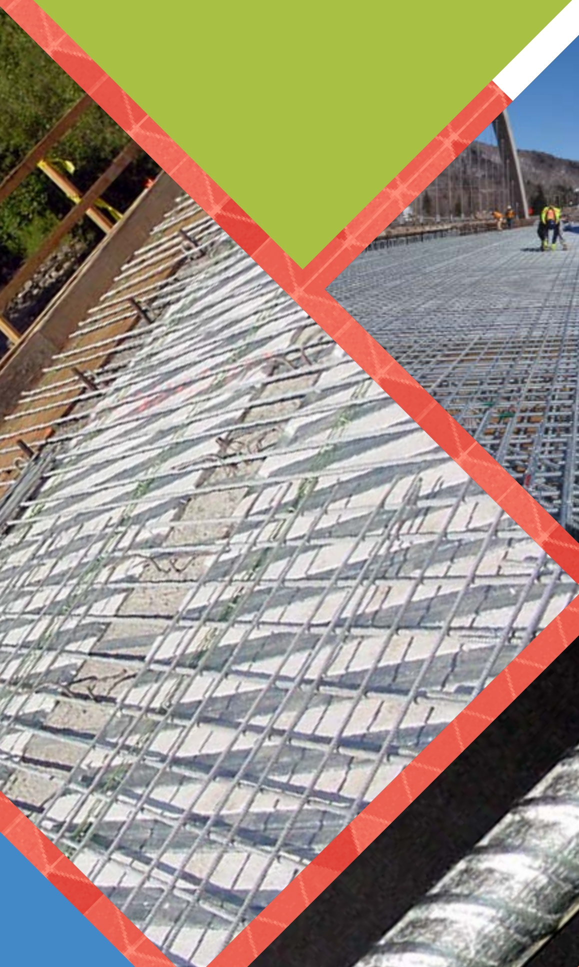
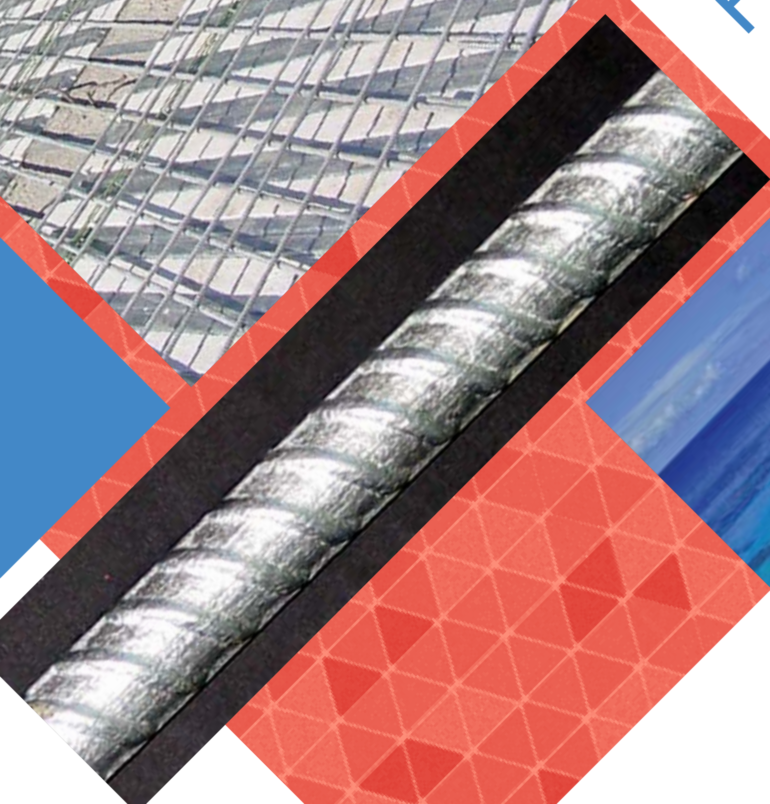
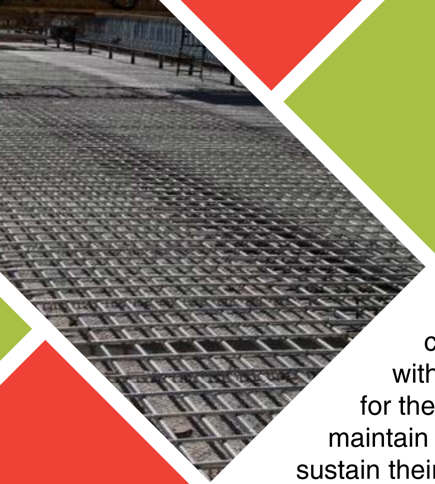




