Hot Dip Galvanized Reinforcing Steel
A Concrete Investment

Zinc Protects!

Introduction

Reinforced concrete is one of the most widely used modern construction materials. It is inexpensive, readily available, has a range of attractive properties and characteristics and is suitable for a variety of building and construction applications. It is also used in a number of exposure conditions, which in some cases highlights one of the main weaknesses of reinforced concrete: the potential for the steel reinforcement (rebar) to corrode, resulting in staining, cracking and failure of the surrounding concrete.

Sydney Opera House

For over 50 years hot dip galvanized (zinc) coatings have been used around the world to effectively and economically protect rebar from corrosion.

The Rebar Corrosion Problem

Concrete is a porous material made up of small pores and capillaries through which corrosive elements such as water, chloride ions, oxygen, carbon dioxide and other gases travel into the concrete matrix, eventually reaching the rebar. For each concrete mix at some threshold level of corrosive elements, steel depassivates and corrosion starts. Concrete itself exhibits good compressive strength but has poor tensile strength, generally about one-tenth of the compressive strength. When iron rusts, its corrosion products are 2-10 times more voluminous than the original steel which generate stresses that exceed the tensile capacity of the surrounding concrete, causing it to crack and spall. Once cracking has occurred, the structural capacity of the element may be compromised and costly repairs may be needed to extend its useful life.

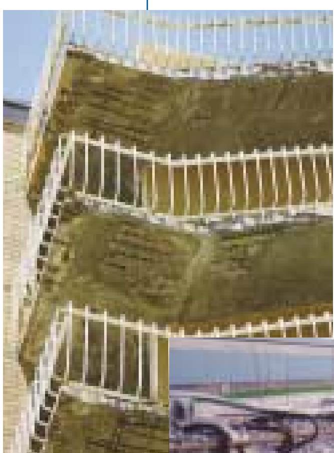
Preventing Rebar Corrosion

The most cost effective and efficient method of minimizing the risk of rebar corrosion is to ensure that the concrete cover over the reinforcement is of adequate thickness and that the concrete itself is dense and impermeable.

Another important line of defense is protecting the rebar itself by hot dip galvanizing. Hot dip galvanized coatings form an impervious metallic zinc and zinc alloy barrier around the steel that isolates the steel surface from the surrounding concrete. Galvanized rebar offers many advantages over conventional unprotected rebar, including:

• Zinc has a higher chloride concentration threshold for corrosion than bare steel. This significantly delays the initiation of corrosion from the ingress of chlorides to the galvanized rebar surface.

• The corrosion rate of zinc in concrete is lower than that of steel,



Effect of corroding reinforcing steel

and zinc corrosion products, once they form, do not create the same deteriorating internal stresses that occur when steel corrodes in concrete.

- Zinc coatings sacrificially protect steel, which means that at any break in the coating the surrounding zinc will corrode preferentially and electrochemically protect the adjacent exposed steel from corroding. As a result, a galvanized coating cannot be undercut by iron corrosion products as is the case with other barrier coatings (e.g., epoxy).

- The better corrosion resistance of galvanized rebar allows greater tolerance of concrete variability and placement.

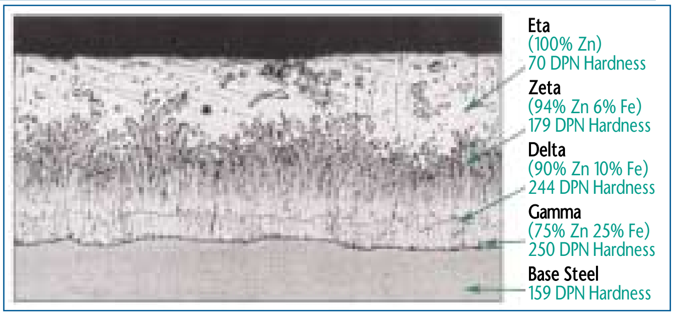

Straight lengths of galvanized rebar

- The zinc coating provides corrosion protection of the rebar prior to it being embedded in concrete.

These characteristics of galvanized rebar greatly reduce the risk of rebar corrosion that causes rust staining, cracking and spalling of the concrete. Galvanized rebar extends the maintenance free life of a concrete structure and greatly improves its overall lifecycle cost.

