Appendix D
USACE Field Experience and Lessons Learned

D-1. Belleville Locks and Dam Investigation

a. An investigation of thermal spray coatings performance was performed in the Huntington District at Belleville Locks and Dam (LD) during FY86 and FY87. Four thermal spray coating materials were applied, two in FY86 and two in FY87. The coatings were all applied to a contiguous area primarily on the downstream side of one tainter gate. This gate had been most recently coated with a vinyl zinc-rich paint system (5-E-Z). At the time of the metallizing, the paint had been exposed for approximately 1 year. Portions of the gate exhibited extensive corrosion. Essentially, 100 percent of the area near the downstream waterline was completely bare. This condition is fairly typical of Ohio River structures. Submerged baffles on the downstream sill are intended to prevent strong downstream undercurrents that could present safety problems or damage the riverbed. The baffles cause water and collected debris to circulate against the downstream skinplate. The erosive action of the debris rapidly removes the vinyl coating. Vinyl paints on most Ohio River dams only last from 1 to 2 years along the downstream waterline. Thermal spray coatings and paint sealers were evaluated at Belleville LD to test their resistance to this phenomenon.

b. In FY86 aluminum-bronze alloy (89Cu, 10Al, 1Fe) and 18-8 stainless steel coatings were applied by arc spray at Belleville LD. In FY87 85-15 zinc-aluminum alloy and zinc coatings were applied by flame spray. The coatings were applied from about 1.5 m (5 ft) above the downstream waterline to the bottom of the gate and then up about 0.6 m (2 ft) on the upstream skinplate. Each coating was applied to about a fourth of the gate. The nominal thickness of each thermal spray coating was 400 μm (0.016 in.). Vinyl and epoxy coatings were used to seal the 18-8 and aluminum-bronze coatings. A vinyl wash primer was used to seal the 85-15 and zinc coatings.

c. Thermal spray coating performance was monitored periodically.

(1) Failures and degradation of the 18-8 stainless steel and aluminum-bronze coatings were noted after less than 1 year. The 18-8 stainless steel coating exhibited extensive pinpoint rusting. The aluminum-bronze coating showed significant physical damage, pinpoint rusting, and small areas of delamination. It was concluded that cathodic coatings such as 18-8 stainless steel and aluminum-bronze should not be used on immersed steel because of the high potential for galvanic corrosion.

(2) The zinc coating was completely eroded from parts of the gate after just 2 years of exposure. Eroded areas corresponded with areas with the highest water velocity. Zinc oxide on the surface of the coating is weakly adherent and readily erodes to expose metallic zinc, which subsequently oxidizes and erodes. Zinc metallizing along the downstream waterline was approximately 10 percent eroded after 4 years and 50 percent eroded after 8 years. Zinc-aluminum alloy coating forms much harder and more adherent oxidation products than does zinc coating. With the exception of some small delaminated patches, very little reduction in film thickness of the zinc-aluminum coating was noted after 4 years of exposure. Numerous small areas of coating, approximately 12.7 to 25.4 mm (0.5 to 1 in.) in diameter, were observed to have failed cohesively. The cohesive delamination was restricted to the lower portions of the gate, where water velocities are highest, and had not occurred along the waterline, where scouring from debris is the most severe. After 8 years, the delaminated areas had expanded to encompass approximately 75 percent of the lower portion of the gate. Cohesive failures of this nature may be the result of blister formation caused by the expansion of oxidation products within the zinc-aluminum coating. Coating thicknesses as high as 0.889-1.143 mm (35-45 mils) were measured adjacent to the delaminated patches during the annual inspections. Areas of high thickness are probably indicative of expanding blisters within the

coating. For the most part, the coating delamination had not exposed or resulted in corrosion of the substrate. Film thicknesses measured in the delaminated areas were in the 0.076- to 0.127-mm (0.003- to 0.005-in.) range and are adequate to provide continued protection. Some damage to the zinc-aluminum coating was observed after 8 years, and minor areas of corrosion had begun to appear. It appeared that after 8 years the coating system was approaching the end of its useful life and that replacement would probably be required in 2 to 4 years.