HOT-DIP GALVANIZED REINFORCING STEEL

SAFE
DURABLE
SUSTAINABLE
LONG LASTING

AMERICAN GALVANIZERS ASSOCIATION



Hot-Dip Galvanized Reinforcing Steel

Reinforcing steel (rebar) is widely used in a variety of applications from bridges to reinforced buildings to enhance the tensile strength of the surrounding concrete. However, the addition of these strengthening elements can prove problematic for the structure if proper care is not taken to avoid corrosion. Because of the porous nature of concrete, moisture and road treatment chemicals can seep into the concrete, reaching the rebar within. When a project is constructed with a building material not able to survive its environment for the length of the design life, natural resources are needlessly consumed to continually repair and maintain the structure. In addition to the waste of natural resources, building structures that cannot sustain their environment can lead to hazardous situations. Accidents caused by corroded structures can lead to huge safety concerns, loss of life, resources, and more.

The deterioration of reinforced concrete structures is estimated to cost more than $20 billion. Increasing by nearly $500 million each year, spalling and concrete deterioration has become a major liability for highway agencies. There is, however, a way to protect these infrastructure investments from the ravages of corrosion. Using hot-dip galvanized steel rebar for corrosion protection in concrete reinforcing elements, such as decking, piers, or piles, ensures they will resist spalling and stand strong for generations.

SAFETY

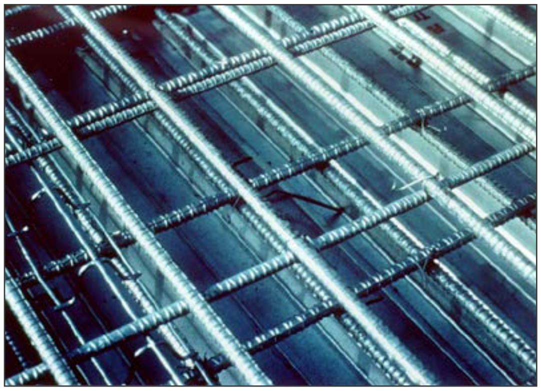
Because concrete is a porous material, corrosive elements will inevitably seep deep into the exposed concrete, eventually reaching the rebar within. If left unprotected, the steel will begin to rust, creating corrosion products 2-10 times more voluminous than the original steel. The volume of these corrosion products will begin to create stress that exceeds the tensile capacity of the surrounding concrete, causing it to crack and spall. This can be dangerous for the vehicles, pedestrians, or wildlife below, and can weaken and compromise the stability of the concrete structure.

Corroded reinforcing steel caused dangerous spalling in the concrete on the underside of this bridge

Hot-dip galvanized reinforcing steel eliminates the risk of spalling, because the zinc corrosion products are less voluminous and migrate away from the bar into the matrix of the concrete. The migration alleviates the potential for increased pressure, thus eliminating the risk of spalling.

DURABILITY

Hot-dip galvanized steel rebar takes advantage of the inherent benefits of the metallurgical bond created during the galvanizing process. Galvanized rebar has a bond strength of 3,600 PSI, meaning when rebar is dropped, kicked, stepped on, or rubbed against existing concrete or other rebar pieces on the jobsite, the protective coating will remain tightly adhered. From installation through the use phase, galvanized rebar proves its tough, durable zinc coating can withstand the rough handling inherent in bridge or highway construction without succumbing to the damaging effects of corrosion.

