly enhance the performance characteristics of surfaces exposed to UV light. Modifying alkyds with silicone combines the workability of the alkyds with the durability, gloss retention, general weather resistance, and heat resistance of the silicones. Silicone alkyds are widely used as a maintenance upgrade finish over conventional alkyd coatings because of these improved properties. Silicone alkyds are used rather extensively for stack coatings and similar areas where moderately high temperatures are involved. USACE structures at which alkyds are used and improved gloss retention, weather resistance, and durability are desired should be considered for upgrades with silicone alkyd products.

(10) Impact/abrasion. Impact and abrasion resistance are extremely important characteristics in coating selection. Although impact and abrasion resistance frequently are discussed in the same breath, they can designate two different exposure environments. For example, a coating must resist rupturing from the rapid expansion of a metal as it is deformed from a sudden impact. To resist this type of impact, coatings must have a high degree of flexibility such as most formulations of a vinyl coating. Formulations of epoxies and polyurethane coatings are excellent choices for abrasion resistance, but the inherent brittle qualities of the

coating would cause it to fracture easily on impact. These coatings perform best where abrasion may be in the form of heavy equipment movement, foot traffic, or even scouring by tools and equipment. Abrasion also may be a result of naturally occurring phenomena, such as windblown sand or sand carried by waves of water. Consequently, it is extremely important for the coating specifier to determine if the exposure environment necessitates a coating that will withstand constant abrasion, sudden impact, or a combination of the two.

(11) Special exposures. Special exposure environments such as food processing and potable water may be subject to regulations of the Food and Drug Administration (FDA) and the National Sanitation Foundation (NSF). In addition to mixed exposure conditions, there most certainly will be extraneous circumstances such as inaccessibility and limitations on surface preparation methods. These situations could have a significant effect on coating system selection and should be thoroughly investigated prior to choosing a coating system. Sources of help for making decisions about these situations are discussed in the ensuing paragraph.

*b. Identifying areas that cannot be properly coated.*

(1) Many times due to design or configuration, structures, items, or areas to be coated do not readily lend themselves to proper surface preparation and coating application. This is particularly true with items designed with back-to-back angles or cavities and crevices that can result from riveted or bolted connections, weld undercutting, overlapping plates, skip welds, lap welds, etc. Essentially, any area that provides cavities or crevices in which air, moisture, dirt, or debris can become entrapped is a candidate for premature coating failure, unless properly sealed and/or caulked. Some initial design considerations such as full seal welding or alternative construction materials (i.e., fiberglass) could be used to avoid such problem areas. However, most structures are already built, and it would not be cost effective or practical to institute design changes. Consequently, caulks and sealants are widely used in many areas. For example, caulking compounds perform well when immersed in fuel oils, water, and chemicals. However, caution should be used when selecting caulks and sealants for immersion environments. Previous successful use in a given immersion environment should be an essential selection factor. Coating suppliers and manufacturers can be a good source of information about whether a particular caulk or sealant will provide good protection in atmospheric or immersion service environments.

(2) Recently, technological developments in the use of low viscosity, penetrating epoxy sealers make them practical for use in areas that are difficult to coat. These two-

component products are tolerant of poor surface preparation, produce minimal stress in the curing process, and are 100 percent solids. These products work with wicklike action, which penetrates and effectively seals off the hard to reach areas; and they can be applied by flooding the surface (with a garden-type low pressure sprayer), much like using a penetrating oil, and allowing the epoxy product to “wick in” and seal back-to-back angles and cavities. Products such as these are proving to be viable alternatives in lieu of, or in conjunction with, caulking compounds in atmospheric exposure.

*c. Identifying regulated requirements.* In addition to performance restrictions on coating types in various service environments, there are regulations on the type and amount of VOCs that can be emitted into the atmosphere. These regulations vary from state to state and even from county to county. Compliant coatings are being formulated with a higher solids content, less solvent, and with water as the solvent. Prior to specifying a coating, it is important to investigate national, state, local, and corporate regulations regarding the use of non-VOC-compliant coatings. The Clean Air Act and the Clean Air Act Amendments of 1990 are affecting the coatings industry by requiring the U.S. Environmental Protection Agency (USEPA) to restrict emissions of VOCs into the atmosphere. (Chapters 4 and 11 provide additional information.)

(1) Because of the emissions from coatings (solvents in particular can contribute to the formulation of ozone at low atmospheres), the USEPA has been directing the use of VOCs. Nationwide regulations are being developed to restrict the VOC content in architectural and industrial maintenance coatings for field applications. These restrictions list the maximum VOC per gallon of paint, and they vary according to the category of coating and its usage.

(2) Before specifying coatings for marine, architectural, or industrial use, the state and local bureaus of air pollution control should be contacted to determine the specific restrictions that may apply. Regulations may specify the maximum allowable VOC per gallon or the total number of gallons permitted to be applied per day or year. After the limitations are determined, the coating manufacturers can be consulted to determine the specific brands that are suitable for use. Note that when investigating acceptable coatings, it is the VOC “as applied” that counts rather than the VOC “in the can.” For example, a solvent-based coating containing 419 g/L (3.5 lb/gal) VOC in the can that must be thinned 10 percent for application will exceed the 419 g/L (3.5 lb/gal) threshold at the time of application. If the local regulations restrict the use of materials to those containing 419 g/L (3.5 lb/gal), this coating could not be used.

*d. Identifying surface preparation alternatives for new construction.* Coating selection is influenced by the degree of surface preparation that can be achieved as well as by the method of coating application that may be allowed. Surface preparation usually is determined by the severity of the service environment (i.e., immersion, normal weathering, dry interior), the type of substrate, and the coating system. As a general rule, the more aggressive the environment is surrounding the item to be coated, the higher the degree of cleaning required. Cleanliness has a direct influence on adhesion and long-term service life. For example, in immersion service, a minimum acceptable surface cleanliness is generally in conformance with SSPC-SP 10, although SSPC-SP 5 is preferred. Cleanliness is only one factor in surface preparation. Profile or surface roughness also is a factor. A rule of thumb for profile or anchor pattern is that the depth of profile should be from one fourth to one third of the total coating thickness, up to a thickness of 0.30 mm (12 mils). For example, a coating system of 0.30 mm (12 mils) should be applied over a profile of from 0.07 to 0.10 mm (3 to 4 mils). The purpose of the profile is to allow for mechanical bonding of the coating to the surface. Profile actually increases the total amount of surface area wetted by the coating system. In new construction, there generally are few logistical limitations of blast cleaning, if the substrate is to be shop-prepared. However, because of the proximity to sensitive areas in the field, abrasive blast cleaning may not be allowed. The relative advantages and disadvantages of each procedure are discussed below. (See Chapter 7 for additional details on surface preparation.)

(1) Total field blast cleaning and painting of new steel. Blast cleaning and painting of new steel may be performed entirely in the field after erection, or they may be accomplished entirely in the shop. The primary advantage to total field blast cleaning and painting is that damage to the paint system prior to service is essentially eliminated. Total shop-applied systems may be damaged by handling and the installation/erection process or onsite repair procedures. Uncontrollable variables, such as weather and climate, often adversely affect field operations and eventually shop allocation if the shop is poorly equipped.

(a) Neither field blast cleaning nor painting may be performed during high humidity, rain, fog, haze, etc. Typically, paint specifications prohibit any work when the surface temperature of the steel is less than  $-15\text{ }^{\circ}\text{C}$  ( $5\text{ }^{\circ}\text{F}$ ) above the dew point. The influence of the dew point is more of a concern on coastal sites or in the cooler northwest and northeast sections of the country. If work is performed when the dew point is too high, the consequence may be flash rusting of the freshly cleaned steel, moisture entrapment between the paint and the substrate causing poor

adhesion, or moisture mixing with the freshly applied paint inhibiting proper curing. Conversely, extremely dry, arid conditions can present problems if the coating specified requires a certain amount of moisture in the air to properly cure (i.e., moisture cured urethanes and ethyl silicate type inorganic zinc-rich primers).

(b) Wind also may interfere with the field work by causing clouds of blast cleaning waste and overspray to drift onto the roadways, neighborhoods, and rivers. The liabilities incurred from drift on automobiles or into nearby residential neighborhoods may be substantial. Many specifications prohibit spray painting where wind speeds exceed a certain level or blow in a specific direction. Furthermore, on some days the wind is too strong to work from staging for safety reasons. Paint application by brush or roller can prevent drift; but it is slower, more labor intensive, and more expensive. In addition, not all paints readily lend themselves to application by brush or roller. This is especially true of some formulations of the high performance coatings such as vinyls, inorganic zinc-rich, acrylic urethanes, and other high-build high solids coatings.

(c) Temperature is another factor that may interfere with field work. The temperature of the steel after overnight cooling is less likely to be at least  $-15\text{ }^{\circ}\text{C}$  ( $5\text{ }^{\circ}\text{F}$ ) above the dew point. Many paints, especially epoxies, cannot be applied when the steel temperature is below  $10\text{ }^{\circ}\text{C}$  ( $50\text{ }^{\circ}\text{F}$ ), because the curing process is temperature dependent. Few paints can be safely applied at or near  $0\text{ }^{\circ}\text{C}$  ( $32\text{ }^{\circ}\text{F}$ ). Because low temperatures restrict coating application, it is impossible to blast clean or paint for months at a time in the northern areas where winters are severe. High temperatures, above  $32\text{ }^{\circ}\text{C}$  ( $90\text{ }^{\circ}\text{F}$ ), also can present problems by reducing coatings pot life or by causing solvents to flash off too rapidly. This results in incomplete film formation, poor wetting, dry spray, loss of gloss, and poor adhesion to the substrate because of poor wetting. Also, topcoats applied over inorganic zinc primers are more likely to bubble and pinhole at high temperatures.

(d) To blast clean and paint a structure in the field, the erection of extensive scaffolds and staging may be required. Staging may be an additional expense, and a subcontractor may be needed to erect the staging and coordinate scheduling arrangements. Staging may have to be moved a number of times before the job is completed. Blast cleaners and coating applicators have limited mobility and accessibility when work is done from staging or scaffolds. Such limitations decrease the amount of work performed and the production quality. Limited accessibility hampers the applicator as well as the inspector.

(e) There is a greater opportunity for surface

contamination when all of the blast cleaning and coating are performed in the field. Uncoated beams generally receive less care and may be dragged across the ground and/or be subjected to dirt or road salts in transit, and the beams may be exposed to coastal or industrial atmospheres at the jobsite. Contamination may occur on the steel or in between field-applied coats of paint. Steel contaminated with corrosive salts or anions is difficult, if not impossible, to thoroughly clean later.