D-2. Racine Locks and Dam

a. Thermal spray system 6-Z-A was applied by wire flame spray to tainter gates at Racine LD during 1994. Recycled steel grit abrasive was used to prepare the substrate prior to application of the thermal spray coating. The blast media was sampled and observed under magnification (30x). It was noted that the media was a mixture of irregular and angular shaped particles. Reportedly, the specified blast profile depth was achieved on the job; however, the profile was probably somewhat rounded because of the blast media mix that was used.

b. Laboratory adhesion tests of the 85-15 zinc-aluminum alloy coating over substrates prepared using different blast media have shown a significant dependence on the shape of the profile and a less significant, but still measurable, dependence on profile depth. Coatings applied over rounded profiles of 0.025 and 0.076 mm (0.001 and 0.003 in.) had average adhesions of 690 and 1980 kPa (101 and 291 psi), respectively. Coatings applied over angular profiles of 0.025 and 0.076 mm (0.001 and 0.003 in.) had adhesions of 7010 and 8230 kPa (1031 and 1210 psi), respectively. Areas of delaminated coating were noted at Racine LD after only 1 year of exposure. The suspected cause of these failures is inadequate surface preparation resulting from the use of a blast media containing significant irregular shaped particles. The irregular shaped particles are too rounded to produce the angular profile needed for good thermal spray adhesion.

c. Cohesive failures and areas of deficient metallizing thickness were also noted. Cohesive failures are most likely due to poor application technique, such as too great of a gun-to-surface distance. Cohesive failures may also have been caused by intercoat contamination or improper equipment setup. These failure causes can be addressed through more thorough inspection and scrutiny of the work in progress. This manual provides additional recommended procedures and methods to address these failures including bend and pull-off adhesion tests and stricter controls on the blast cleaning process.

D-3. Robert C. Byrd Locks and Dam

Thermal spray system 6-Z-A is currently being applied by wire flame spray to new roller gates at Robert C. Byrd LD. Work is scheduled for completion during FY98.

D-4. Pike Island Locks and Dam

a. Portions of the exterior of gate No. 6 at Pike Island LD were metallized with system 6-Z-A in 1995. The metallizing was sealed with vinyl system No. 4. The remainder of the gate was painted with vinyl zinc-rich system 5-E-Z.

b. The gate was inspected during 1996 and several failures were noted. Two large areas (0.929 m^2 and 0.278 m^2 (10 ft^2 and 3 ft^2)) on the downstream skinplate were bare and corroded. In some cases, the thermal spray coating along the edges of the bare areas could be lifted and peeled back for 6.35 to 12.7 mm (0.25 to 0.5 in.). Other small areas of thermal spray were delaminated or damaged. Many of the stiffeners near the bottom of the gate were bare. The bottom 12.7 mm (0.5 in.) of the downstream skinplate was bare metal. Several areas of lifted coating were noted on the downstream skinplate. Presumably, these will eventually be removed by impacting debris. Several scratches in the coating on the upstream skinplate were rusting.

c. The delamination failures are probably due to poor surface preparation, including inadequate surface profile depth and angularity. The skinplate and stiffeners are deeply pitted from previous corrosion. Deep pits are difficult to clean and may have sharp edges that require grinding. Some of the failures are probably caused by the severity of the exposure site, most notably the corroding scratches on the upstream skinplate. The bare metal on the bottom 12.7 mm (0.5 in.) of the downstream skinplate is probably the result of galvanic corrosion between the thermal spray coating and the stainless steel contact imbedded in the concrete sill. This problem is inherent in the design of this and many other dams and is also a problem when standard paint systems are used. Delamination failures on the gate stiffeners could probably be improved by grinding the sharp edges to provide a minimum radius. The stiffeners are also a problem area for paint coatings because the force of impacting debris is concentrated on a much smaller area.

D-5. Olmsted Prototype Investigation

a. A series of prototype dam gates were constructed and installed adjacent to Smithland LD. The prototype gates are a part of a study conducted by the Louisville District in preparation for the design and construction of the Olmsted LD project. The U.S. Army Construction Engineering Research Laboratories (USACERL) performed an evaluation of test coatings at the prototype facility. Coatings were evaluated for corrosion protection and zebra mussel resistance. One of the test coatings was thermal spray system 6-Z-A. The evaluation was conducted during 1996 after 6 months of immersion at Smithland LD.