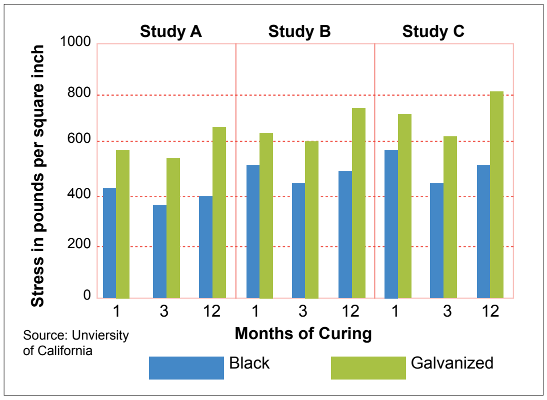


Hot-dip galvanizing reinforcing steel provides corrosion protection in concrete

Exposure to the elements is a given for any bridge and highway construction site, and this can be problematic for rebar lying in wait. While epoxy coated rebar is particularly susceptible to UV damage, temperature effects, and handling limitations, hot-dip galvanized steel is not susceptible to these factors. Galvanized steel rebar will not be damaged by the sun's rays as it waits for implementation. The durable zinc coating withstands the effects of UV light, as well as exposure to rain or snow, protecting the rebar both as it waits and in use. Similarly, cold temperatures will not in any way affect the coating, meaning galvanized rebar is ready for use when you are. Lastly, as mentioned before, hot-dip galvanizing provides abrasion resistant corrosion protection for reinforcing steel.

PERFORMANCE IN CONCRETE

Bond Strength



Galvanized steel's superior bond strength

Good bonding between reinforcing steel and concrete is essential for reliable performance of reinforced concrete structures. When protective coatings on steel are used, it is essential to ensure they do not reduce bond strength. Several factors affect bond strength, including whether the bars are straight or deformed (ribbed), the protective coatings on the rebar, and the surface condition of the rebar, which ranges from new to rusted.

Various studies (see the book, *Galvanized Steel Reinforcement in Concrete*[1]) have looked at the bond strength of black rebar (uncoated), hot-dip galvanized, and epoxy-coated rebar. In some cases, the bond strength between galvanized rebar and concrete may take slightly longer to develop than the bond between uncoated rebar and concrete. However, according to the studies, the bond between galvanized rebar and concrete is in fact as good or better than the bond between uncoated or epoxy-coated rebar and concrete. The bond strength of hot-dip galvanized rebar is believed to be aided from calcium hydroxyzincate crystals, which develop between the galvanized coating and concrete.

In studies, epoxy-coated rebar has been found to have a lower bond strength than both galvanized rebar and black rebar. One study[2] by the American Society of Civil Engineers (ASCE), found epoxy-coated rebar had a reduction in bond strength of 20% to 50% when compared to black rebar. In another study[3], epoxy-coated rebar slipped in concrete 200% more than galvanized or black rebar. Laboratory data support and field test results confirm, reinforced concrete structures exposed to aggressive environments have a substantially longer service life when galvanized rebar is used as opposed to uncoated or epoxy coated steel rebar.

Zinc Reaction in Concrete

During curing, the galvanized surface of steel reinforcement reacts with the alkaline cement paste to form stable, insoluble zinc salts accompanied by hydrogen evolution. This has raised the concern of the possibility of steel embrittlement due to hydrogen absorption. Laboratory studies indicate liberated hydrogen does not permeate the galvanized coating to the underlying steel and the reaction ceases as soon as the concrete hardens.

ASTM A767 requires hot-dip galvanized reinforcement be chromate passivated after galvanizing. Many cement mixtures contain small amounts of chromate that may serve the same purpose as chromate passivating the zinc coating. The reaction between the alkaline cement paste and the zinc coating is dependent on the amount of zinc coated surface in the concrete with the potential for reaction increasing with more zinc metal in contact with the concrete.

Ductility and Yield/Tensile Strength

Studies of hot-dip galvanizing on the mechanical properties of reinforcing steel show little effect on the tensile or yield strength or the ultimate elongation of rebar, provided appropriate steel selection, fabrication practices, and galvanizing procedures are followed. When rebar is fabricated prior to hot-dip galvanizing, bend radius should follow ASTM A 767, *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*. If rebar is fabricated after galvanizing, standard industry practice, as per the Concrete Reinforcing Steel Institutes's (CRSI) *Manual of Standard Practice*, should be followed.