(f) Health and environmental considerations related to blast cleaning in the field also must be evaluated. Current Occupational Safety and Health Administration (OSHA) guidelines require the contractor to take precaution to protect workers from exposure to free silica and nuisance dust during blast-cleaning operations. (See Chapters 10 and 11 for detailed information on these subjects.)

(2) Total shop cleaning and painting. Greater control over the working environment and easy accessibility to the entire surface are the principal advantages to performing work in the steel fabrication shop. Accessibility to all areas of the structural steel is greatly improved in the fabrication shop. The use of overhead cranes to manipulate pieces of steel reduces manpower requirements and virtually eliminates the need for scaffolding during the blast-cleaning and coating operations. However, the shop cleaning and priming procedure has drawbacks. A major drawback is that full-time inspection is rarely available, at least on small- and medium-sized fabricating jobs. Thus, shop inspection may be limited. Little can be determined concerning surface preparation and paint application after the work is done. Another major drawback is that shop coating results in a lengthened waiting period between priming and subsequent application of field coats. During this period the primer coat becomes hard and weathered, and it can become contaminated with dust, grease, and other surface soils that are detrimental to the adhesion of any subsequent coats. Long field storage periods tend to increase the opportunity for marring and scratching of the primer coat and, in extreme cases, may lead to its general deterioration. The paint application section of CWGS 09940 requires shop-coated steel to be stored out of contact with the ground and in a manner that will minimize the formation of water-holding pockets. This provision is considerably important. The shop coat of curved tainter gate sections field stored for months with concave surfaces up has on occasion deteriorated and rusted appreciably during storage as a result of water standing in the depressions. This is an understandable reaction because linseed oil paints are entirely unsuited for extended immersed exposure in a storage area. The guide specification additionally states that shop-coated steel shall be cleaned and repainted or touched up whenever it becomes necessary to maintain the integrity of the coating paint film; this requirement also is important.

In one known case, shop-coated steel was stored at the construction site for more than 18 months, and the provision to periodically touchup and repaint was not enforced. Consequently, at the time of erection the steel was in such poor condition that it required extensive cleaning and the application of a new primer coat, for which the contractor put in a claim for additional payment. This raises the question about what criteria should be used by field inspection personnel in determining if the shop coat needs touching up or a complete renewal. (Chapter 6 will be particularly helpful to inspection personnel in determining what type of corrective action is necessary.)

(a) Other shop problems and mishaps also have been observed. Air in heated shops warms more quickly than the steel surface; and, because the relative humidity increases as the air warms, condensation on the steel is possible. Paint is sometimes stored in a cold, unheated room and under such cool conditions can become very viscous. The resultant cold, thick coating may cause the applicator to thin the material excessively to reduce the viscosity and make it more sprayable. Excessive thinning reduces the volume solids of the coating and results in a lower dry film thickness and inadequate substrate protection.

(3) Shop primed plus field topcoated. A compromise may be found between accomplishing the work entirely in the field or entirely in the shop. This entails performing blast cleaning and applying the prime coat in the fabrication shop. The topcoat and any intermediate coats are applied in the field. This compromise includes the advantages from performing the work in the fabrication shop and the advantages with field application. Unfortunately, although there are advantages, such compromise is also not without shortcomings.

(a) The most obvious advantage to a compromise procedure is that the steel arrives at the jobsite with at least some degree of protection. Contamination of the steel substrate has not been eliminated because the prime coat may become contaminated while the steel is in transit to the site, in storage, or during construction. This is especially true if the steel is exposed to an industrial or coastal environment. Solvent wiping or high pressure washing of the prime coat prior to the application of further coats of paint may be specified to remove contaminants.

(b) Touchup of the prime coat generally is required to repair damage incurred in transit or during construction. Field welds, nuts, bolts, and areas around bolted connections also must be addressed. Surface preparation is vital. Some coatings (such as alkyds) may require only hand-tool cleaning; other coatings (i.e., zinc-rich coatings) require the type of surface preparation that can be achieved only by abrasive blast cleaning. Experience has shown that as much

as 30 percent of the surface area of water tanks often needs touchup, and some bridges may require only 10 percent touchup. Occasionally, the question arises about whether the responsibility for touchup lies with the fabricator or the contractor in the field, and how much touchup the responsible party should be required to perform. Accordingly, adequate field touchup should be clearly outlined in the project specification and understood by the parties responsible for the work.

*e. Identifying surface preparation alternatives for maintenance.* Based on the decision to maintenance paint an item or structure, several maintenance recoating alternatives may be considered: spot priming only, spot priming followed by full overcoating, or total removal and replacement. This paragraph will discuss the alternative methods of surface preparation that can be used in conjunction with these maintenance recoating methods. (See Chapters 6, 7, and 8 for additional information.)

(1) Spot priming only. Prior to spot priming, the mechanism of spot surface preparation and the cleanliness to be achieved must be determined. Spot preparation is required to remove localized areas of visible corrosion and/or loose, deteriorated, or poorly adherent coatings. Prior to general surface preparation, any grease and oil contaminating the surface should be removed by solvent cleaning in accordance with SSPC-SP 1. General surface preparation techniques such as abrasive blast cleaning and hand- or power-tool cleaning have a tendency to spread and/or redistribute grease and oil on the surface rather than removing it. Spot removal of loose coating, loose rust, and loose mill scale can be accomplished by hand- or power-tool cleaning or spot abrasive blast cleaning.

(2) Spot priming followed by full overcoating.

(a) The mechanisms of spot surface preparation given in the previous paragraph can be used if this recoating alternative is chosen. However, the method of preparing intact, well adherent coatings for overcoating must be addressed. The primary concern in overcoating an existing coating system would be system compatibility. The compatibility of recoating systems could be assessed by preparing a test patch. After an overcoating system is found to be compatible with the existing coatings, methods should be used to remove surface dirt, chalk, grease, oil, and other surface contaminants. These methods include solvent cleaning, pressure cleaning with detergent at less than 34,450 kiloPascals (kPa) (5,000 psi), high pressure water jetting with detergent (34,450 to 137,800 kPa [5,000 to 20,000 psi]), high pressure water cleaning (34,450 to 137,800 kPa [5,000 to 20,000 psi]) with abrasive injection, ultra-high pressure water jetting (137,800 to 275,600 kPa

[20,000 to 40,000 psi]) with abrasive injection, or brush-off blast cleaning using fine sand and low abrasive blasting pressures.

(b) Glossy, hard, smooth, or slick existing coating systems may require roughening to promote adequate adhesion. Hand- or power-tool roughening of the existing coating may be done by using hand- or power-tool methods such as sanding. The surface gloss must be removed and the visible surface roughened after preparation. Brush off blast cleaning (SSPC-SP 7) also may be used to clean and roughen the existing coating using the methods outlined here.

(3) Complete removal and replacement. If the recoating decision process has found that the most economical and practical option is complete removal and replacement of the existing coating, the following surface preparation methods may be used. These alternatives in conjunction with the desired surface cleanliness will produce a substrate that essentially can be recoated as a "new" surface. Standard abrasive blast cleaning, high pressure water jetting with abrasive injection, ultra-high pressure water jetting with abrasive injection, or wet abrasive blast cleaning to the desired cleanliness may be used to completely remove the existing coating. When blast cleaning cannot be used, power-tool cleaning to bare metal (SSPC-SP 11) can be used to remove old coatings.

*f. Identifying coating application alternatives.* In addition to surface preparation alternatives, coating application alternatives should be explored. Local regulations on spray application of coatings (proximity to roads/highways, parking lots, residential areas) may restrict the application method used. Brush or roller applications may be required, which may restrict the choice of coating system used because certain coating systems do not lend themselves to application methods other than spray (e.g., vinyls, inorganic zinc-rich primers). Some coatings (referred to as "dry falls") are formulated so the overspray during atomization dries prior to landing on an undesirable resting place.

*g. Cathodic protection system as an alternative.* The primary function of cathodic protection and coatings is to prevent corrosion. As corrosion protection has become more critical, a marriage of the two processes has occurred. Experience has shown that damage to organically coated surfaces is almost unavoidable during construction and in service. Cathodic protection frequently is used in conjunction with coating systems and immersion service where breaks and holidays in the coating expose an unprotected metal substrate. Protecting some structures in these environments may be difficult, if not impossible, with

coating systems alone, especially on complex, configured structures. Thus, the combination of coatings and cathodic protection actually provides good, reliable corrosion protection. USACE has found cathodic protection systems in conjunction with CTE systems to be excellent choices in this regard. (Detailed information on cathodic protection is given in Chapter 2.)

### **5-3. Coating Selection Criteria**

The final selection criterion is to determine how effective the coating system will be in preventing corrosion of the underlying surface in the service environment. Clearly and accurately defining the service environment, soliciting coating manufacturers' recommendations, applying test patches of candidate coating systems in the service environment, and obtaining a successful field history of a generic coating system in an identical or similar service environment will enable the coating specifier to select the coating system that will provide long-term protection of the plant and/or facilities.

*a. Supplier recommendation.* Major manufacturers of coatings and coating systems typically have invaluable information on application parameters of their coating systems, both in terms of temperature restrictions and chemical resistance. Therefore, the suppliers of coating systems should be asked about information on the types of products that will perform in the service environment(s) identified. However, most manufacturers do not have exhaustive information on every service environment that may be encountered; and previous experience with a given coating system in a certain environment may not always be available. Also, some suppliers may not have information because they are not familiar with Government specification paints unless they are actual producers of them. In these instances, a test patch applied and evaluated in accordance with ASTM D5064 at the location of intended service is highly recommended prior to large-scale application.

*b. Ease of application.* The ease with which the coating can be applied will impact applicator productivity and coating film integrity. That is, if a coating material cannot be applied without complicated equipment and specialized techniques to produce a continuous, void-free film, it may not be cost effective to apply such a system unless, of course, the service exposure demands such a system. Therefore, ease of application should be an important consideration during coating system selection.

*c. Maintainability.* The maintainability of a coating system is another factor to be considered, and how it will be maintained (by outside contractor or by plant personnel). If plant personnel are responsible for coating system

maintenance, it is imperative that they be familiar with any specialized equipment or application techniques and properly trained in their use. The surface preparation that will be required during maintenance painting also must be considered. It may be as simple as a solvent wipe (SSPC-SP 1) and reapplication, or as extensive as scarification (SSPC-SP 3 or SP 11) or abrasive blast cleaning of the surface followed by application of the repair system.