Hot Dip Galvanized Rebar

The hot dip galvanizing process applies a continuous metallic zinc coating to steel rebar by immersing the bars in a bath of molten zinc at about 450°C. A metallurgical reaction takes place between the steel and the zinc producing a coating made up of a series of iron-zinc alloy layers which form at the steel/zinc interface with an outer layer of pure zinc (the eta phase) adhering



Microstructure of a hot dip galvanized coating

to the outer surface as the rebar is removed from the zinc bath.

The unique structure of a hot dip galvanized coating offers many important advantages over other coatings. The galvanized coating is metallurgically bonded to the underlying


Rebar emerging from the molten zinc bath

steel, producing a coating that has an order of magnitude greater adhesion than, for example, fusion bonded epoxy coatings. In addition, the iron-zinc alloy layers of the coating are actually harder than the underlying steel which, combined with a soft outer layer of pure zinc, produces an extremely tough and abrasion resistant coating. Galvanized rebar can generally be treated in the same manner as uncoated rebar and does not require special handling precautions to protect the coating during handling, transport to, and placement at, the job site. Further, the bond strength of galvanized rebar to concrete is no less than that of uncoated bar, and in many cases is somewhat better. This allows the same reinforced concrete design specifications (bar size, lap lengths, etc.) to be used for galvanized rebar as unprotected rebar.


Galvanized rebar stored at job site

North American bridge decks

Applications of Galvanized Rebar

Galvanized rebar and other fittings (including bolts, ties, anchors, dowel bars and piping) have been widely used in a variety of reinforced concrete structures and elements. Particular circumstances where the galvanizing of reinforcement is likely to be a cost effective engineering decision include:

- transport infrastructure, including bridge decks, road surfaces and crash barriers;
- light weight precast cladding elements and architectural building features;
- surface exposed beams and columns, and exposed slabs;
- prefabricated building including units such as kitchen and bathroom modules and tilt-up construction;
- immersed or buried elements subject to groundwater effects and tidal fluctuations;
- coastal and marine structures; and
- high risk structures in aggressive environments.

Precast window panels

Sewage pipes

Sea water cooling channels

Rail tunnel

Safety barrier

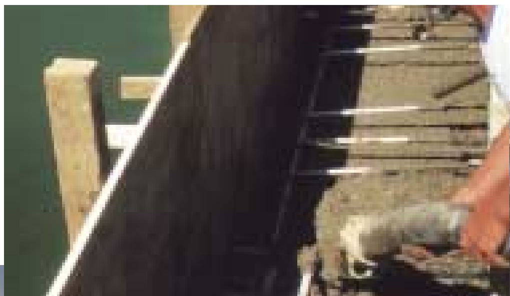
Tunnel

Many examples exist around the world where galvanized rebar has been successfully used in a variety of types of reinforced concrete buildings, structures and general construction, including:

- reinforced concrete bridge decks and pavements;
- cooling towers and chimneys;
- coal storage bunkers;
- tunnel linings and water storage tanks and facilities;
- docks, jetties and offshore platforms;
- marinas, floating pontoons and moorings;
- sea walls and coastal balustrades;
- paper mills, water and sewage treatment works;
- processing facilities and chemical plants;
- highway fittings and crash barriers; and
- concrete lamp posts and power poles.

Some prominent examples, many of which are well known buildings and major structures from around the world, are described on page 10.

Sea wall



Floating marina

Steelworks - coke ovens storage

Field Studies of Galvanized Rebar Installations

Practical experience and research over many years have clearly demonstrated the benefits of galvanizing for corrosion protection of steel reinforcement in many types of environments, including high chloride exposure situations. Galvanizing has been shown to extend the time to corrosion of reinforcement and reduce the risk of physical damage to concrete structures through delamination, cracking and spalling.

Tioga Bridge, PA, USA

US Bridge Decks

Periodic inspections of many bridge decks in the United States, including coring and removal of sections of the galvanized rebar, revealed the rebar had suffered only superficial corrosion and that the deck was sound and uncracked. In many cases, the bridge decks examined were over 30 years old and had relatively high chloride levels, far in excess of the generally accepted American Concrete Institute 201 Committee threshold value for corrosion of untreated steel rebar of 0.15% by weight of cement (1.0 lb Cl^-/yd^3 of concrete). Table 1 summarizes the results generated from these investigations by Construction Technologies Laboratories. More details of these reports can be obtained from: www.galvanizedrebar.com.

