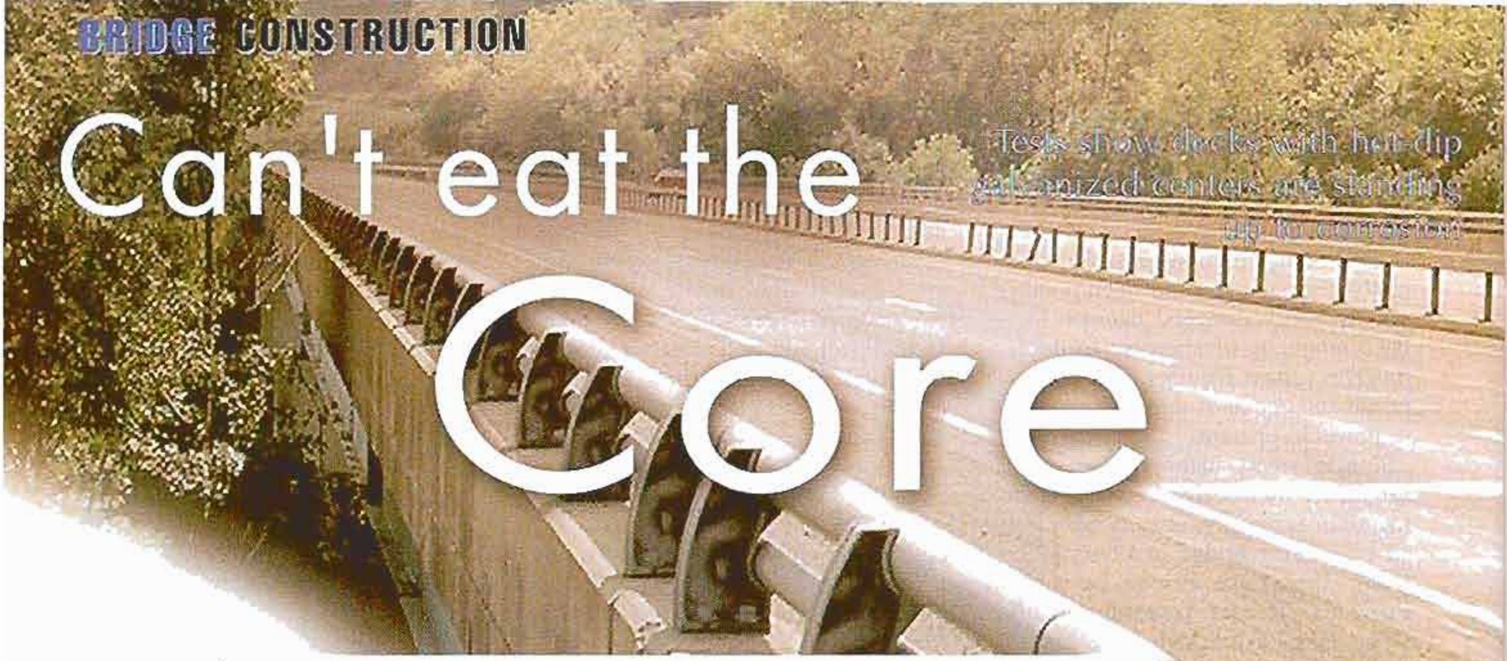

Can't eat the Core

Tests show decks with hot-dip galvanized centers are standing up to corrosion

Phil Rahrig
Contributing Author

Hot-dip galvanizing has been used for decades in coastal regions, the northern U.S. and several Canadian provinces as a corrosion protection system for reinforcing steel in concrete. The use of hot-dip galvanizing is growing due to its verifiable performance history, an initial cost that is competitive with common barrier protection coatings and a virtually maintenance-free life of 75-plus years. Recent inspections of bridges in Pennsylvania, Vermont, Wyoming, Florida and Michigan (installed in the 1970s) are exhibiting no substantial degradation in their reinforced concrete bridge decks. Core samples taken from these bridges indicate a zinc coating on the bars that exceeds the initial coating thickness required on newly galvanized rebar and should provide an additional 40-plus years of corrosion protection.

Level leap

Concrete is a permeable material and in certain corrosive environments (coastal climates and climates that require deicing salts in the winter), the entrance of moisture, salts and oxygen can initiate corrosion of reinforcing steel. The development of dense corrosion products on the surface of black (uncoated) rebar builds up pressure against the surrounding concrete. When these expansive forces elevate to a level that exceeds the strength of the concrete, cracking and spalling occur, ultimately resulting in failure.