*d. Cost.* Appropriate coatings systems selection must take into account paint performance as well as paint economics and balance performance against total cost. Top quality coatings should be compared generically, but identification by generic name in itself is no guarantee of quality. Coatings should be purchased on specifications from reliable coating manufacturers. A protective coating should not be purchased unless its volume solids content and the resin content of the solids are known. Economics plays a key part in selecting a coating system. In fact, under some circumstances, economics may determine the system choice. Therefore, coating costs, in most instances, should be less important than the coating properties that provide the basis for long-term, effective coating protection. Costs should be considered only after the coating or coatings have been selected that will satisfactorily overcome the corrosion problem for which they will be used. For example, during the selection process, two or three coatings all may have the necessary qualifications. Cost then can determine which of the coatings that entirely satisfy the conditions involved will be the most economical choice. Additionally, the cost of the coating system depends on the generic type, the spread rate, the ease of application, maintainability, and projected service life of the system. When choosing the most economical coating system, factors for determining this suitability may include the following.

(1) Environmental resistance. Coatings will be cost effective only if they are used within the limits of their environmental resistance. If an environment is too severe for a coating, that coating will require expensive maintenance, and a different coating material or construction material should be used.

(2) Duration of protection desired. Most coating materials will deteriorate because of their organic or sacrificial nature, and they will require maintenance and periodic renewal. The length of time required for refurbishment may be less in some environments than in others. The cost and difficulty of refurbishment or replacement must be assessed to arrive at the appropriate coating or construction material.

(3) Surface preparation required/allowed. Most coating

systems must be applied over a relatively clean substrate such as that obtained by blast cleaning, grinding, or acid etching. If the required surface preparation is not economical, the use of other construction materials may be more cost effective (i.e., stainless steel, plastics).

(4) Application/curing conditions. If ambient conditions cannot be made suitable for the application and/or cure of the coating system, other means of corrosion protection must be considered (i.e., cathodic protection).

(5) Availability of labor/material. The application of coatings is labor-intensive, and if sufficiently skilled equipment or labor is not available, the cost effectiveness of using protective coatings may be reduced.

(6) Health and safety considerations. Solvents, resins, and certain pigments in coatings may be hazardous to personnel applying the protective coating or the safety and health of personnel in the surrounding area. Safety, health, and environmental considerations at the time of original application and during touchup and repair may be sufficient to reduce the cost effectiveness of coatings compared to other construction materials.

(7) Mobilization/demobilization. There are costs associated with bringing equipment, material, and labor to a jobsite. The costs for transportation and setup of equipment are commonly called mobilization costs. The costs to remove equipment and material from a jobsite are called demobilization costs. These costs can be considerable on large projects, and they must be considered in assessing the costs of a coatings operation. For fixed-site coating facilities (i.e., paint shop) the item to be coated must be transported to and from the shop. These costs may be significant and should be included in cost estimates.

(8) Access costs. The cost of rigging, scaffolding, or otherwise gaining access to the work area can be expensive, particularly when coating a large bridge, water tank, or elevated structure.

(9) Preparation costs. Prior to actually starting surface preparation and/or coating work, certain preparation costs must be assessed. The cost to mask or otherwise protect items not to be painted, to grind or round sharp edges, to enclose the work area, or to protect adjacent work areas or the environment can all be considered preparation costs.

(10) Coating system installation costs.

(a) Coating material costs. Coatings are usually supplied in 1-, 5-, or sometimes 55-gallon containers, and they generally are invoiced at a dollar cost per gallon. These

costs may be considerable on a large job; and, as a rule of thumb, they range from 10 to 15 percent of the cost of the total jobs. However, the coating material cost may be a substantially higher percentage of the total cost if other costs (i.e., surface preparation) are minimal. Rather than the cost per gallon, some specifiers consider the system cost per square foot (i.e., the cost to cover a given area at the required film thickness). Thus, a coating system that builds to a greater thickness in one coat, or has a higher percent solids by volume, ultimately may be cheaper even if the cost per gallon is higher than another material. In this case, application labor would be saved because fewer coats would be required to attain a given thickness. Other specifiers consider cost per year of service life. The evaluation incorporates the expected service life of the coating system in the assessment of its cost. Therefore, a coating that costs \$10 per gallon and lasts for a year will be more expensive than a coating that costs \$20 per gallon but lasts for 5 years. The most comprehensive assessments consider the system cost square foot per year and try to optimize both application savings and service life longevity.

(b) Coating application costs. Labor time associated with the actual application of the coating must be considered. The number of coats required is a major factor in establishing this cost as each coat application is a separate operation. The cost of application labor is a major expense on most jobs, usually second only to the surface preparation.

(c) Surface preparation costs. The labor cost of surface preparation is a major consideration for all coating work. The costs for surface preparation can vary considerably, depending on the method and the extent of surface preparation requirements. As a general rule, when blast cleaning or using other thorough degrees of surface preparation, the costs of labor and equipment may approach 40 to 50 percent of the entire cost of the project. The surface preparation required usually is determined by type of coating system chosen for application. Some coating systems (i.e., vinyl, inorganic zinc rich) require thorough, labor intensive surface preparation such as that by blast cleaning to "White" or "Near White" metal cleanliness; other coating systems are more tolerant (i.e., epoxy mastics) and may not require as thorough, or as expensive, a degree of surface preparation. However, the service life of virtually all coatings is increased by a greater surface cleanliness.

(d) Equipment costs. The cost of wear and tear on surface preparation equipment and application tools and equipment (including operational and maintenance costs) must be considered. Rental rates that can be used as a guideline for equipment costs frequently can be obtained from equipment rental companies.

(e) Curing/drying considerations. Some coatings require an extended cure time prior to being placed in service. Heat curing may be required for certain coatings used as tank linings. If required, special curing conditions may increase the cost of the coating system.

(f) Trade or craft interference/downtime. The coating application process (e.g., surface preparation) is time consuming and may require traffic control, stoppage of operating equipment, or downtime in the immediate vicinity of the work area. Also, nearby workers may object to the noise, odors, and potential hazards associated with the coating operations. Those indirect costs also should be evaluated when considering coating work costs.

(g) Environmental/health and safety costs. Environmental, health, and safety factors are extremely important and may be difficult to assess, but potentially they can be expensive. The Federal Government, most states, and many local communities have strict environmental laws that must be obeyed. Similarly, in the area of worker protection, OSHA requirements must be obeyed on any painting job. The cost of compliance during field painting may be high in comparison to another construction material or another means of corrosion protection. Compliance may be easier during painting in the shop as opposed to painting in the field. Compliance considerations ultimately may be among the most important cost considerations. Environmental protection costs can be as much as, or more than, all of the other costs combined. (Chapters 10 and 11 provide additional information on this subject.)

(h) Indirect costs. Painting projects, as is true with most other construction or maintenance projects, must be properly planned and require specifications, proper management, and adequate inspection to ensure specification conformance. Although these costs also must be considered when evaluating other methods of corrosion protection, they are vital considerations for all coating projects.

(11) Cost estimation and decision making. Preparing accurate estimates of the cost of painting is not easy, and even professional estimators working for painting contractors sometimes estimate inaccurately. Most cost estimates are based on one or more of the following: an estimation of the surface area to be painted, an estimation of costs per unit surface area, an estimation of the man-hours required, and an estimate of the materials and equipment costs.

(a) Surface area to be painted. The surface areas of each item to be painted are measured or estimated, and the cost of painting per unit area (i.e., a square foot) is then applied to achieve a total painting cost. For example, if an area to be painted has a number of pipes of various diameters,

doors, windows, floors, pieces of equipment (e.g., tanks, pump housings, fans, and motors), structural steel, and overhead truss work, the total surface area of each of these items would be estimated or measured. Books and tables are available for estimators to use when making unit area (square foot) calculations. The Painting and Decorating Contractors of America (PDCA) estimating guide provides tables for calculating unit areas in square feet as well as labor rate figures for coating each of these unit areas. After the square footage has been calculated, the time required to conduct surface preparation and/or paint application also must be calculated for each unit area for each category of work (i.e., speed at which a wall or floor can be coated might be entirely different than the rate for coating a series of 76-mm [3-in.] pipes). Thus, appropriate labor rates for each work item should be applied to the unit area of that work item. The cost for unit area multiplied by the total area within each category provides the total cost of painting when all categories are summed.

(b) Man-hour estimates. Many nonpainting operations are part of the overall costs of coating work. For example, mobilization/demobilization, rigging and scaffolding, time for inspection, time for cleanup, and time for equipment maintenance all must be considered when estimating costs. These costs usually are estimated in man-hours or man-days by the estimator. By knowing the particulars of the project, including its size, shape, completion date, and areas to be coated, the estimator can approximate the size of the crew and the equipment required. With this information, a knowledgeable estimator will prepare a schedule sequencing a work order for the job. The work order will indicate when moves must be made from one area to another during the course of the work. The nonproductive costs associated with each move (i.e., transported equipment, rigging, or scaffolding) then can be estimated for each move and applied to the total job costs. Similarly, during the painting operations, other costs (for inspection, cleanup, touchup of defective or damaged areas, maintenance of equipment, etc.) also should be included. These costs usually are estimated in man-hours per unit operation. The estimator evaluates the work to be done and estimates the man-hours needed to complete it. The surface area being painted is not calculated.

(c) Wage rate. The wage rate of most workers usually is known, but the speed at which they work is difficult to estimate. Estimates of labor rates are in estimating guides; however, most painting contractors and experienced coating estimators know by experience what work productivity rates are. Most painting contractors and professional estimators use their own labor rates and do not rely on estimating guides. However, most specifiers use the labor rates presented in estimating guides.

