A TALE of TWO DOTs:

Concrete Bridges and Different Approaches to Metalizing for Corrosion Protection

By Lori R. Huffman, *JPCL*

The best of times and the worst of times might describe the lifespan of concrete bridges in exposures where corrosion of the rebar is likely. The ravages of coastal environments, specifically, have taken their toll on concrete bridges, causing spalling and structural damage that have put these bridges in jeopardy and have put departments of transportation DOTs in a hurry to find economical methods of corrosion protection before replacement becomes unavoidable.

This article will discuss the problem of rebar corrosion in concrete bridges, the corrosion protection offered by thermal spray coatings, and the approaches taken by the Oregon and Florida DOTs to use thermal spray technology to address their specific concerns.

REINFORCED CONCRETE: WHAT GIVES?

In coastal environments where salt-laden air and moisture promote water ingress and chloride contamination of concrete bridges, what gives eventually is the concrete itself. Once a sufficient amount of chloride reaches the steel rebar, conditions are favorable for the steel to corrode. And, as corrosion products build on the rebar, they push the concrete outward, leading to cracks and eventual spalling.

Thermal-sprayed zinc coatings on concrete protect the corroding rebar, either by galvanic (sacrificial) protection or in conjunction with impressed current cathodic protection, which is powered by a DC power source. Metalizing is almost exclusively a maintenance item, says Jorge Costa, P.E., of Corrosion Restoration Technologies, a contractor with expertise in thermal spray. Metalizing is applied to existing concrete structures that are already suffering from corrosion caused by chloride contamination.

Yaquina Bay Bridge in Oregon, above and background, 1936. The bridge was metalized in 1992. Courtesy of the Oregon DOT

Cummins Creek Bridge in Oregon, a completed metalizing-cathodic protection project. Courtesy of the Oregon DOT

BACKGROUND

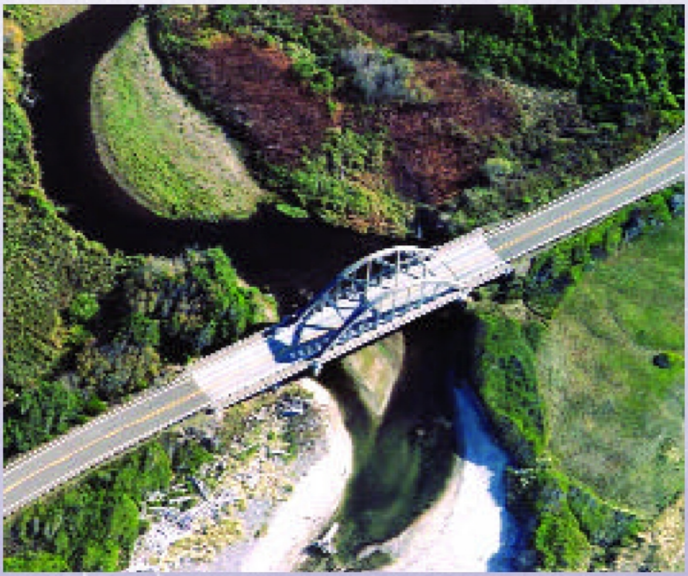
In 1985, the California Department of Transportation (CALTRANS) patented the use of flame-sprayed zinc for impressed current cathodic protection to protect rebar, says Dave Wixson of TMS Metalizing Systems, Ltd., which makes thermal spray equipment. By the late 1980s, the Oregon Department of Transportation (ODOT) had decided to use metalizing and impressed current cathodic protection as a means of saving its historic coastal bridges. The Florida Department of Transportation followed shortly thereafter by adopting thermal-spray zinc coating for galvanic protection of its deteriorating concrete bridges.

Guidance on Thermal-Spray Coating of Concrete

Although the Society for Protective Coatings (SSPC), NACE International, and the American Welding Society (AWS) have a joint standard on metalizing steel, neither SSPC nor NACE has published a standard on metalizing reinforced concrete. However, says Wixson, specifiers can find guidance in AWS C2.20/C2.20M:2002, Specification for Thermal Spraying Zinc Anodes on Steel Reinforced Concrete.