b. USACERL found that the average film thickness of the metallized coating was 0.635 mm (0.025 in.), exceeding the required average of 0.406 mm (0.016 in.). This gate was not used as a working prototype, but was immersed in the river with the skinplate-side facing down. The skinplate had less than 0.01 percent corrosion, and the downstream side had no visible corrosion . No corrosion was observed on the edges of the gate. The excellent corrosion protection was particularly impressive in light of the mechanical damage evidenced by the deep gouges suffered by this gate during placement and retrieval. The downstream side of the gate has three magnesium anodes. The metallized coating showed a significant amount of blistering, especially along the edges of the gate and in two of the recessed bays on the downstream side of the gate. The worst blistering was found adjacent to two of the three magnesium anodes. Blisters were typically 25.4 to 76.2 mm (1 to 3 in.) in diameter with some being larger. Some of the blisters were broken, although most were intact. There was no observed corrosion associated with the blistering. Blistering may have been caused by the magnesium anodes. The use of sacrificial anodes with significantly higher potential than that of the 85-15 zinc-aluminum alloy coating can produce a current demand close to that of bare steel. This in turn may result in hydrogen evolution and high pH, which may cause blistering of the thermal spray coating. Blistering probably did not occur adjacent to the third anode because of the mud accumulation in this bay. Adhesion of the 85-15 metallizing was excellent except for the blistered areas. The adult zebra mussel population on the metallized portions of the downstream side of the gate (face up side) was only about 1 per square meter. The stainless steel piston rod coupling fixture had in excess of 1000 juvenile zebra mussels per square meter. The average length of the juvenile mussels was about 0.2 mm. The adult zebra mussel density in a small isolated area of the skinplate (face down side) was about 100 per square meter. Based on the size of the adult mussels (10 to 15 mm), it seems likely that they are too old to have settled out on the gate as veligers and instead probably relocated onto the gate from another surface.

c. It was concluded from this study that sacrificial magnesium anodes should not be used in conjunction with thermal spray coatings. It was also observed that 85-15 zinc-aluminum coating provided significant resistance to the settlement of zebra mussel veligers.

D-6. Locks and Dam 53 Investigation

a. Coated test coupons and material samples were placed in test at LD 53 in 1988. Test materials were installed at this sight to investigate the hypothesis that the rate of corrosion is accelerated by some external influence. The results of this evaluation are of interest to the Louisville District because of the replacement dam under construction at Olmsted, IL.

b. Test coatings were evaluated for surface rust, rust undercutting, qualitative adhesion, and blistering. Qualitative adhesion was performed by cutting parallel scribes through the coating using a knife. The coating was lifted from a third cut that was perpendicular to the first cuts. Excellent adhesion equates to no lifting while poor adhesion is complete lifting with no coating elongation. Intermediate values may also be described. Blistering and percent surface rust are described in ASTM standards. The condition of test materials other than coatings is described in general terms. The following compilation shows the condition of the test materials in 1994.

Material or Coating	Condition
Fiberglass grating	no swelling or cracking
Zinc metallizing/epoxy	no defects, adhesion excellent
Galvanized A36 steel	approximately 10-15% rust
A588 steel	general corrosion, 3.17- to 6.35-mm (0.12- to 0.25-in.) thick scale approximates appearance of LD53 pilings, red surface and black underneath
6061 P6 aluminum	10-15% of surface is pitted, black and white corrosion products, jagged pits
E-303/MIL-P-24441	no blistering, adhesion excellent, 3.17-mm (0.12-in.) undercut
MIL-P-24441	surface rust and blisters visible at bolt hole, 3.17- to 4.76-mm (0.12- to 0.18-in.) undercut, adhesion very good
V-766	adhesion excellent, light black sub-film corrosion, blistering at bolt holes, 3.17- to 4.76-mm (0.12- to 0.18-in.) undercut
VZ-108/V-766/V-102	no defects, adhesion excellent
V-106	blistering at bolt holes, adhesion excellent, 1.58-mm (0.06-in.) undercut, dark black sub-film corrosion
V-766/V-103	no blistering, adhesion excellent, light black sub-film corrosion
C-200A	no blistering, adhesion excellent, 3.17- to 4.76-mm (0.12- to 018-in.) undercut
E-303/C-200A	no blistering, adhesion excellent, no undercut
V-766/V-102	no blistering, adhesion excellent, 3.17- to 4.76-mm (0.12- to 0.18-in.) undercut

c. All of the coating systems performed within the expected range. Zinc metallizing topcoated with MIL-P-24441 epoxy, E-303 zinc-rich epoxy primer topcoated with MIL-P-24441, and VZ-108 vinyl zinc-rich primer topcoated with V-766 gray vinyl and V-102 aluminum vinyl were in very good to excellent condition after 6-years exposure at LD53. Any of these coating systems should provide excellent long-term corrosion protection at dam sites on the lower Ohio River. The rest of the coating systems would provide a lesser degree of protection but may still be suitable for some applications.