(d) Cost of materials and equipment. The number of gallons of paint, thinner, cleanup solvents, etc., must be estimated, based on the square footage of the areas being coated and estimated loss factors during the course of application. Material loss factors, including overspray and materials remaining in the can, generally range from 20 to 50 percent of the total paint purchased, depending on weather conditions and the type of surface being coated. Based on these estimates, the total amount of paint to be ordered and used on a job can be calculated. The cost of the equipment used on a job also must be estimated and might include charges for the use of compressors, spray guns, airless or conventional spray pots or guns, air and paint hoses, etc. Fuel costs for diesel compressors and electrical generators (if required) also must be estimated. Most painting contractors have developed standard cost estimates for items such as diesel fuel and electrical consumption and can estimate these rates on a daily, weekly, or monthly basis. These equipment/material costs must be factored into the cost of painting. The cost of consumable supplies and equipment must be estimated; abrasives, cleaning rags and cloths, respirators or respirator cartridges, overalls or protective clothing, masking tape, and small tools such as scrapers or wire brushes are all considered expendable consumable items. The cost of these items must be estimated and applied to the total cost of the job. When each cost category is properly estimated and totaled, the comprehensive budget estimate for the painting job can be made. Costs for overhead, insurance, licenses, taxes, etc. must be added to the direct cost to arrive at a total cost.

(12) Alternate ways to prepare coating budgets. Rather than taking the time and making the effort to detail the costs of a painting project as described here, many estimators budget coating work by other means. These estimates are generally less accurate and may be subject to some bias. The accurate determination of painting costs is important to management's decision to provide budget funds for painting operations. Some commonly used budgeting techniques are given here:

(a) Budget estimates for the current year based on the cost of painting conducted in the previous year. Budget estimates may be allocated on a "total funds" concept whereby a certain percentage of maintenance funds are attributed to maintenance painting.

(b) Funding allocations—whether new construction or maintenance painting—only a certain amount of funding is set aside for coating work. No real budget estimates are made, and work is done by either a contractor or in-house plant painting force until the funds are depleted.

(c) Contractor estimates—items or areas to be painted are determined, then one or more painting contractors are asked to provide a cost estimate to conduct the painting work.

(d) Single-source painting programs—some coating manufacturers and independent coating consultants have established single source painting programs whereby a contract is extended to the plant or facility owner (usually at a certain cost per year over a multiyear period). For the contracted cost, a complete painting program is established, and all painting work is conducted. Detailed budget estimates are made by the single-source contractor rather than the facility owner. The facility owner is given an annual cost amount for painting to include in his maintenance budget.

(e) No budget estimate—some owners do not prepare budgets but contract with a friendly local painter or use their own work force to paint on an "as needed" basis. Costs are invoiced, usually on a monthly or weekly basis. At the end of the painting season, the amount expended for painting work can be totaled.

(13) Life cycle costs of coating systems. Accurate budget estimates should be made for each of the corrosion protection methods to be considered. The budget estimates should include costs for the initial work as well as for all future maintenance activities to obtain a "life cycle" cost. For example, initially the cost of installing a stainless-steel-clad lining to a tank may be twice as much as painting the tank, but over a 20-year expected life there may be no maintenance costs. So although it may cost half as much to paint the tank interior as to use a stainless-steel lining, the tank will need to be repainted every 5 years. Thus, over a 20-year-life cycle of the tank, it will cost twice as much to paint the tank as it would to protect it with a stainless-steel cladding. However, when cash flow is slow, painting may be the most economical means of corrosion protection. If a decision to paint is made, a hope may be that future cash flow or profitability will improve and enable the payment of expected higher future maintenance costs. Factors involved in decision making are complex and specific, and they vary considerably because of return on investment strategies, tax considerations, cash flow availabilities, potential for technological advancement, legislative restrictions and marketing, or sales analyses. However, the costs of corrosion prevention alternatives (including painting) must be estimated properly to provide management with the proper tools to make a prudent decision. Thus, there are many alternatives available to the informed engineer to protect a structure. Ultimately, however, the economic selection of a particular system involves two criteria:

duration of effective protection and costs to obtain effective protection.

(14) Estimating the duration of protection.

(a) The length of protection of a properly selected and applied protective coating system will depend on the corrosive environment. Specific coating recommendations for a given environment can be subclassified as subjective and objective. The problem with subjective recommendations is one of credibility—whom to believe. The experience and biases of a person making the statement must be considered prior to accepting a solution to the problem. A subjective recommendation may be satisfactory for most small painting jobs or industrial application for which little money will be expended. However, for large jobs when substantial funds will be expended, or the consequences of failure will be serious, misinformation may be costly. As a result, evaluation of protective coatings using an objective approach may be desired. Objective evaluations of the protective life of a coating system are based on the observation of actual performance of coating systems in a given environment. If properly conducted, empirical evaluations generally are considered more accurate and usually provide the basis for knowledgeable recommendations. Objective empirical testing for convenience can be subcategorized into laboratory testing and field testing.

(b) Laboratory testing consists of standardized tests involving various atmospheric or immersion test chambers and devices for measuring flexibility, extensibility, adhesion, scratch or impact resistance, and other coating characteristics. Field testing involves coatings exposed in a nonlaboratory corrosive environment; examples are test sections on a bridge or water tank or coated test panels placed in various corrosive environments. Generally, laboratory testing precedes any field testing. During the course of either laboratory or field testing, the coating being tested is observed to determine its mode and rate of failure.

(c) Laboratory tests frequently are designed to accelerate failure conditions found in the field to reduce the time of coating failure to a reasonable period (usually about 30 to 60 days). Acceleration usually is accomplished by increasing the exposure extremes or increasing the frequency of exposure to corrosive elements (such as salt fog cabinets and weathering cabinets in which a cycling exposure of water and UV light repeats every hour or so). Both the exposure extreme and the frequency of exposure may be combined in one test (such as reagent or immersion tests for coatings that in service are not expected to withstand strong chemical or immersion conditions). These tests will give a “ranking of performance” and provide a screening, but not necessarily a “duration of protection.” Generally, the best

performing coating specimen in a laboratory test series will also perform well in actual use. However, this is not always a valid assumption. Actual field testing is often the preferred and most accurate method to provide an estimate of duration of protection, which is generally expressed in months or years.

(d) Most field tests are not accelerated tests but are coating exposures in the actual (or similar) service environment in which the coating is expected to be used. Therefore, failure is not accelerated. Coating systems being tested will deteriorate at the same rate as the coating will be expected to deteriorate in actual service under the same conditions. Field tests may not be fully representative of field conditions if there are environmental changes, mechanical or flexural influences, and other factors that are not adequately induced into the test protocol. Because coating systems for atmospheric exposure protect for 15 years or more, real time testing to “failure” is not practical. However, close observation of candidate coatings and their comparative rate of degradation will enable selection of the best coatings prior to complete failure. This observation is commonly done in field testing and when using test panels. Suitable selection criterion can be obtained within 6 to 24 months for many systems. The best method of determining the extent and duration of protection is to observe and record the failure history of a given system in actual use. If care is taken and proper records are kept, this determination can and should be done for every protection system in use. Unfortunately, information thus obtained often becomes obsolete as superior coatings and protective methods become available and technology advances.

#### **5-4. Service Environments for USACE Structures**

Of primary importance in coating selection is the degree of surface cleanliness. Proper surface preparation is necessary to create a satisfactory level of adhesion between the applied coating system and the substrate. Adhesion is a key characteristic affecting coating performance. Various generic coating types may achieve adhesion by different methods. For example, the coating may form a protective thin film by merely lying on the surface, or there may be a chemical reaction with the substrate. Good coating adhesion is an essential coating characteristic and becomes even more important as the aggressiveness of the exposure environment increases. When properly applied, a coating’s rate of success is directly in proportion to its adhesive bond strength. As a result, various USACE exposure environments will be discussed below with regard to the minimum surface preparations required to provide adequate adhesion for the various exposures. Four exposure environments can be used to categorize a vast majority of

USACE painting projects: interior; atmospheric, normal weathering; atmospheric, severe weathering; and immersion or frequent wetting by splash, spray, or condensation from fresh or salt water. Although immersion and frequent wetting initially may appear to be different exposures, experience shows that, generally, the same generic coating systems are successfully used in both exposures. The information on selecting a coating system discussed earlier in this chapter will be particularly helpful in identifying coatings that will perform well in these exposures.

*a. Interior exposure.* Interior surfaces are classified as those that are located within weather-tight structures and are not exposed to atmospheric elements. Although the majority of these exposures are mild, there may be circumstances under which conditions may alter an environment and a more corrosion-resistant coating may be required. For example, unanticipated leakage or equipment malfunctions may result in added environmental stresses, such as condensating moisture or high humidity within an otherwise “normal” environment. Additionally, areas or items that, for various reasons, may become inaccessible after installation or construction should be carefully coated to assure that a coating system for adequate long-term protection is applied. Interior exposure is the mildest exposure environment a coating will encounter. Products used on interior surfaces may be used for aesthetics or decorative purposes only. However, in some instances a coating system must be able to perform in areas of frequent cleaning and scrubbing (i.e., high traffic areas, restrooms). Generally, there are restrictions on the type of preparations that can be performed indoors. There are few, if any, extraneous influences that could stress a coating under circumstances to adversely affect adhesion. However, care must be taken to choose coating systems that are compatible with each other and the substrate to which they are applied. Particular assistance in this regard is discussed in Chapter 4.

*b. Atmospheric, normal weathering.* Weather resistance is the key variable in atmospheric exposures, but this environment can be extremely complex. A coating in atmospheric exposure must be capable of withstanding a variety of conditions that include cyclic heating and cooling, airborne contamination, alternate wetting and drying, UV resistance, and maximum exposure to the deteriorating effects of oxidation. Exposures also may vary from hot, dry climates and humid, tropical environments to constantly cool or cold climates. Therefore, a coating system capable of withstanding a variety of exposure conditions is essential. With strong adhesion qualities, the coating can withstand most environmental stresses that otherwise would affect its integrity.

*c. Atmospheric, severe exposure.* A salt-laden marine

environment or a heavily contaminated industrial exposure is extremely corrosive. Coatings with increased resistance to these environmental conditions are required. These types of exposure conditions are considered to be moderate to severely corrosive to a coating system, and coating systems must be selected accordingly.

(1) When a weathering environment becomes further complicated by the addition of severe exposure elements (e.g., corrosive chemicals, high humidity, severe abrasion, or salt conditions), more sophisticated surface preparation techniques must be used. These added exposure elements will stress the coating system at the point of weakest adhesion. The coating must exhibit good adhesion, and a high order of coating resistance will be required (e.g., a two-part epoxy or urethane coating). As the service demands on a coating system become greater, so does the need for more thorough surface preparation. Abrasive blast cleaning is required to achieve optimal cleanliness and adhesion.