Surface Preparation and Application Procedures

Typical surface preparation for reinforced concrete receiving thermal spray coatings is non-aggressive blast cleaning to remove laitance and efflorescence and to impart a profile on the concrete surface. Wixson warns that overblasting to the extent of removing the cement paste and exposing the aggregate will cause problems with the bond of the thermal spray coatings, which adhere mechanically to the concrete. Following abrasive blasting, the surface of the concrete is blown down to remove dust, says Costa. Water washing is avoided because wet surfaces can compromise the bond of the applied metalized coating. Costa notes, however, that thermal-sprayed zinc has been successfully applied to damp surfaces in humid environments.



Big Creek Bridge in Oregon, another completed metalizing-cathodic protection project.
Courtesy of the Oregon DOT

Application of thermal spray zinc is made in several passes to build the metalizing to a thickness of 18 to 20 mils, says Wixson. Multiple application passes are necessary because one thick coating application can shrink upon cooling, causing adhesive stress and subsequent delamination of the coating. Once applied, the zinc will increase its bond to the concrete, says Costa. In fact, he says, bond strength is measurably increased in as little as 24 hours following application.

Metalizing concrete surface
Courtesy of Corrosion Restoration Technologies

Humidity and temperature must be controlled strictly during the application process, says Rich Wanke of Great Western Corporation, because wet concrete will inhibit the bond of thermal-sprayed zinc. His company uses indirect boiler heating systems to heat enclosed work areas to approximately 95 F. Once the temperature falls to between 80 and 85 F, the enclosure is "pumped down" with a HEPA-filtered negative air system, which recirculates the air to the boiler system to remove moisture that has been driven from the concrete. In addition, thermal spray application can take place only after the concrete surface has been held at a minimum of three degrees Fahrenheit above the dew point and approximately 40% humidity, he adds.

Measuring the applied thickness of the metalizing on concrete can be difficult, says Wixson. Several strategies for measuring metalizing thickness include the use of ultrasonic thickness testers, steel reference coupons situated every 100 sq ft in the work site, or the tracking of material consumption during thermal spray operations. According to Wixson, typical consumption is one lb of zinc per sq ft for a 20-mil thickness.

Activator Jump Starts Zinc

A humectant (moisture-absorbing) activator can be applied over thermal-sprayed zinc to keep the metalized coating actively corroding. The activator is particularly suitable for bridges in non-marine environments where atmospheric conditions are not consistently humid, says David Whitmore of Vector Corrosion Technologies, which provides products and services for preventing corrosion in concrete. The proprietary activator is sprayed onto newly metalized concrete. By absorbing moisture from the air, the activator causes active initial corrosion of the zinc, which helps to halt corrosion of the steel rebar. Once corrosion of the rebar is stopped, less current is required from the zinc.


Trial for metalizing concrete under way Courtesy of Vector Corrosion Technology

Flame Spray versus Arc Spray

When metalizing technology was new, flame-spray guns were the dominant application technology for thermal sprayed coatings. However, this technology had a few significant limitations, including low productivity rates and the yielding of a characteristically porous zinc film, says Costa. Advances in metalizing led to the development of arc-spray equipment, which offered significantly higher production rates compared to flame-spray metalizing, and which created denser, less porous zinc coatings, owing to the speed at which the zinc particles are propelled from the arc-spray gun to the concrete surface, he says. Although flame-spray metalizing is still used, arc-spray application has become the dominant technology for bridge projects.

OREGON DOT USES METALIZING TO SAVE HISTORIC BRIDGES

In the late 1980s, the Oregon DOT began a program to inspect the historic concrete bridges along its coast. The 11 bridges, designed in the Art Deco style by Conde B. McCullough between 1919 and 1936, were spalling from years of ingress of salt-laden moisture and corrosion of the rebar. The DOT had to demolish the Alsea Bay Bridge in 1989 because rebar corrosion had damaged the structure so significantly that it could not be repaired. The cost of replacing the bridge was $45 million, and the state lost one of the largest and most beloved of the McCullough bridges.

Curtis B. Cryer, PE
Oregon DOT

The inspection program further revealed that the DOT stood to lose 20 major concrete bridges on the coastal highway over the next 20 years if preventive measures were not taken, says Curt Cryer of the DOT. The DOT chose to metalize the steel-reinforced concrete structures because the method would preserve the McCullough bridges without obscuring their distinctive Art Deco design and detailing.

