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Use of Coatings on Hydraulic Steel Structures

Part 2–Supplemental Information

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PURPOSE AND INTRODUCTION: This technical note is the second in a two-part series that contains information about coatings systems and coating conditions that exist within the U.S. Army Corps of Engineers (USACE or Corps) and U.S. Bureau of Reclamation (USBR). This second volume focuses on common coating problems, special topics related to coatings, and specific examples encountered in the field survey.

COMMON PROBLEMS: Many coating problems are a result of the environment the coated structure is exposed to. A significant cause of coating failure is ultraviolet (UV) exposure. Failure of this type is considered chemical degradation, and this type of exposure can quickly degrade a coating by weakening the chemical bonds. Another cause of failure is due to impacts and abrasion; failure of this type is considered physical degradation. Edges and corners of structures are the most subject to impact and abrasion from floating debris because they are more exposed than other parts of the structure; therefore, they are the first to fail.

Examples of coating problems include: excessive thickness that causes cracking (Figure 1) or too thin of a coating (Figure 2), corrosion that occurs near bolts, rivets, welds, and other surface irregularities (Figure 3), entrained air that occurs during spray application of the coating (Figure 4), and impact from objects or debris (Figure 5).

Figure 1. Example of failure due to excessive thickness.

Figure 2. Example of failure from too thin of a coating.

Figure 3. Examples of failure near bolts, rivets, and welds.

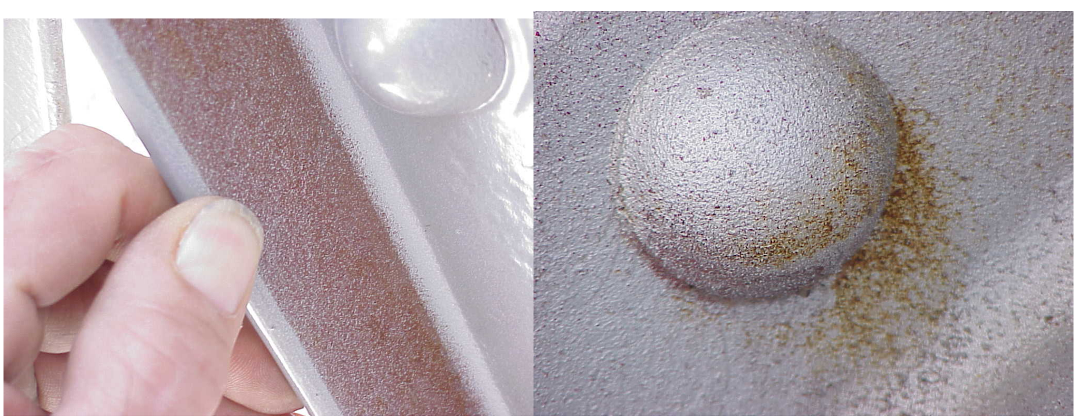

Figure 4. Examples of failure due to entrained air from spraying.

(a) (b)

Figure 5. Examples of failure due to: (a) impact of object on hydraulic piping with 3-year-old aluminum epoxy mastic coating, and (b) impact of debris-filled water on 34-year-old Tainter gate vinyl coating.

Typical coating failures include: epoxies chipping when brittle and worn corners and edges of machinery are impacted (Figure 6) and loss of thickness due to chalking. Other coating failures caused by the environment include: erosion, abrasion, corrosion under the coating, undercutting along the steel/coating interface, and delamination in debris-filled high-flow water.

Figure 6. Examples of failure of epoxy coating due to edge chipping.

Applying the wrong coating for the intended application is poor planning and will result in premature failure. This is the case when oil-based paint is applied to concrete or galvanized conduit. This misapplication has been observed, and what occurs is that the alkaline surface reacts with the oil to essentially form soap. Poor intercoat adhesion can also occur if incompatible primer and topcoat are chosen (Figure 7). Surface preparation is very important in these cases.