(2) New generation two-part surface tolerant epoxy mastic coatings are gaining rapid acceptance in severe atmospheric exposures. Technological advances within the protective coating industry have brought about development of coatings that exhibit excellent surface wetting characteristics, rust inhibition, abrasion resistance, and chemical resistance. These mastics can be applied to marginally prepared surfaces, such as hand-tool or power-tool cleaning, and show improved service life in situations in which abrasive blast cleaning may not be feasible. Although epoxy mastics provide improved performance, they do not perform as well as equivalent paints applied to a higher degree of surface preparation. As a general rule, the more severe the environment encountered, the more resistant the coating must be; consequently, the more precise the surface preparation requirement becomes.

*d. Immersion or frequent wetting exposure.*

(1) Most immersion or frequent wetting of USACE structures involves exposure to fresh water or seawater. The effect of water on most coating materials is extremely severe. Resistance to water is perhaps the most important coating characteristic because all coatings come into contact with moisture in one form or another. Water, which affects all organic materials in some way, is actually close to being a universal solvent. Therefore, no one coating system can be effective under all water conditions. For example, dam gates and trash racks may require a coating system different from that of the flume bringing water into the dam. Additionally, different types of water may be encountered, such as deionized acidic or sulfide water. Highly conductive water, such as seawater, leads to rapid formation

of anode/cathode areas on the steel that result in severe pitting. The rate of corrosion is proportional to the amount of oxygen in the water; water with a high oxygen content will create similar anode cathode corrosion areas. Therefore, no single type of material will provide a universal answer to coating problems. The water molecule is extremely small and has the ability to penetrate into and through most inorganic compounds. The water molecule passes through the intermolecular spaces of the organic material and either can remain there in an absorbed state or can pass through the compound. Moisture generally will come to an equilibrium, with as many water molecules passing into the organic material as evaporating out of the surface. So a relatively constant water content is maintained in the organic material, depending on the moisture vapor at any given time.

(2) Because of this highly penetrating characteristic, water has more of an effect on organic compounds than any other material. Because most coatings are organic in nature, they must have the highest possible moisture resistance to maintain their properties and provide their structure with a long period of corrosion protection. For a high performance, corrosion-resistant coating to have a water resistance, it must withstand continuous immersion in water or seawater, and it must do so without blistering, cracking, softening, swelling, or loss of adhesion. It also must withstand repeated cycles of wet and dry conditions and abrasion from floating ice and debris. Coatings tend to absorb and retain water in their molecular spaces, and each coating has a level of water absorption. If a coating is strongly adhesive and there is no interface between the coating and the substrate, the moisture will remain in a relatively inert state. At any given moisture pressure, as many molecules leave the coating as enter it. Thus, the best corrosion-resistant coatings generally have the lowest water absorption rates (e.g., CTEs, vinyls, and inorganic, zinc-rich coatings).

(3) The moisture vapor transfer rate is the rate at which moisture vapor transfers a protective coating when there is a difference in moisture vapor pressure on one side of the coating compared to the other side. Each coating also has a characteristic moisture vapor transfer rate. Generally, the lower the moisture vapor transfer rate, the better the protection provided by a corrosion-resistant coating. The transfer of moisture through a coating depends on the difference in pressure between the two sides of the coating. There is no difference in pressure from one side to the other if the coating has excellent adhesion, and the coating soon comes to equilibrium with the moisture in the air or the water in the surface of the coating. The water molecules penetrate into the coating and are absorbed while an equivalent number are evaporated from the coating, so the amount of moisture in the coating remains constant.

(4) If the coating has poor adhesion, either inherently or because it has been applied over a contaminated surface, there is an interface between the coating and the steel (as in dam gates and trash racks) and moisture vapor can transfer into this area. Soon after the coating is applied, there is little moisture vapor pressure on the interface area, so there is a tendency for moisture to pass in the direction of the poor adhesion. Moisture can condense in this space or, if the temperature of the coating increases, the moisture vapor within the void can develop sufficient pressure to create a blister. With poor adhesion, the moisture vapor can penetrate between the steel and the coating, expanding the blister.

(5) The primary requirements for coating to be used for immersion are good adhesion and resistance to moisture vapor transfer, ionic penetration, osmosis, chemicals, cathodic disbondment, and variations in temperature. Snow water, distilled water, or deionized water are close to if not the most penetrating of all the chemicals in which a coating is immersed. But, as the content of the water is increased it becomes more aggressive; primarily because it is much more conductive and corrosion can take place at a much more rapid rate. Although it is commonly known that seawater is aggressive, polluted fresh water may be more destructive to coatings than some seawater. When choosing a coating system for an immersion environment, the conditions should be precisely determined prior to selection. Even solutions with minor contaminants that were scarce enough to be deemed unimportant have caused many coating failures in immersion conditions.

(6) Protecting metallic structures immersed in fresh water is a complex problem. However, when the additional corrosive elements in seawater become apparent, the destructive magnitude of this exposure environment becomes considerably more intricate and complex. Structures immersed in seawater, like their freshwater counterparts, naturally experience multiple exposure environments. The salinity of seawater and its associated high electrical conductivity, along with the surface growth organisms, greatly contribute to the overall corrosivity of seawater. These organisms become destructive when they attach themselves to, and physically penetrate into, a coating film. This growth process is commonly known as fouling; coatings developed to prevent or inhibit this process are called antifoulants. Unfortunately antifoulant coatings are not formulated with exceptionally long service lives, primarily because they are used to prevent marine organisms from fouling on smooth and regular surfaces of ships at rest. Since ships are frequently dry docked, and cleaning and repainting operations can take place, the need for antifoulant coatings with an extended service life is not necessary. Initially, antifoulants would appear to be a logical system choice for USACE structures with similar exposures.

However, on closer examination and through experience with questionable performance of antifoulants applied to irregularly shaped fixed structures (such as gates), this system option has not proven to be highly successful. Therefore, choosing antifoulant paints as a coating system for some USACE structures should be carefully considered. A discussion of coating systems for structures immersed in seawater would be remiss if it did not also reference splash zone or surfaces continually wet by well aerated seawater. Experience has shown that paint films normally deteriorate more rapidly in splash zones than in other zones, primarily because the abundance of oxygen fuels the corrosion process.

(7) Coating systems applied in such environments as immersion or frequent wetting exposures require a high degree of surface preparation. The minimum requirement is generally that presented in SSPC-SP 5. All forms of surface contamination, including possible chloride contamination from salt water, must be removed, and coatings formulated for the required immersion resistance need to be used. Coatings that typically perform well in immersion or frequent wetting exposures are discussed in Chapter 4.

## 5-5. Coating System Selection for Ferrous Components in Fresh Water

### *a. Ferrous metal components.*

(1) Current alkyd coating systems required in CWGS 09940 (systems 1 and 2) are: alkyd primer/phenolic aluminum paint (two coats), rust-inhibitive linseed oil and alkyd primer (two coats), and rust-inhibitive linseed oil and alkyd primer/alkyd gloss enamel (two coats). Because these coating systems are for mild interior exposures and basically consist of primer only formulations, they are readily touched up. Surface preparation may be performed by hand- or power-tool cleaning.

(2) Candidate maintenance systems would be new technology versions of direct-to-metal (DTM) 100 percent acrylic waterborne industrial coatings and higher solid VOC-compliant alkyd primer systems.

### *b. Ferrous metal components subject to atmospheric weathering—normal.*

(1) Current coating systems. Current alkyd coating systems required in CWGS 09940 (systems 1 and 2) are: linseed oil primer/phenolic aluminum (two coats) and linseed oil and alkyd primer/phenolic aluminum (two coats). In this normal atmospheric weathering exposure, many

formulations of alkyd generic coatings would perform satisfactorily.

(2) Candidate maintenance systems. Candidate maintenance systems would be high solids VOC-compliant lead- and chromate-free versions of alkyd primers and finish coats. Most existing alkyd systems can be successfully recoated with long oil alkyd resin systems. Additionally, DTM waterborne, 100 percent acrylic primers and finishes are successful in overcoating existing or aged alkyd systems. New generation acrylics provide more superior gloss retention, color retention, flexibility, and weatherability than traditional alkyd systems. Water-reducible alkyd systems also have found market acceptance; however, their performance characteristics do not rival those of DTM acrylics.

(3) Candidate systems for new steel. Candidate systems for new steel would be high solids VOC-compliant versions of exterior alkyds both waterborne and solvent reducible. Strong competitors to the traditional alkyd systems are the new generation waterborne acrylic industrial primers and finish coatings. Much like their alkyd counterparts, waterborne acrylic coatings are easy to apply and relatively inexpensive, but have the added advantages of improved gloss retention, weatherability, and low odor.

(4) Special concerns and cautions. Portions of these alkyd coatings applications will be done in the shop. Surface preparation for a normal atmospheric weathering exposure is commonly accomplished by complying with SSPC-SP 1, SSPC-SP 2, or SSPC-SP 3. Of primary concern is that these ferrous metal components are often shop-primed and placed in storage for an extended period prior to final erection and finish coating. Untopcoated, these primers do not possess good weatherability; therefore, appropriate precautions must be taken to properly protect the structure while in storage. Adequate protective coverings to protect from moisture and debris accumulation on the substrate are necessary. Additionally, proper blocking and stacking techniques should be used to avoid ground contact in storage. Prior to erection and before finish coating, a careful inspection will be necessary to identify deficiencies (such as prime coat handling or erection damage) and for preparation and touchup as appropriate.

### *c. Ferrous metal components subject to atmospheric weathering—severe.*

(1) Current coating systems. Current alkyd coating systems required in CWGS 09940 (systems 1 and 2) are: linseed oil primer/phenolic aluminum (two coats) and linseed oil and alkyd primer/phenolic aluminum (two coats).

Other systems would be those as identified in 5-5*b* above, with the special concerns and cautions identified in item 5-5*c*(4) below.

(2) Candidate maintenance systems. Candidate maintenance systems would be those described in 5-5*b* above, with special concerns and cautions as identified in 5-5*c*(4) below.

(3) Candidate systems for new steel. Candidate systems for new steel would be those previously described in 5-5*b* above, with the special concerns and cautions as identified in 5-5*c*(4) below being applicable.

(4) Special concerns and cautions.

(a) The anticipated difference between normal weathering and severe weathering environments generally does not necessitate changing the coating systems. Traditionally, systems that perform well in “Atmospheric Weathering—Normal” environments also will perform under these “Atmospheric Weathering—Severe” exposures. However, the longevity of the system may shorten. Consequently, several options can be used within these normal and/or severe atmospheric weathering environments to improve system service life, e.g., improving the surface cleanliness or applying additional coats of paint. For example, applying a second coat of primer or another finish coat would improve the protective quality of the coating. Additionally, surface preparation may be upgraded to abrasive blast cleaning per SSPC-SP 6. However, there may be instances when a unique exposure will require a change in a generic coating type. These situations can be addressed on a case-by-case basis.