The DOT put together a team of engineers from different disciplines (including electrical, chemical, mechanical, and structural specialties), with the goal of assessing the bridges, ranking the structures for maintenance, and arresting corrosion, says Cryer. Thermal-spray zinc hooked into an impressed current system is now protecting eight of Oregon's bridges, the first of which (Cape Creek Bridge) was metalized in 1991. Another three bridges are slated for metalizing and impressed current cathodic protection by 2010, says Cryer.

Partnering Helps Ensure Success

Oregon DOT treats each bridge metalizing project as a unique undertaking, says Cryer. The agency partners with contractors performing the metalizing and requires everyone on the job, from the engineers and contractors to the inspectors, to undergo training. The DOT prequalifies its metalizing contractors and encourages these contractors to hire people who have worked on previous metalizing projects for the state, he says. Likewise, whenever possible, the DOT attempts to keep experienced in-house inspectors on the bridge metalizing jobs.

Performing the Work

The DOT typically specifies the use of thermal-sprayed zinc over the entire surface of its concrete bridges, says Cryer. He points out, however, that several bridges metalized early in the program did not receive thermal-sprayed zinc on the railings, because no application procedure existed for these areas. The DOT is now metalizing rails on its current projects, with guidance from the State Historic Preservation Office. The met-

Cape Creek Bridge, the first of Oregon's historic bridges to be metalized (1991)
Courtesy of the Oregon DOT

alizing projects are enclosed to prevent damage to sensitive local environments, such as estuaries, says Cryer.

The process of preparing the concrete for the application of the thermal-sprayed zinc involves multiple steps. The contractor is responsible for locating stray metals protrusions from the concrete that might short out the impressed current system. The metals are removed to a depth of ½ in. Rebar at the surface of the concrete is either coated with an epoxy or isolated with a non-conductive patch. Damaged concrete and previously repaired areas are removed and patched. The concrete is then sweep blasted to remove laitance and efflorescence and impart a profile.

The DOT began its metalizing work by specifying the application of 20 mils of thermal-spray zinc; the most recent contract reduced the applied thickness to 15 mils, Cryer says. Once the thermal-sprayed zinc has been applied, the DOT requires the contractor to check the adhesion of the zinc and the applied thickness. Typically, an experienced operator will take these measurements every 500 sq ft, says Cryer.

Dave Wixson
TMS Metalizing
Systems, Ltd

In the early 1990s when the DOT began its bridge metalizing program, flame spray equipment was used. Once it took on larger concrete bridge projects, the DOT turned to arc spray metalizing for its improved productivity. However, says Cryer, the DOT still uses flame spray metalizing for local touch-up work during metalizing projects and for repair work on metalized bridges.

Typical impressed current power supply
Courtesy of Great Western Corporation

Concrete Repair: A Salty Question

Adding salt to concrete repair materials might seem a bit strange, but the Oregon DOT includes a small amount of salt (0.12 lb per 100 lb of mix) to bring the electrical conductivity of the patch nearer to that of the adjacent concrete. "It's probably not advisable in most cases," says Cryer, but for an 80-year-old bridge contaminated with a huge amount of chlorides, the repaired concrete would spall off if its conductivity did not approach that of the old concrete. The DOT's approach of actually matching the salt content of old concrete has changed over the years, especially after one attempt to match the content of a significantly contaminated bridge led to a problem with the curing of the repair material, says Cryer. The DOT then examined how smaller amounts of salt would affect the conductivity of the new concrete and found that the salt content of the new concrete could still be effective at an order of magnitude smaller than that of the old concrete.

As for the concrete repairs, the DOT uses a fast-setting mortar that is very conductive and that cures quickly. Typically, the repair mortar cures for two weeks before thermal-sprayed zinc is applied. Large areas with thick applications of repair mortar are cured for 20 to 30 days before thermal spraying, Cryer says.

Choosing Impressed Current CP

The DOT chose to install an impressed current cathodic protection system to its concrete bridges. Cryer explains that the galvanic method of cathodic protection works adequately early in the protection cycle, but once zinc byproducts form at the interface of the zinc and the concrete, electrical impedance increases at the interface, and more current is needed to charge the steel rebar. "We trickle a small electrical current through the bridges," says Cryer. A DC power supply is installed on the bridges, with the negative charge connected to the rebar. The conductive zinc metalizing is connected to the power source and receives a positive charge. Because chloride ions are negatively charged and because like charges repel, the chlorides are driven away from the rebar to the positively charged zinc.