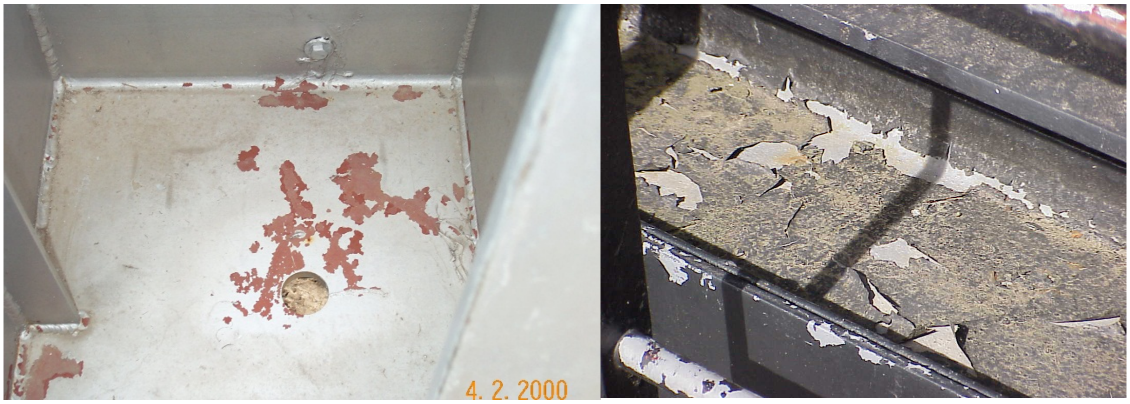

Figure 7. Examples of coating failure due to poor intercoat adhesion and poor surface preparation.

A coatings truism states that "if the quality of the surface preparation is poor, then the quality of the paint itself matters very little." Problems can begin during surface preparation (Figure 8). The preferred surface preparation for metal that will be submerged is "white metal blast". Near-white metal blast (within 5%) may be acceptable, but this may be difficult to define and may cause disagreement with a contractor. The contractor may have a different opinion on what is "stained" or how much is 5%. A surface that is touched by the hand after white metal blasting introduces contamination in the form of oil and salt. This contamination has been found to create rust in a very short time. The duration of time between white metal blasting and application of the coating is important and is generally required to be within 8 hours. Before the surface is painted, the structure should not experience a temperature surpassing the day's dew point, as this would cause condensation and flash rusting. A containment structure is typically used when blasting to collect all waste from the blasting process. This containment structure can also protect against weather and other elements as well as be humidity-controlled.

(a) (b)

Figure 8. Examples of failure due to poor surface preparation on: (a) hydraulic cylinder and (b) lift gate.

A big challenge when utilizing contractors is to ensure that they read and follow the contract. The contract is typically written to include important aspects of guide specifications that need to be carefully adhered to. However, a contractor will typically want to meet the bare minimum of what is specified, and thus whether that minimum has been met can be called into question. An example of this could be the surface profile peak count not reaching the specified count. A contract must be sufficiently detailed so that a contractor knows exactly what is expected and has no problem achieving it.

A quality control problem with two-part epoxies that occurs at low temperatures is amine blush, where the amine (hardener) migrates to the surface because the components did not fully react. This problem will cause a second coat not to stick. The proper use of a test kit that determines the amount of mixing can mitigate this problem.

Nonvisible contaminants are another cause of coating failure. Examples of these types of contaminants include salt on bridges from deicing salts or salt from the sea if the structure is near the ocean. There are test kits to check for salt contamination. The Corps may use these kits where structures come into contact with brackish water, but the kits are seldom used on structures located on fresh water.

Fluctuating water levels also pose a problem for submerged applications because of increased dissolved oxygen. Other environmental stresses on coatings include freeze-thaw, debris, thermal expansion/contraction, thermal cycling, and impact.

Some common problems (and relevant applications) specific to the USBR's coated structures include cavitation damage (turbines, stay vanes, draft tubes), erosion (pump volute areas, high-sediment level waters), fluctuating water levels (gates, trash racks), high-velocity water (outlet works, hollow jet valves, penstocks), and areas where metalwork exists in concrete (pH corrosion cell).