(b) There is no clear-cut parameter to describe a marine-exposure environment. Although corrosion is accelerated by the moisture- and salt-laden air, the degree of corrosivity varies from mild to severe. Generally, corrosion is intensified or decreased in proportion to the distance from the shore, with a rapid decrease in corrosivity as the distance from the shore increases. As with other severe atmospheric exposures, a mild marine environment can be adequately protected by improving surface preparation cleanliness or adding coating film build as previously described in 5-5*c*(4)(a) above. Because corrosion and film undercutting, especially at points of discontinuity in the coating film, are greatly accelerated in the presence of salt, locations close to salt water require special attention. Chlorides (salt) are often invisible contaminants, and their presence may go undetected. Salts can present complex problems in surface preparation if they are not successfully removed. Specialized test methods assure that chloride contamination has been adequately removed (see Chapter 9).

Because the salts are water soluble, common methods of removal are by steam cleaning or pressure water blasting. The methods should be accomplished prior to general surface preparation to prevent the redistribution of chloride contamination. In highly contaminated environments, the complete removal of salts and the upgrading of surface cleanliness are extremely important.

(c) Alkyd systems generally have been found to provide adequate protection in mild-marine environments, with corresponding improvements in surface preparation or added film build, as the severity of the exposure increases. In more severe exposures, as on complex structures in proximity to seawater, consideration must be given to choosing a generic coating of superior resistance. Experience has shown that vinyl systems perform well in these situations. Improved protection is noted when this vinyl system is coupled with an inhibitive zinc-rich primer.

*d. Ferrous metal immersion and frequent wetting—fresh (inland waters) or prolonged wetting by splash, spray, or condensation.*

(1) Current coating systems. Metallized systems requirements are specified in CWGS 05036. Current vinyl, CTE, and epoxy polyamide coating systems specified in CWGS 09940 are:

- Vinyl (four to five coats)
- Zinc-rich vinyl/vinyl (three coats)
- CTE (two coats)/CTE (two coats)
- Zinc-rich epoxy (two coats)/CTE (two coats)
- Epoxy polyamide (two to three coats)
- Zinc-rich epoxy (two coats)/epoxy polyamide (two to four coats)
- Systems which have performed well in “Immersion and Frequent Wetting—Fresh (Inland Waters) or Prolonged Wetting by Splash, Spray, or Condensation” environments which are not listed in CWGS 09940 are formulations of phenolics, coal tars, asphalts, Neoprenes<sup>TM1</sup>, inorganic zinc-rich, and organic zinc-rich coatings.

(2) Maintenance painting. Maintenance painting, such as spot touchup, frequently is required to repair smaller failing or damaged areas on a structure. This process further lengthens the service life of a structure with an otherwise intact coating system. These maintenance repairs frequently are made to structures that cannot be taken out of service for long periods of time. Proper spot repair can

---

<sup>1</sup> DuPont Company, Wilmington, Delaware.

permit the structure to remain in service until it is feasible to shut down for complete maintenance repainting. Obviously, surface preparation techniques are limited and are generally on the order of those given in SSPC-SP 2 or SSPC-SP 3. Viable candidates for such nonpermanent repairs are solvent-based coal tars and surface tolerant, two-part immersion-grade epoxy mastic coatings. Keep in mind that these repairs are considered only temporary to preserve the structure until proper blast cleaning and recoating with a system shown in CWGS 09940 can be accomplished.

(3) Candidate systems. Candidate coating systems for new steel are recent technological developments in formulations of epoxies, such as epoxy novalacs and 100 percent solid epoxies. Additionally, 100 percent solid versions of polyurethane coatings are rapidly gaining recognition. Unfortunately, as with some new technologies, specialized methods of application are necessary. The 100 percent solid coatings often require complex plural component spray equipment. Therefore, skilled applicators are essential when using these systems. Industry-wide use of these systems will become prevalent as more restrictive VOC limits are enacted.

(4) Special concerns and cautions. Special concerns and cautions with existing systems are straightforward. The coating systems listed in CWGS 09940 for "Immersion and Frequent Wetting—Fresh (Inland Waters) or Prolonged Wetting by Splash, Spray, or Condensation" all require a high degree of surface preparation, generally, a minimum of abrasive blast cleaning per SSPC-SP 5. Because high performance systems are generally spray applied, highly skilled applicators are required, particularly on detailed and intricate structures. Vinyls are solvent deposited so they are easily cleaned and softened by higher solvent strength aromatic hydrocarbons and ketones, such as methyl ethyl ketone (MEK). Properties such as ease of cleaning and resoftening with solvent allow vinyls to be easier recoated and provide good bonding between cleaned coats. Also vinyls, as a result of their curing mechanism, often can be applied at much cooler temperatures. Unfortunately, the manufacture of VOC-complaint formulations of vinyls is progressing rather slowly, and the future use of these coatings may become more restricted.

(a) CTEs provide exceptional performance but are inherently difficult to apply. Because of their exceptional hardness, they are prone to intercoat delamination problems if critical recoat times are not observed. When overcoating for maintenance purposes, CTEs can present special surface preparation difficulties. When overcoating is required, the manufacturer should be contacted for special surface preparation requirements. Generally, the minimum requirement would be brush-off blast cleaning.

(b) Zinc-rich epoxy and zinc-rich vinyl coatings, in addition to being somewhat difficult to apply, require constant agitation to prevent heavy metallic zinc particles from falling out of suspension in the container. If not properly agitated, the resultant spray-applied film will not be homogeneous in regard to proper zinc particle distribution throughout the dry film. Consequently, the galvanic protection properties of the zinc coating are inhibited.

*e. Painting of penstocks, spiral cases, spiral case extensions, and draft tube liners.*

(1) Interior water contacting surfaces.

(a) Preferred systems. Of the existing systems listed in CWGS 09940 for painting penstocks, spiral cases, spiral case extensions, and draft tube liners, CWGS 09940 system 6, based on CTE, has provided a good history of corrosion protection and would be considered the preferred coating option. CWGS 09940 vinyl systems of the 4, 5, and 6 series have also proven successful when painting penstocks, spiral cases, spiral case extension, and draft tube liners.

(b) Special concerns/cautions. The curing mechanism of CTE is temperature dependent. Therefore, cool (surface, material, ambient temperatures <10 °C (50 °F)) temperatures would slow the curing/reaction process and could negatively impact construction scheduling. Conversely, vinyls, such as the 4, 5, and 6 series, cure by the mechanism of solvent evaporation, which permits application and curing. Where there is severe abrasion or high water velocities with large amounts of suspended abrasive matter (debris, ice, etc.), vinyls provide comparable performance to CTEs, but with the added flexibility of application at lower temperatures and fast dry/cure.

(2) Exterior surfaces of penstocks and appurtenances.

(a) Preferred system. Because of variable exposures of items on the exterior surfaces of penstocks and appurtenances ranging from outside weathering surfaces of penstocks to penstocks in humid tunnels, various systems are needed to adequately protect exterior surfaces of penstocks and appurtenances. Because there may be considerable variability in exposures, it is necessary to choose a system that will perform in the most severe exposure (high humidity and condensating moisture). Therefore, CWGS 09940, system 3 (vinyl) is the preferred system of corrosion protection. Also, because vinyls dry rapidly by solvent evaporation, they are more readily adaptable to the difficult drying condition encountered on exterior surfaces of penstocks and appurtenances than other generic types, such as epoxy or CTE.

(b) Dehumidification equipment. Particularly in summer months, condensating moisture and humidity present difficult problems in the coating of penstocks. Warm, moisture-laden air passing through the cool air naturally causes condensating moisture on the surfaces. Dehumidification equipment will be necessary to create ambient conditions more favorable to coatings application.

(c) Special concerns and cautions. In repair, replacement, or new construction of penstocks, hydrostatic pressure testing usually is required prior to placing the system in service. Testing requires that certain weld seams remain uncoated until testing is complete. Field touchup of welds may leave the structure with an aesthetically unpleasing patchwork appearance, and adjacent coating may be damaged in the repair process. Therefore, USACE prefers to prepare and coat penstocks completely in the field. Unfortunately, field painting of completed penstocks presents particular health, fire, and explosion hazards, which must be carefully controlled with properly engineered ventilation systems (see Chapter 10). Special concerns with spent abrasive recovery, handling, and disposal also must be addressed.

*f. Surge tanks.*

(1) Interior surfaces of surge tanks. Surge tank interiors are well protected by using CWGS 09940 vinyl systems (3, 4, and 5 series) and CTE system (system 6). When painting surge tank interiors, mixed exposure conditions necessitate coating systems formidable to the exposure. Although there appears to be no clear preference for CTE or vinyl, a case-by-case consideration can aid in system selection. For economic reasons and simplicity, it is advisable to coat the surge tank surfaces with the same system as used in the penstocks.

(2) Exterior surfaces of surge tanks.

(a) Exterior surge tank surfaces can be effectively protected with CWGS 09940 system 2, linseed oil and alkyd primer/phenolic aluminum or system 3, vinyl, with the determining factor being the actual exposure.

(b) Special concerns and cautions are necessary when painting surge tank exteriors. As with many other USACE components, normal weathering predisposes the use of system 2 when climatic conditions or reservoir temperatures produce frequent wetting or prolonged periods of condensating moisture. Under such conditions, vinyl (system 3) should be used. Surface preparation would be sandblasting as outlined in CWGS 09940. If the exposure environment is not clearly defined, the vinyl system, which exhibits good resistance to both exposures (normal weathering or high moisture), should be used.

*g. Crest gates.*

(1) Existing exposures on crest gates may range from normal weathering exposure to areas of immersion and frequent wetting. Exposures such as immersion and frequent wetting are best protected using CWGS 09940 system 3, 4, or 5. Normal weathering exposure areas of crest gates would be well protected using CWGS 09940 systems 1 and 2 for steel in normal atmospheric exposures.