Over time, the impressed current

cathodic protection system consumes the thermal-sprayed zinc, which oxidizes and forms byproducts such as silicates. Eventually, the interface between the zinc and the concrete surface is filled by the powdery oxides, says Cryer, and the zinc layer disbonds. The thermal-sprayed zinc must be removed and reapplied at this point. According to Cryer, thermal-sprayed zinc on the Yaquina Bay Bridge has begun to expend itself in localized areas. The metalizing project was completed in 1992 on this bridge, and zinc on only one of the towers has been affected. The DOT is investigating the reason for the localized exhaustion of the zinc coating. The first bridge the DOT metalized is still performing well after 15 years in service, Cryer says.

Typical coastal bridge damage
Courtesy of the Oregon DOT

Sounding for delaminated concrete
Courtesy of Great Western Corporation

Cryer notes that it is possible to inadvertently decrease the life of thermal-sprayed zinc when used with impressed current cathodic protection. Running excessive current through the system will consume the zinc and shorten its service life. "You should only supply enough [current] to keep the rebar from corroding, not enough to exhaust the zinc," he says. "We run the system at a much lower level—at least one-tenth of what AASHTO suggests for protection." AASHTO recommends that impressed current systems be run at 2 milliamps per square foot. The Oregon DOT runs its systems at 0.2 milliamps per square foot, Cryer says.

Costs of Metalizing

In addition to the productivity of the application methods used for thermal spray metalizing, several other variables have influenced the cost of metalizing projects in Oregon, says Cryer. These variables include the complexity of both the bridge design and the required enclosure. Cryer notes that the cost of metalizing concrete bridges has ranged from $6 to $15 per sq ft since the DOT's program began.

FLORIDA'S PROGRAM

The Florida DOT's foray into metalizing began much like Oregon's, as a response to an urgent and expensive corrosion problem in a concrete bridge. The DOT is responsible for maintaining a chain of 48 bridges in the Florida Keys that were built between 1978 and 1983, says Rod Powers, state corrosion technologist with the DOT. The bridges were built with concrete reinforced with epoxy-coated rebar. By 1986, the DOT found that corrosion had begun to develop in one of the bridges in an area of insufficient concrete cover (approximately one in.) over the reinforcement.

Rich Wanke
Great Western
Corporation

Strategy Focuses on Spot Metalizing

The corrosion problem came to a head with the Niles Channel Bridge, where extensive corrosion of the columns was found within two to three feet of the high water mark, says Powers. Notably, the corrosion was not confined to areas of reduced concrete cover, but rather appeared in areas with anywhere from four to six in. of cover. According to Powers, the Niles Channel Bridge is a fairly simple concrete structure that suffered from three major problems: chloride-laden materials of construction, inferior concrete, and poor construction details. With a potential replacement cost in the billions of dollars, the DOT had to find a means of slowing, or better yet, halting the corrosion of the reinforcing steel.

The bridge had been repaired many

Delaminated concrete is marked.
Courtesy of Great Western Corporation

times during its service life, and the substructure had undergone major rehabilitation because of corrosion. The DOT wanted to determine whether metalizing the concrete would extend the durability of the concrete repairs and prevent the "halo effect." This effect happens when a new repair becomes cathodic to the surrounding area, resulting in the accelerated failure of the concrete on the periphery of the repaired area.

The DOT found a metalizing contractor to apply thermal-sprayed zinc to the repaired areas, which were completed in mid-1989. "Virtually every pier had been repaired using conventional methods," says Powers. This bridge would mark the DOT's first use of zinc metalizing as a sacrificial anode, he says.

In April 2001, the DOT and its chosen metalizing contractor went to the bridge to apply zinc metalizing to representative areas of repair, but were shocked to find that all the repairs completed two to three years earlier had failed. The DOT could not find an area to carry out its test project, says Powers. Instead, the DOT located newly spalled areas of the bridge, made conventional concrete repairs to these areas, and applied thermal-sprayed zinc over the repairs.

After spot metalizing these conventionally repaired areas of the bridge, the DOT found that the thermal-sprayed zinc was providing the necessary corrosion protection to keep the concrete at the peripheries of the repaired areas from being attacked. Based on this experience, the DOT planned to continue with conventional concrete repairs and spot metalizing until the number and extent of galvanically protected areas would make it practical to expose the remaining unprotected reinforcing steel in the splash zone and establish electrical continuity so that metalizing or another form of galvanic protection could be used in these areas.