Table 1

Summary of US Bridge Inspections by Construction Technologies Laboratories, Inc.

Location	Installed	Inspection Date	Water Soluble Chloride Content (% by weight of cement)**	Zinc Coating Thickness mils	Zinc Coating Thickness µm
Boca Chica Bridge, FL*	1972	1975	0.3	5.1	130
		1991	0.26 – 0.40	4.0	102
		1999	0.38 – 0.74	6.7	170
Tioga Bridge, PA*	1974	1981	0.1	5.9	150
		1991	0.15	8.8	224
		2001	0.35	7.8	198
Curtis Road Bridge, MI	1976	2002	0.14 – 0.96	6.1	155
Spring Street Bridge, VT	1971	2002	0.43 – 1.14	7.5	191
Evanston Interchange, WY	1975	2002	0.85 – 1.55	9.3	236
NYS Thruway I-87 Bridge	1990***	2003	0.07 – 0.11	8.0	200
NYS Thruway Seneca River	1990***	2003	0.02 – 0.27	14	355

* Multiple inspections were made on these bridges. Since coating thickness measurements are made on rebar samples taken from bridge cores that have been removed from the deck, it is impossible to perform this inspection in the same spot. Also, hot dip galvanized coating thicknesses can vary 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.

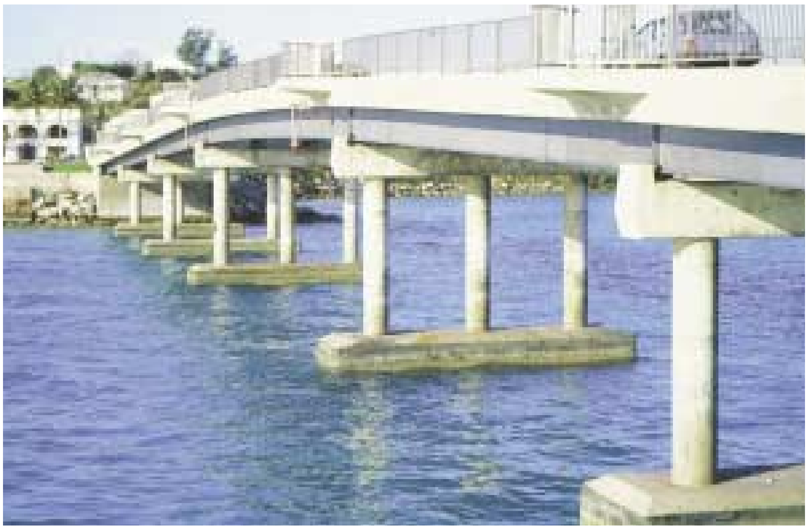
**Based on estimated cement content of 14%

***Estimated build date

Athens Bridge, PA, USA

Boca Chica Bridge, FL, USA

Aerial view of the Islands of Bermuda



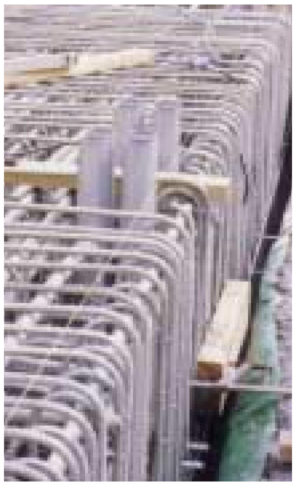
New Watford Bridge, Bermuda

The Bermuda Experience

Similar performance of galvanized rebar is obtained in Bermuda, verifying the long term durability of galvanized reinforced concrete in marine environments. For over 50 years, all docks, jetties, bridge decks, substructures and other infrastructure in Bermuda are, as a matter of course, constructed with galvanized rebar. A 1995 inspection and coring of the then 42 year old Longbird Bridge revealed that the galvanized rebar still had a zinc coating thickness well in excess of a new hot dip galvanized coating specification, at concrete chloride levels ranging from 3 to 9 lb/yd^3 (1 to 4 kg/m^3). Furthermore, detailed examination of concrete cores from these structures discovered that the zinc corrosion products that did form had migrated a considerable distance (about 0.4mm) beyond the zinc/concrete interface into the surrounding concrete matrix with no visible effect on the concrete.