(2) Special cautions/concerns in coating crest gates may include variable exposure environments impacting on crest gates and depending on whether the painting surfaces are exposed upstream or downstream. The upstream side usually will receive the most severe exposure (immersion, abrasion, etc.). However, depending on certain conditions such as high tailwaters, downstream surfaces also may experience rather harsh exposures. Therefore, the most long-term, cost-effective method of coating would be the exclusive use of CW 09440 system 3 (vinyl with aluminum topcoats); or, if superior abrasion and mar resistance to debris and/or seasonal ice is desirable, use CWGS 09940 vinyl system 4 or 5 series.

*h. Control gates and valves of reservoir outlet works.*

(1) Preferred systems. Existing coatings listed in CWGS 09940 for control gates and valves of reservoir outlet works frequently are dependent on the level of exposure. CWGS 09940 systems 3, 4, 5, and 6 series, vinyls, and CTE are viable choices. Special attention should be given to the following concerns and cautions when specifying a coating system.

(2) Special concerns and cautions.

(a) Coating selection may vary considerably from project to project, depending on the following variables. Whether the water control device is operated fully opened or partially opened is important. If operated fully opened, whether the component is removed from the flowing stream of water should be noted; the component may be exposed to various degrees of abrasive ice- and/or debris-filled, fast-moving, turbulent water. If operated in the partially closed position or if exposed to flowing water, the severity of erosion and abrasion would be magnified. Additionally, the elevation and other characteristics of the service inlet may permit abrasives (ice, debris suspended matter, etc.) to adversely impact the system's service life. With this in mind, the following coating recommendations should be carefully considered. Structures in low-to-moderate water velocities (45.7 to 61.0 mm/sec [15 to 20 ft/sec]) with abrasive qualities are good candidates for coating with CWGS 09940 system 4 or 5 series or CTE. However, if extremely severe conditions can exist, neither of these systems are advisable,

and one of the specially reinforced systems (see Chapter 4) may be appropriate. Many types of gates (slide gates, tainter gates, tractor gates, fixed wheel, etc.) can be painted without difficulty; however, special attention is required when painting tractor gates. Specifically, the stainless steel roller chain and track assembly must be carefully protected during field painting. While in the erection phase, the roller chain most likely will not be installed, the stainless steel track will be bolted to the gate. Care must be taken to mask off or otherwise protect these track surfaces properly from blast damage, and to seal off bearings and other rubbing surfaces from abrasive blast particles.

(b) As previously discussed in this chapter and Chapter 2, a strong potential for galvanic corrosion can be set up by the coupling of dissimilar metals, such as stainless steel roller chains and tracks with tractor gate carbon steel surfaces. Therefore, a cathodic protection (CP) system frequently is used for enhanced corrosion prevention of the carbon steel surfaces on these gates. The specified coating must exhibit high dielectric strength, in addition to being carefully applied to avoid holidays. In this regard (high dielectric strengths), the use of CTE is superior to vinyl systems and is recommended for use on control gates and valves of reservoir outlet works in conjunction with a CP system. Discussions of total field painting procedures revealed that fewer holidays are noted when surface preparation and painting are done entirely after erection in the field. Therefore, these gates should be totally field painted with CP systems attached. Alternatively, total shop painting with CTE and attaching CP anodes prior to installation, with no field touchup, also has proven to be effective and economical. Also, CP is particularly effective in protecting bare steel exposed as a result of damage from impact or abrasion which may occur while the structure is in service.

(c) If the foregoing preferred options are not possible, careful consideration of the difficulties with recoating CTEs should be addressed. Specialized surface preparations, such as brush blasting, will be required if critical recoating times are exceeded.

(d) Hydraulic lines on control gates and valves of reservoir outlet works also present unique coating problems, particularly if they are immersed in water because hydraulic lines are vulnerable to exposure damage (from ice, debris, etc.). These hydraulic lines should be isolated with dielectric coupling and cathodically protected.

*i. Trashracks for water intakes.*

(1) CWGS 09940 systems 4 and 5 series (vinyl) with zinc-rich primers provide the best protection to difficult-to-

coat trashracks. From a design standpoint, trashracks present numerous coating difficulties, such as sharp edges. Because of their design and the fact that they are subject to flowing water with abrasive debris, seasonal ice, and mechanical raking damage, coating service life typically is shortened. Therefore, trashracks may best be left uncoated, with the possible exception of those in environments of severe corrosivity. If these items are coated, a periodic structural integrity inspection program is highly recommended. Oftentimes, it is more cost effective and easier to fabricate new racks than to attempt to refurbish existing ones.

(2) Special concerns/cautions when coating these items are straightforward. When the abrasive gouging action of ice is present, systems 4 and 5 series (vinyl) perform well; the zinc-rich primer systems provide the best performance. If the outage period is short or the weather is cool, the faster dry, low-application-temperature (>2 °C (35 °F)) vinyl systems would be appropriate coating choices.

*j. Navigation lock gates, valves, and miscellaneous submerged metal.* Lock gates and valves are well protected in this exposure using CWGS 09940 vinyl (systems 4 and 5 series) and CTE (system 6). The massive lockwall armor and protection angles are not critical to basic project functioning. Painting on construction (CWGS 09940 system 2) and possibly periodic maintenance for aesthetic purposes appears to be practical.

*k. Navigation dam gates.*

(1) Systems in existence are CWGS 09940, vinyl systems 4 and 5.

(2) Special concerns and cautions in painting navigation dam gates involve exposures unique to the structure. Gates are generally of the roller, tainter, or vertical-lift type. The exposure environment is that of turbulent water, physically trapped abrasive debris, drift materials, and seasonal ice. The abrasion-resistant qualities of system 4 or 5 generally are thought sufficient to provide good protection. However, in extreme conditions, metallized systems (see Chapter 4) should be considered. Roller and tainter gates have interior and exterior surfaces that require painting. Because grating protects the interior from abrasion, CWGS 09940 system 3 will provide adequate protection. Vinyls are high in solvent fumes and highly flammable; therefore, special care (see Chapter 10) is required for ventilation systems when coating with vinyls.

*l. Freshwater (including potable) tanks.*

(1) Preferred systems. Existing systems for freshwater

tanks are CWGS 09940 vinyl system 3, 4, or 5 series.

(2) Special concerns and cautions.

(a) Potable water tank lining demands coating systems free of harmful toxic chemicals. Special regulations, such as those of the NSF, govern such coating systems. Vinyls, because of their inert qualities, readily lend themselves to immersion in freshwater (including potable) tanks. They are neither toxic nor physically harmful to the person who drinks water that has come in contact with these coatings.

(b) Abrasion action from ice movement is often a factor in colder climates. Systems 4 and 5 series should be used in lieu of the less abrasion-resistant system 3.

(c) In conjunction with cool water stored in a tank interior, condensating moisture frequently is found on the exterior surfaces of the vessel. If this condensation becomes commonplace, the use of CWGS 09940 system 3 on the exterior surface is advisable.

*m. Equipment for local protection projects.* The equipment for local protection projects (slide gates, flap gates, etc.) and the portion of pumping units below the pumping station operating floor should be painted with a cold-applied coal-tar paint system, system 7 from CWGS 09940. This system is used because the manufacturers of the equipment involved are not prepared to thoroughly blast and apply the more costly and less user-friendly vinyl systems. Moreover, local flood-protection projects are given to local authorities, who are responsible for the maintenance of the completed project, and the maintenance of surfaces painted as advised here is more within their capabilities and experience. In essence, the recommended systems are more user-friendly and surface tolerant to the inexperienced applicator. Miscellaneous items of fabricated steel should be hot-dip galvanized after fabrication. Specifications for pump discharge lines are given in EM 1110-2-3105; they are to be coated on the inside with hot-applied, coal-tar enamel; however, this procedure is difficult in coating operations in small diameter piping. If the lines are buried in soil, the outside of the lines must be coated with hot enamel plus a felt wrap, which is applied in the shop in accordance with the American Waterworks Association (AWWA) Standard C203-91. The CTE, CWGS 09940 system 6 or 6AZ, also would be highly effective on discharge lines but it is not routinely available as a shop-applied coating.

*n. Floating plant (steel construction) operating in fresh water.* Varying surfaces and exposure environments are associated with the painting of a floating plant. Although this in itself is not unique, the additional color scheme

regulations imposed by ER 1125-2-303 often require the specifier to employ some alternative system combinations. Federal Color Standard 595 is used to dictate many of the color schemes for floating plants. Certain of the smaller crafts, such as skiffs, rowboats, launches, small boats, barges, and scows, are exempt from color scheme requirements. The following paragraph addresses coating application to the component.

*o. Exterior surfaces of steel hulls.*

(1) Certain modifications of CWGS 09940 vinyl systems 4 and 5 can acceptably accomplish coating of the entire hull. When special color concerns as identified in CWGS 09940 are necessary, such as hull surfaces above the waterline, substituting the last two spray coats of vinyl system 4 or 5 and/or substituting two black vinyl coats per V-103 is appropriate to achieve the special color. Also two final coats of Fed. Spec. TT-E-489 (black alkyd) may be used to achieve the special color.

(2) A garnet-reinforced system has been used for hull bottoms because frequent running aground results in severe abrasion and gouging of the coating system. Additionally, abrasion protection can be achieved by first priming the hull bottom with 2 to 3 mil of vinyl zinc-rich primer VZ-108, and following with the garnet-reinforced coating.

*p. Interior surfaces of steel hulls.* Hull interiors are subject to accumulating water, condensating moisture, and high humidity. Like other exposures of this type, these surfaces are well protected using CWGS 09940 systems 3, 4, 5, and 6 series. However, these systems necessitate sandblasting and may prove costly. A less expensive alternative would be to use a cold-applied, solvent-based coal tar (MIL-C-18480A(3)) in a two-to-three coat application. The saving is realized because of the lesser degree of surface preparation required by the manufacturer and the overall material costs. If the hulls remain dry, there are many less expensive systems, such as alkyd primers/alkyd topcoats, that can be applied over lesser degrees of surface preparation (i.e., SSPC-SP 3).

*q. Painting of steel decks.*

(1) Steel decks, if painted, are prescribed by the referenced regulation to be deck red, color 10076 of Federal Standard No. 595. The color requirement is waived when special, approved types of deck coatings are to be used. Red deck paint (Mil. Spec. DOD-E-18210B), three coats, is intended primarily for use on interior decks of naval vessels. It is based on a durable alkyd-phenolic-type of vehicle and is considered suitable for either interior or exterior use on floating plants operating in fresh water. This type of paint

should be used only on well prepared surfaces that are sandblasted to a commercial or better grade. Sand reinforcement of the second coat would be desirable when a nonskid surface is needed. Substitution of an inhibitive-type primer instead of the first coat of deck paint might be beneficial to the three-coat Mil. Spec. DOD-E-18210B system, but it is not considered essential for plants operating in fresh waters.