Jorge Costa
Corrosion Restoration Technologies

Considering Other Galvanic Methods

This turning point has been reached on many columns of the Seven Mile Bridge, says Powers. The DOT has designed a sacrificial zinc jacket that is now being tested for use on the columns. Powers notes that the DOT is searching for a galvanic cathodic protection system that will extend the service life of the concrete bridges another 35 years. "Once we've established continuity and done conventional repairs, we might find that thermal-sprayed zinc is more cost effective than jacketing or impressed current systems such as titanium mesh and gunnite," says Powers. "It will take a lot of study and number crunching to determine the most appropriate and cost-effective approach."

Interior scaffolding for metalizing
Courtesy of Great Western Corporation

Long-Term Success

The Florida DOT can point to one example of long-term success in its program: the application of thermal-sprayed zinc to the 109 pier caps on the Howard Frankland Bridge, which spans Tampa Bay. According to Powers, virtually every cap (located 14 to 16 feet above the splash zone) had experienced corrosion by the time the DOT applied metalizing in 1992. A study completed in 2004 concluded that corrosion had been halted in these caps through the sacrificial protection of the metalizing. At the time of the study, the zinc was found to be almost completely consumed, says Powers. A contract to reapply metalizing to the caps is now in the works.

David Whitmore
Vector Corrosion Technologies

In areas of bridges near the splash zone, the DOT reports that zinc metalizing will contain corrosion on approximately 80% of a structure for five years before being completely consumed. Powers explains that the shorter service life of the metalizing in these conditions is due to the auto-corrosion of the zinc in the presence of wet conditions.

A CONTRACTOR WEIGHS IN ON METALIZING

"Experience is an important component in terms of success in the field," says Costa. This expertise must be shared by everyone, from project managers to the applicators operating the arc-spray gun. Owners, too, need to understand the metalizing process as it pertains to cathodic protection. "Experience pays off when problems occur. You need to know not just the 'how' but also the 'why'," he says.

The experience of the thermal-spray contractor should extend to the arena of surface preparation, as well. Because the quality of the surface preparation is so critical to the success of the metalizing, "the guy that does the metalizing needs to be doing the surface preparation," says Costa.

Understanding the bond characteristics of the chosen thermal-sprayed coating is critical, he says. A crew member who has overblasted the concrete substrate and exposed the aggregate will, in effect, decrease the bond strength of the zinc when applied, and may also have diminished the effective contact area for the metalizing. For example, should the exposed aggregate consist of river rock, which has a very high electrical resistance, the completed cathodic protection system may sputter or fault, he says.

PROS AND CONS OF METALIZING

Although a few other transportation agencies (including those of Texas, Virginia, Alaska, and Ontario) have tried metalizing on some of their concrete bridges, the idea has not been widely adopted. Cost, especially for application, certainly gives some owners pause. Another reason for their reluctance may be that metalizing is sometimes considered a complicated and tedious task, says Cryer.

The arguments for thermal spraying of zinc on concrete bridges can be persuasive. Despite its cost, the method offers one of the few effective means of halting corrosion and serious structural damage on aging concrete bridges. And, in comparison to the cost of replacing deteriorated bridges, the galvanic and even impressed current cathodic protection systems using thermal-sprayed coatings could be considered a bargain.

Several points must be taken into account when considering the use of thermal-sprayed zinc. Cryer cautions that thermal-sprayed zinc should not be used in splash zones because it can be depleted in as little as two years. In these areas, the Oregon DOT has used a zinc anode embedded in a cementitious material and attached directly to the rebar. A concrete cover is then applied at three or more inches thick, he says.

Wanke, whose company has been involved in Oregon's bridge projects, notes that the biggest problem with metalizing and impressed current cathodic protection is the quality of the rectifiers and their ability to provide consistent current. "It's hard to get a high-grade, reliable rectifier system," he says. He points to a bridge that his company recently inspected, where the thermal-sprayed zinc looked brand new on the west side of the bridge (connected to one rectifier) and was damaged on the east side (connected to a different rectifier).

Departments of transportation with concrete bridges in coastal environments are challenged to prevent re' corrosion and avoid structural dan that could mean the building prohil tively expensive replacement bridges. This article has presented the strategies of two departments of transportation that have adopted thermal spray technology and found success in their unique approaches.