Hot-dip galvanized rebar has shown great success in protecting reinforcing steel from corrosion in harsh conditions, including coastal and chloride-containing environments. The coating—comprising zinc and zinc-iron alloys—produces corrosion products that differ from the corrosion products of black steel because they are less dense. Therefore, when corrosion initiates on the zinc coating of galvanized rebar, the corrosion products do not build up pressure against the surrounding concrete but, rather, migrate away from the bar to fill in small capillaries and voids. This also slows the ingress of chlorides by essentially blocking the path of the chlorides to the galvanized reinforcing steel.

A certain level of chlorides in concrete is necessary to initiate active corrosion of steel reinforcement, and is commonly referred to as the "chloride threshold."

The corrosion of black steel in concrete does not begin until a level of 1.1 lb of chloride per cu yd of concrete is exceeded. When the chloride levels exceed this value, corrosion of the black bar will commence, and cracking and spalling of the concrete will eventually occur. The chloride threshold of zinc before active corrosion initiates is approximately five times higher than that of black reinforcing steel (5.5 lb/cu yd). This fact means that the onset of corrosion when using galvanized rebar is years beyond that of unprotected rebar, due to the extended time it takes to accumulate such a high level of chlorides.

The development of dense corrosion products on the surface of black (uncoated) rebar builds up pressure against the surrounding concrete. When these expansive forces elevate to a level that exceeds the strength of the concrete, cracking and spalling occur, ultimately resulting in failure.

Wait for it to dry

Accelerated corrosion testing is often used in an attempt to estimate the service life of corrosion-resistant coatings in various environments. The test procedure isolates one environmental parameter which is then increased until the test sample fails. The difficulty in correlating accelerated testing results to actual real-world performance of hot-dip galvanized rebar lies in the fact that there are multiple integrated parameters that affect the corrosion rate of zinc in real-world performance. The concentration of the salts, pH and wet/dry cycles all influence the corrosion rate of zinc. Individually evaluating the effects of these parameters does not accurately represent the environment that the galvanized rebar will be exposed to after installation.

Another problem with accelerated testing is that the galvanized reinforcing bars are not allowed to dry during testing. In the field when wet concrete becomes dry, the pH of the concrete environment may be near 12.5, but the drying of the concrete allows the zinc coating to form a protective passivation layer. The formation of the passivation layer (or patina) is the main mechanism for inhibiting corrosion on zinc-coated steel. Without the formation of the patina, it is nearly impossible to relate the test results to real-world performance.

Why hot-dip galvanized reinforcing steel works

- No corrosion creeping under the zinc coating;
- No holidays in the zinc coating; the hot-dip galvanizing process ensures complete coating coverage;
- Zinc corrosion products are less dense than black steel corrosion products and migrate away from the bar into the voids of the concrete and thus no cracking or spalling forces are exerted;
- Zinc corrosion products passivate the rebar, elevating the corrosion threshold to a range between five and 10 times that of bare rebar;
- Zinc corrosion products block the progress of chloride ions to the rebar;
- Zinc corrosion rate is very low in dried concrete, where the pH is usually within the range of 5-12.5;
- The bond strength of hot-dip galvanized rebar is about 600 psi, i.e., as high or higher than plain bar; and
- Zinc is a galvanic and barrier protection system, sacrificially corroding to protect the substrate steel and also providing a metal barrier to electrolytes.

Real results

Since accelerated tests are not reflective of the actual corrosion rate of hot-dip galvanized reinforcing steel, field performance in the most severe environments over several decades is the only way to accurately demonstrate corrosion protection. In both coastal and northern environments, chlorides are introduced into the concrete by moisture saturated with salts. The chlorides penetrate the concrete and eventually accumulate to sufficient concentration at the bar surface to begin a corrosive attack. Since zinc corrosion products accumulate around the hot-dip galvanized bar surface, the chloride penetration to the bar becomes more difficult and the time to first corrosion of the substrate rebar steel is significantly delayed.

This is exactly the case on a number of bridges tested by Construction Technology Laboratories (CTL). In each case, CTL took half-cell potential measurements of a bridge section to determine the highest corrosion spot on the bridge surface. Core samples were then taken at those locations to measure the chloride level at the hot-dip galvanized bar surface and the zinc coating thickness remaining on the bar.

Longbird Bridge, Bermuda

One of the oldest bridges incorporating hot-dip galvanized reinforcing steel is Bermuda's Longbird Bridge. Constructed in 1952, the most recent examination of the bridge's reinforcing steel took place in 1995. After 42 years of service—and despite chloride levels in the concrete several times greater than the threshold for active corrosion to occur—the average thickness of the hot-dip galvanized coating still exceeded the minimum requirement for new rebar, indicating additional service life of 40 or more years without maintenance.