HOW COATINGS ARE TESTED: Accelerated weathering is a method of side-by-side comparison of coating products that are applied to identical surfaces, and this method is used by both the USBR and the Corps to evaluate coatings. Unfortunately, most accelerated tests do not correlate well to field testing or real-life results; however, properly conducted accelerated weathering tests can be an aid in selecting appropriate products. In general, if a material yellows or chalks in accelerated tests, it is going to do the same in field conditions.

Outdoor racks provide the most realistic weathering tests, but they can only provide testing for the environmental conditions where the racks are located. There are methods, however, for simulating environmental conditions. For example, a salt fog chamber exposes the test coupon to a combination of salts and wet/dry cycles. A Cleveland humidity chamber simulates condensation. The UV accelerated weathering chamber uses fluorescent bulbs emitting UV-A and UV-B light. Rotating test samples between salt fog, UV, and freezing temperatures, and then repeating the cycle is the best practice. However, none of these techniques represent immersion in water. And thus, there is no impact or abrasion tests with these methods. There are abrasion tests, however. The Taber abrader is a rotating wheel that scuffs the surface of the specimen, but it still is not representative of the abrasion action of debris in water. A close approximation for real-world abrasion is rotating the sample in a sand slurry, which has been tried in a 5-gallon bucket. The USBR has experimented with simulating cavitation, but it has not been able to accurately reproduce the type of cavitation occurring at a dam.

Additionally, laboratory weathering will not accurately represent how long a coating will last in the field. A weathering cabinet such as the "salt fog" chamber contains a 5% sodium chloride (NaCl) atmosphere, which is not a real environment anywhere on the earth; in fact, that atmosphere may actually help to preserve some coatings.

HOW COATINGS ARE INSPECTED: The only reliable inspection technique for coatings is visual; this means seeing it with the naked eye. There is a commonly used numerical rating system for visual inspections. To use this system, the inspector does not need to know a lot about paint. There is a nine-point rating system, using A, B, C ratings (in descending order) with the possibility of plusses and minuses (+/-) added to each letter. This type of rating should be completed every year, in order to track degradation and determine the rate of degradation.

There are also many ASTM and ISO standards for evaluating coatings.[1] Some of the most common standards (and their shortened titles) include: ASTM D870, "Water Immersion" (2015); ASTM D4587-11, "QUV" (2011); ASTM D5894, "Cyclic Weathering (Prohesion)" (2010); ASTM D 2794-93, "Direct Impact" (2013); ASTM G8-96, "Cathodic Disbondment" (2010); and ASTM D4541, "Pull Off Adhesion" (2009).

However, even these testing methods do not exactly match field conditions, and it is for this reason that the USBR has developed a few testing procedures that are more representative to actual field conditions. A commercial test method, electrical impedance spectroscopy (EIS), measures the coating conductivity, which can be used to infer moisture levels. The premise for this test is that if moisture goes through the coating, then the coating has failed. However, from a corrosion perspective, the substrate will only rust if gaseous oxygen also passes through the coating. EIS monitoring was tried in Okinawa, Japan, but was not successful due to equipment sensitivities.

REGULATIONS THAT AFFECT COATINGS: There are environmental regulations that affect coatings. The Clean Air Act allows each state to determine the level of air cleanliness it desires, and to enforce it. Federal regulations put restrictions on the advertisements manufacturers use for certain products- they must accurately advertise where the coating may be used. Where the coating may be used will determine the VOC limit for that coating. Applications which are considered "immersion impacted," which include lock gates, are exempt. Impacted immersion coatings have a limit of 780 g/l which is what allows high-VOC content vinyl resins to be used on certain structures.

Architectural coatings, which are typically applied to structures, are typically regulated at the state level and may have different VOC limits. In some situations, high-solvent coatings may be used if applied outdoors.

[1] See Reference section for full titles of these standards.

In 1978, a new law went into effect that prohibited lead in household paints (CPSC 1977). Subsequently, the Consumer Product Safety Commission (CPSC) issued a ban of all paint and painted products containing lead above a certain threshold.

Industrial maintenance coatings have a federal limit of 450 g/l, but state and local air-quality districts may have more stringent regulations than the federal limit or may have lower limits in place. For example, most of California has a set limit, but many of the air quality districts may have a lower VOC limit or no limit at all. These limits are set forth for everyone who cannot justify impacted immersion use.