Additionally, the effect of galvanizing on the ductility of steel bar anchors and inserts after being subjected to different fabrication procedures has been investigated. The study concluded with correct choice of steel and galvanizing procedures, galvanizing causes no reduction in the steel's ductility.

Fatigue Strength

An extensive experimental program examining the fatigue resistance of steel reinforcement shows deformed reinforcing steel, exposed to an aggressive environment prior to testing under cyclic tension loading, performs better when galvanized.

Installation and Handling

When galvanized steel is specified (see the AGA's publication, *Suggested Specification for Hot-Dip Galvanizing Reinforcing Steel*) the design

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requirements and installation procedures employed should be no less stringent than for structures where uncoated steel reinforcement is used. In addition, there are some special requirements to be observed when galvanized steel is used. These requirements include steel selection, detailing of reinforcement, dissimilar metals in contact, bending bars, and welding. More detailed information regarding these design requirements can be found in the AGA publication *Hot-Dip Galvanized Reinforcing Steel: A Specifier's Guide.*

Overlap lengths of hot-dip galvanized reinforcing steel are identical to uncoated steel rebar because of the equivalent bond strength to concrete. Additionally, galvanized reinforcing steel can be handled and placed in the same manner as black steel rebar because of its superior abrasion resistance.

SUSTAINABILITY

Sustainable development is an increasingly important consideration in construction projects. The zinc of the hot-dip galvanized coating, as well as the steel itself, are both 100% recyclable. Furthermore, the longevity of the coating eliminates the need for expending additional energy in the future on maintenance and upkeep. Additional energy is saved by eliminating the need to replace hot-dip galvanized products, which would require more energy and natural resources to create and transport new steel.

The zinc in hot-dip galvanized coatings is a natural element, the 27th most abundant in the Earth's crust, and is essential to all life. Zinc is necessary in many biological processes, and is used in many common products such as diaper rash cream, sun block, and common cold remedies. Hot-dip galvanizing does not add to landfills like paints and other materials do, and in fact, a large percentage of the original product is produced from recycled material (zinc and steel).

[1] Yeomans, S.R. (2004). *Galvanized Steel Reinforcement in Concrete*. Elsevier Ltd., Oxford, UK.

[2] Mathey, R.G., & Clifton J.R. (1976). *Bond of Coated Bars in Concrete.* Structural Engineering Division. American Society of Civil Engineers, 102, ST 1, 215-229.

[3] Kayali, O., & Yeomans, S.R. (2000). *Bond of Galvanized Steel in Concrete.* Cement and Concrete Composites, 22, 6, 459-467.

Visit www.galvanizedrebar.com for more information regarding using galvanized rebar for corrosion protection.

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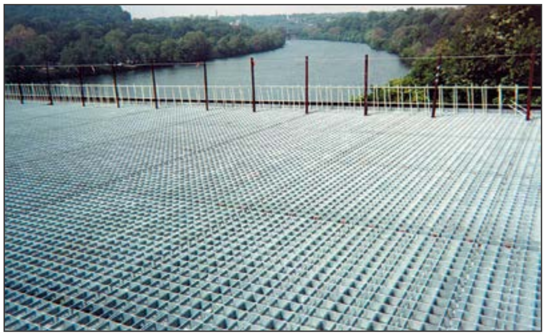
Case Studies

STRAWBERRY MANSION BRIDGE - PHILADELPHIA, PA



Almost 100 years after the Strawberry Mansion Bridge was erected, the City of Philadelphia forced it to close for renovation. Almost 60,000 ft^2 (5,574 m^2) of hot-dip galvanized open-grid flooring was filled with concrete. Galvanized rebar connected the grids instead of welds. This not only saved welding costs but also avoided any possibility of future problems with the welds. This bridge was constructed to accommodate the pedestrian and trolley traffic of the 1890s. Retaining the bridge's historical character and detailed ornamental aspects was a requirement of this restoration. Hot-dip galvanized steel has helped to preserve this reminder of the 19th century and assures that visitors will be able to enjoy its graceful structure well into the 21st century.