(2) Vinyl paint system from the 5 series having the V-106 topcoat from CWGS 09940 is the correct finish color and will perform well as a deck paint, although it would be somewhat difficult to sand-reinforce for antiskid purposes because of its fast-drying characteristics. The addition of fine garnet directly to the finish coats of this system will provide added abrasion resistance but minimal benefit in improved antiskid properties.

*r. Exterior surfaces of floating plant.*

(1) The color scheme for the painting of floating plant surfaces is prescribed in ER 1125-2-303. The surfaces involved are subject only to atmospheric exposure; although beneficial, blast cleaning may not be justified. If wire brushing and scraping (per SSPC-SP 2) are used, the surfaces will have corrosion products and mill scale present. One or two coats of a primer with good wetting properties, such as an alkyd rust-inhibitive primer, is advisable. Primed surfaces then could be finish coated with two coats of a semigloss enamel conforming to Fed. Spec. TT-E-529 (2) Class A. Enamel conforming to Fed. Spec. TT-E-489 Class A, or TT-V-1593 (silicone alkyd) should be used if a high gloss finished surface is desired. Both of these specifications include a range of gray, ivory, black, and red from which those suited to the floating plant color scheme may be selected. The finish coat enamels are relatively fast-drying materials and should not be applied to surfaces primed with slow-drying, alkyd primers without proper drying times.

(2) If an upgraded system is desired, the surfaces subject to atmospheric exposure could be cleaned by blasting to at least the commercial grade, and one or two coats of an alkyd rust-inhibitive primer should be applied. Finish coats of enamel conforming to Fed. Spec. TT-E-489 or TT-E-529 then could be used to comply with the required color scheme.

(3) Stacks of floating plants are required to be painted black with trim colors of red and aluminum. The use of special paints for these surfaces is determined by their maximum operating temperatures. Ordinary alkyd black paints, such as those included in Fed. Spec. TT-E-489 or

TT-E-529, will tolerate temperatures of up to about 135 °C (275 °F) for extended periods, as would an aluminum paint made with an alkyd vehicle (Fed. Spec. TT-V-109). Black paints (Fed. Spec. TT-E-496) will withstand temperatures of up to 204 °C (400 °F). For temperatures higher than 204 °C (400 °F), paints made with silicone or modified silicone binders must be specified. Fed. Spec. TT-P-28 covers a modified silicone-aluminum paint with a heat-resisting capability to temperatures up to 649 °C (1200 °F). MIL-P-14105C formulated products will resist temperatures as high as 760 °C (1400 °F) and are available in some colors. However, these products are expensive and frequently are available on a special order basis only.

## 5.6. Coating System Selection for Ferrous Surfaces in Seawater

*a. Ferrous metal surfaces of fixed structures.*

(1) Current systems. Current systems found in CWGS 09940 are:

- CTE (two to three coats).
- Epoxy zinc-rich primer/CTE (two coats).
- Epoxy polyamide (two to three coats).
- Epoxy zinc-rich primer (two coats)/epoxy polyamide (two to four coats).

Other existing systems (not listed in CWGS 09940), which have performed well, are formulations of coal tars, asphalts, Neoprenes™, and organic zinc-riches.

(2) Candidate maintenance systems. Maintenance painting, such as spot touchup, frequently is required to repair small failings or damaged areas on a structure. This process further lengthens the service life of a structure with an otherwise intact coating system. These maintenance repairs may be made to structures that cannot be taken out of service. Proper spot repair can permit the structure to remain in service until a time that is feasible to shut down for complete maintenance repainting. Surface preparation techniques are limited and generally are on the order of SSPC-SP 2 or SSPC-SP 3. Viable candidates for nonpermanent repairs are solvent-based coal tars and surface tolerant two-part immersion-grade epoxy mastic coatings. Keep in mind that these repairs are considered only temporary to preserve the structure until the time proper blast cleaning and recoating can be accomplished.

(3) Candidate systems for new steel. Candidate coating systems for new steel are recent technological developments in formulations of epoxies, such as epoxy novalacs and 100 percent solids epoxies. Additionally, 100 percent

solid versions of polyurethane coatings are rapidly gaining recognition, and inorganic zinc-rich coatings topcoated with organic paints also have performed well. Specialized methods of application may be necessary and most commonly require complex plural component spray equipment. Therefore, skilled applicators are essential when using these 100 percent solid epoxy and polyurethane systems. Industry-wide use of these systems will become prevalent as more restrictive VOC limits are enacted at the Federal, state, and local level. Contemplated systems must all be evaluated individually and specifically in this seawater immersion environment.

(4) Special concerns and cautions. Special concerns and cautions for immersion service in seawater were discussed in paragraphs 5-2a(3) and 5-4d. Additionally, the coating systems listed in CWGS 09940 for exposure to seawater all require a high degree of surface preparation—abrasive blast cleaning to white metal.

*b. Steel piling.*

(1) Existing CWGS 09940 CTE systems for coating steel piling are systems 6 and 6AZ (CTE). Systems 6 and 6AZ are suitable for protection of steel pilings. However, there are many questions about steel piling painting.

(2) Special concerns and cautions associated with the coating of steel pilings include the fact that no method of corrosion protection is used on certain portions of steel piling. Studies have shown that the corrosion rates of piling driven into undisturbed soil on the ocean floor corroded at slow rates mainly because of the lack of oxygen. Obviously, as the pilings emerge from the ocean mud floor, the presence of oxygen and consequent corrosivity increases. Moving soils, basic saltwater immersion, tidal movement, abrasives, contaminated waters, and aerated splash zone activity rapidly accelerate corrosive forces.

(a) The installation of pilings by driving them into the sea floor is believed to be particularly abrasive to a coating system. Initially, it was not known whether a coating system could withstand this installation without irreparable damage. However, it has been demonstrated that, when properly coated with CTE coatings, damage is limited to a few inches on the leading edge of the piling and relatively minor scratching in the interlock area. The addition of proper CP can protect these areas from corrosion.

(b) Interlock areas on sheet piling present some unique surface preparation coating difficulties, particularly the grooved areas. Even the best applied coatings to these interlock areas were believed to be damaged in the driving installation process. However, the damage is not as severe

as originally believed. In addition, this is the thickest part of the piling, and corrosion will have little effect on structural integrity. A suggested remedial action is to minimize corrosion through the use of galvanically protecting zinc-rich primer and periodically monitoring the corrosion rate and structural integrity. Experience has shown that, although corrosion will occur, it usually is of a localized nature and not critically harmful to structural integrity. However, corrosivity can vary from site to site, and periodic monitoring is considered vital.

(c) In cool environments, the temperature-dependent cure times of CTE and scheduled coatings operations (in shop and/or field) must be observed. Because exposure environments of pilings may vary (i.e., buried, immersion, splash zone), it seems proper to coat the pilings as outlined here.

(d) Underground portions of steel piling, which are a moderate distance below the groundwater table (or below the water-mud line if driven through surface water) do not seriously corrode. Therefore, the coating system may not be necessary 5 to 10 ft below these indicated levels. Sections of pilings subject to weathering and aerated splash zone activity would also be adequately protected using CWGS 09940 system 6 or 6AZ.

*c. Cathodic protection (CP) and immersion in seawater.*

(1) Certain inherent characteristics of seawater make it of greater corrosivity than fresh water. Because of this heightened corrosive nature, the use of CP in conjunction with immersion coating systems frequently is used for structures in seawater.

(2) High dielectric strengths, or the ability of the coating to withstand the additional stresses of the CP current is extremely important. Because the CP current forces water through the film in a process called endoelectrosmosis, a coating that can withstand this stress, such as CTE, is an important choice in conjunction with CP-induced stresses, of cathodically produced hydrogen gas and alkalis that are generated at the paint-metal interface. The desirable coating quality of high dielectric strength essentially forces the CP current along the painted film to breaks or discontinuities in the coating where it is needed for protection of the bare steel substrate. When choosing a CP system for a structure that is partially seawater immersed and partially atmospherically exposed in the splash zone, CP may not provide adequate protection to the splash zone portion. The highly oxygenated splash zone is severely corrosive and requires higher CP rates that could be detrimental to the submerged CP-protected areas. Additionally, coating choices must be resistant to these forces when used with CP.

## 5-7. Coating System for Iron and Steel Pipe

*a. Black iron or steel pipe.* Existing systems for coating black iron and steel pipe are alkyd inhibitive primers, with ready-mixed aluminum and alkyd topcoats. CWGS 09940 also specifies the use of vinyl systems in some exposures. A clear, varnish-like coating sometimes is present on black and steel pipe. In nonsevere exposures, the coating generally is compatible with alkyd coating systems. Solvent cleaning and hand-tool cleaning generally are adequate for coating with alkyd systems. However, if the exposure environment becomes more severe, a corresponding upgrade in surface preparation and coating choices, such as a vinyl (CWGS 09940 system 3), is appropriate. The required spray application of vinyl on piping in place can prove to be labor intensive. Upgraded surface preparation and protection with additional coats of alkyd or phenolic topcoats may prove to be a viable alternative.

*b. Galvanized pipe.*

(1) Coating systems for galvanized pipe are generally for appearance purposes or for the refurbishing of damaged galvanized components. Zinc-rich epoxy polyamides and

coatings specially formulated for galvanization are useful in this regard. The zinc-rich coatings are abrasion, chemical, and moisture resistant. Consequently, they frequently are used without a topcoat, even in severe exposures. Adhesion to this substrate may be variable because of the galvanizing process, and care must be taken in the surface preparation process to assure that all galvanizing process oils are totally removed before painting. This normally can be accomplished by solvent or detergent cleaning.

(2) Threading and welding of galvanized pipe after production leave exposed steel, which requires touchup. Epoxy zinc-rich primer coatings are extremely effective in this regard. These coatings have good adhesion qualities to existing galvanized surfaces and, in themselves, provide similar galvanic protection to the touchup areas.

(3) Thinly applied vinyl wash coats (0.0076 to 0.013 mm [0.3 to 0.5 mil] dry film thickness [DFT]) also have proven to be an effective tie coat on galvanized pipe that provides a sound base coating for high performance barrier-type topcoats. Primarily though, these systems are used only in frequent condensation and moderate corrosivity, when the galvanization itself may readily react and rapidly deteriorate by galvanic action.