GUIDE SPECIFICATIONS THAT GOVERN COATINGS: The Corps' publication, Engineer Manual (EM) 1110-2-3400: "Painting: New Construction and Maintenance" (1995), provides painting guidance to engineering, operations, maintenance, and construction personnel and to other individuals responsible for the protection of USACE structures. It gives broad-based instructions on corrosion and corrosion protection, using protective coating and state-of-the-art procedures that can be employed on Corps projects.

Painting and coating of the Corps' structures is also guided by several Unified Facilities Guide Specifications (UFGSs). The most-used specifications include: UFGS-09 06 90 "Schedules for Painting and Coating" (2009), UFGS-09 90 00 "Paints and Coatings" (2011), UFGS-09 97 02 "Painting Hydraulic Structures" (2009), and UFGS-09 97 13.00 40 "Steel Coatings" (2014).

UFGS 09 97 02 ("Painting Hydraulic Structures") contains many of the systems recommended for underwater structures in the USACE. For example, system 5-E-X is a common vinyl system used for fresh water structures. System 6 is a common coal tar epoxy system for painting concrete. System 6-A-Z is a coal tar system used for buried steel or saltwater marine structures, and the System 23 series are moisture-cure urethanes for use in atmospheric exposure. For military construction, UFGS 09 90 00 ("Paints and Coatings") is used when painting facilities. UFGS-09 97 13.00 40 ("Steel Coatings") covers the requirements for coating systems, materials, surface preparation, and application of protective coatings on carbon steel. Common problems occurring for those attempting to follow the guide specifications include: final thickness not met and surface preparations not adequate. Failures in these cases are directly related to quality assurance, quality control, and inspection.

The Unified Facilities Criteria (UFC) 3-190-06 "Protective Coatings and Paints" (2004) is a handbook that provides guidance for DoD personnel wishing to apply architectural paints or protective coatings to military structures. This UFC is not for use with ships, aircraft, or automotive vehicles. It is written for general use, i.e., for use by those with little or with significant knowledge of the use of paint and coating materials. The handbook contains information on the composition of coatings, their mechanisms of curing, environmental and safety concerns, necessary surface preparation, selection of coatings for different substrates and structures, application, inspection, and failure analysis.

In addition, EM 1110-2-3401, "Thermal Spraying: New Construction and Maintenance" (1999) contains a description of thermal spraying fundamentals, materials, costs, selection, surface preparation, applications, inspection, testing, maintenance, and safety.

For the most part, USACE-recommended coatings system protocols are generally followed when selected and specified. However, USACE recommendations are not always selected, and a USACE district may instead choose to use an industry product and follow the manufacturer's procedures.

SUMMARY: In this technical note, a number of common problems were presented that plague coatings and create premature failure that leads to corrosion on the structure. Also, a variety of guidelines, inspection methods, and guide specifications were presented under which coatings are selected and applied. Keeping this knowledge in mind allows the needs and constraints of coating experts and design engineers to be addressed, and the effectiveness of corrosion prevention and control practices across the Corps to be improved. The authors also envision this knowledge serving other agencies, organizations, installations, and communities throughout the Nation.

FUTURE WORK: The results of the work and the information gathered have helped to gain a greater perspective on the use and condition of coatings around the Corps. Further investigation into the wide variance in inspection and monitoring of coatings could be highly useful for headquarters as well as districts, in order to better plan for using increasingly scarce maintenance dollars.

This work will culminate in guidance to the Corps for improved coatings quality control, measurement, inspection, and maintenance. This guidance could include updates to relevant current guidance documents and/or new specifications altogether. More widespread use of a simple rating system and collecting that information in a database could be an efficient and useful tool for managers and policy makers.

Future site visits will include specific inspections of coating systems and their conditions. This technical note has helped to shape the kinds of questions to ask and the types of coating failures to look for.

POINTS OF CONTACT: This CHETN is a product of the Water Resources Infrastructure Work Package of the Civil Works Business Area being conducted at the U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory.

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