THE REEF - SOUTHAMPTON, BERMUDA

Nestled in the midst of a tropical paradise, the Reef Plaza is also subject to one of the most corrosive environments imaginable. The aquamarine waters and sunny beach location of the concrete plaza floor are susceptible to harsh sun, beating rains, and briny saltwater - making the steel rebar within the concrete susceptible to aesthetic and structural damage such as cracking and spalling. By utilizing hot-dip galvanized steel rebar, the architect of the project was protecting the plaza from the inside out. The rebar will be protected from the nicks and scratches acquired during handling, meaning the pieces will enter the concrete ready to protect against the rust and corrosion that can cause spalling. Galvanized steel rebar will keep this plaza structurally safe and aesthetically pleasing for many years of tropical delight.

STONEHAM ARCH BRIDGE - STONEHAM, QC, CANADA

This suspended arch bridge is an aesthetically pleasing solution to a unique site requirement. The choice of hot-dip galvanizing was preferred by the engineer because of its durability and cost in this highly corrosive environment. The resulting bridge is a beautiful and cost-effective marriage between structural steel and reinforced concrete.

The arched bridge design, unusual for a highway overpass, was chosen primarily to overcome two problems: uneven and rocky field conditions, as well as the very obtuse angle at which the road passed over the highway, which did not fit well with typical overpass construction. Steel beams were chosen for the deck because of steel's low strength-to-weight ratio. These beams were also designed to be galvanized rather than metallized, again, for economic and performance reasons. As for the reinforcing steel, the choice of hot dip galvanizing was obvious since the concrete arches needed to be protected both structurally and aesthetically.

This type of bridge design, combining steel and concrete, is not often used. The unique design of this type of bridge makes it very interesting both architecturally and structurally. The use of galvanizing in all aspects of the bridge breaks new ground for the industry. Galvanized structural steel, galvanized reinforcing steel in the concrete, and even the supporting cables are galvanized.

The province of Quebec has a long history of being a leader in the use of galvanizing in road structures, going back to both fully-galvanized road bridges in the early 1960s and galvanized reinforcing steel since the 1990s. The new ministry standards for an expected 75-year lifespan further drove the need for galvanizing in road infrastructure of Quebec.

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THE EGG - ALBANY, NY

The Egg at the Empire Center Plaza in Albany, NY, was completed in 1978. The performing arts center was a massive undertaking of architecture, combining aesthetics and function in a concrete and steel form. The concrete and steel stem of the structure extends six stories into the ground. The Egg keeps its shape by wearing a girdle comprised of a heavily reinforced concrete beams utilizing hot-dip galvanized rebar.

The superior durability and corrosion protection of hot-dip galvanized steel made it the logical choice for the reinforcement of the concrete in such an integral factor of the structure's design. The reinforced girdle helps the egg keep its shape and directs the weight of the structure onto the supporting pedestal and stem. Housing two theaters, the building's curved exterior is continued on the interior. The walls are not square with harsh corners, but rather curve even up to meet the concave ceiling to give an appearance of endlessness and improved acoustics. Thanks to hot-dip galvanized reinforcing steel, The Egg's extravagant design has not only wowed citizens and visitors for decades, but it will remain a beautiful centerpiece of Albany for generations to come.

AUTOROUTE 40 RECONSTRUCTION – MONTREAL, QC, CANADA

The Autoroute 40, a six lane Interstate-style highway, is the main East-West artery through the city of Montreal. Originally built in the 1970s, a major rebuilding initiative was launched during the beginning of the millennium to replace the failing concrete roadbed and related structures. Ravaged by de-icing corrosion and very high traffic volume, this highway suffered from the same environmental challenges faced by all highways in Quebec.

In 2004, the Quebec Ministry of Transport chose to perform an experiment. A section of the highway was rebuilt where one direction of the new roadbed utilized hot-dip galvanized rebar, while the opposing direction utilized epoxy coated rebar. The exceptional performance of HDG rebar in this application, as well as the performance of other bridges from the 1960s, led to the decision to galvanize all the rebar in the new 8 km section of Autoroute 40.

The corrosion caused concrete spalling due to poorly protected steel rebar is the Achilles heel of concrete road construction, especially in areas where de-icing salt is often used. Hot-dip galvanized steel rebar was a standout for not only its durability and abrasion resistance, but also its low life-cycle cost. Hot-dip galvanizing is now specified for many high corrosion applications throughout our road infrastructure.

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