Location	Installed	Inspection Date	Chlorides (lb/yd^3)	Zinc Coating Thickness mils	Zinc Coating Thickness µm
Boca Chica Bridge, FL*	1972	1975	1.95	5.1	130
		1991	2.02	4.0	102
		1999	3.21	6.7	170
Tioga Bridge, PA*	1974	1981	0.58	5.9	150
		1991	1.06	8.8	224
		2001	2.23	7.8	198
Curtis Road Bridge, MI	1976	2002	6.88	6.1	155
Spring Street Bridge, VT	1971	2002	4.17	7.5	191
Evanston Interchange, WY	1975	2002	2.55	9.3	236

* Multiple inspections were made on these bridges. Since concrete cores are drilled out of the bridge it is impossible to perform this inspection in the same spot. When performing subsequent inspections, the cores must be drilled in different areas which doesn't allow for corrosion monitoring in one particular area. Hot-dip galvanized coating thicknesses vary slightly over the length of the bars. This explains how a greater coating thickness can be read when measuring the same bridge at a later date.

Curtis Road Bridge, Ann Arbor, Mich.

The latest inspection in 2002 showed the hot-dip galvanized span of this four-span bridge, which was built in 1976, to be in excellent condition. Although in an aggressive environment—with a coring indicating a chloride level 6.88 lb/cu yd of concrete—the zinc coating was still 6.1 mils thick. Even at such high chloride levels, the bridge deck should remain virtually maintenance-free at least until 2040.

Boca Chica Bridge, Key West, Fla.

Located just above salt water, the hot-dip galvanized deck of the first span on the south end of this 2,573-ft-long bridge endures heavy traffic and a harsh chloride attack. The galvanized rebar is maintenance-free, helping to avoid traffic snarls on this critical artery.

Originally constructed in 1972, the Boca Chica Bridge has been inspected three times since, the latest in 1999. Zinc coating thickness has been measured from 4.0 to 6.7 mils, enough to provide corrosion protection to the deck for 60-75 years, despite chloride levels in the concrete 2.5-5 times the level that would begin the corrosion process on uncoated reinforcing steel.

Spring Street Bridge, Montpelier, Vt.

An asphalt cover of 3.5 in. was used on the Spring Street Bridge, built in 1971. More porous than concrete, the asphalt deck allows more chloride-containing moisture to penetrate to the hot-dip galvanized rebar upper deck. Measurements taken in 2002 indicate an average zinc coating thickness of 7.5 mils, far above the minimum required at the time of the initial installation and sure to deliver an estimated 40-plus years of additional corrosion protection.

Evanston Interchange, Evanston, Wyo.

Located on I-80, the Evanston Interchange Bridge was built with hot-dip galvanized rebar in 1975. The upper mat of the deck was constructed with No. 4 and No. 6 rebar. With the original concrete cover averaging 3 in. still in excellent condition, the coring in 2002 indicated a zinc coating thickness of 9.3 mils, easily extending the life of this bridge to 2040 and beyond.

Tioga Bridge (over Mill Creek on Rte. 15), Tioga, Pa.

Over 250 bridges in Pennsylvania utilize hot-dip galvanized steel in the decks, including this 14-span, two-lane bridge on Rte. 15. This important and heavily traveled route from Pennsylvania to the Finger Lakes area of New York receives heavy snowfall and, thus, significant road salt to keep the bridge ice-free. Although these salts contribute to a chloride content in the concrete much greater than that required to initiate corrosion on bare steel, the concrete of the bridge deck will remain in excellent condition for decades.

Originally constructed in 1974, this bridge has been inspected every 10 years since 1981. Remaining corrosion free, the bridge deck coring conducted by CTL in 2001 measured on average 7.0-plus mils of zinc on the rebar, enough to provide corrosion protection for an additional 40 years or more.

Athens Bridge (over the Cehmung River on Rte. 22), Athens, Pa.

This dual, two-lane bridge was built in 1973 with hot-dip galvanized rebar in the concrete deck. The bridge is on a heavily traveled route between industrial areas of Pennsylvania and the Five Fingers of New York where it receives heavy snowfall each year, requiring the frequent use of deicing salts to keep the bridge ice- and snow-free. Despite the high level of chloride at the hot-dip galvanized rebar surface, coring in 2001 showed 11.0 mils of zinc on the bar. This zinc coating thickness will provide an additional 40 years of corrosion protection, meaning little or no maintenance of the deck for PennDOT.

Rahrig is the executive director of the American Galvanizers Association, Centennial, Colo.

LearnMore!
For more information related to this article, go to:www.roadsbridges.com/lm.cfm/rb110413