Jetty at the Royal Bermuda Yacht Club

Studies show that in good quality concrete that is well compacted, cured and of adequate cover, galvanized bar survives for extended periods of time and offers a cost effective method of corrosion protection. In poor quality concrete, however, particularly those with high water/cement ratios and low cover over the reinforcement, galvanizing will delay the onset of chloride induced corrosion of the reinforcement, but this may be of limited benefit.



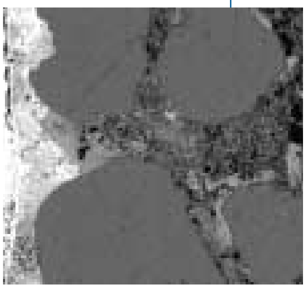
Penno's Wharf, Bermuda

The Tynes Bay Energy Plant, Bermuda (above and left)

Reinforced wall

How Zinc Protects Rebar in Concrete

The corrosion protection afforded by galvanized rebar in concrete is due to a combination of beneficial effects. Of primary importance is the substantially higher chloride threshold (2-4 times) for zinc coatings to start corroding compared to uncoated steel. In addition, zinc has a much greater pH passivation range than steel, making galvanized rebar resistant to the pH lowering effects of carbonation as the concrete ages. Even when the zinc coating does start to corrode, its corrosion rate is considerably less than that of uncoated steel.



SEM image of the interfacial zone between the galvanized coating (white phase, left) and the concrete matrix. The plume of zinc-rich corrosion products (light grey phase, left) can be seen migrating into the cement matrix. Large grey particles are fine sand. (Magnification 100X)

Why Galvanized Rebar Maintains Concrete's Integrity

Zinc's corrosion products are loose, powdery minerals that are less voluminous than iron corrosion products and are able to migrate away from the galvanized rebar surface into the adjacent concrete matrix. As a result, corrosion of the zinc coating causes very little physical disruption to the surrounding concrete.

There is also evidence to suggest that the diffusion of zinc's corrosion products helps fill pore spaces at the concrete/rebar interface, making this area less permeable and helps to reduce the transport of aggressive species such as chlorides through this interface zone to the zinc coating. The reactions between zinc and concrete, and the resulting corrosion product diffusion, also explains why galvanized rebar has such good bond strength with concrete.

Initial Reaction of Zinc in Fresh Concrete

Zinc reacts with wet concrete to form calcium hydroxyzincate accompanied by the evolution of hydrogen. This corrosion product is insoluble and protective of the underlying zinc (provided that the surrounding concrete mixture is below a pH of about 13.3). Research has shown that during this initial reaction period until coating passivation and concrete hardening occurs, some of the pure zinc layer of the coating is dissolved. However, this initial reaction ceases once the concrete hardens and the hydroxyzincate coating has formed. Studies of galvanized rebar recovered from field structures indicate that the coating remains in this passive state for extended periods of time, even when exposed to high chloride levels in the surrounding concrete.

For concretes of high pH, or where some background chlorides are expected, the zinc surface can be passivated, using a range of proprietary post treatments, as a safeguard against excessive hydrogen evolution that may, in serious cases, reduce the pullout strength of the bar. For normal concrete conditions, research has shown no statistical difference in bond strength between galvanized rebar that was passivated and not passivated.

Deep Tunnel Sewage System, Singapore

Cost of Corrosion

For reinforced concrete structures exposed to aggressive environments, such as coastal marine and industrial climates, or de-icing salts, the problem of rebar corrosion is widespread and severe and requires a corrosion-abatement strategy. A 2001 study commissioned by the United States Federal Highway Administration estimated the cost of corrosion in the US to be approaching $300 billion per year. Highway bridges, a large consumer of reinforcing steel, alone contributed over $8 billion to this total, mostly resulting from structurally deficient concrete reinforced decks and substructures caused by rebar corrosion.

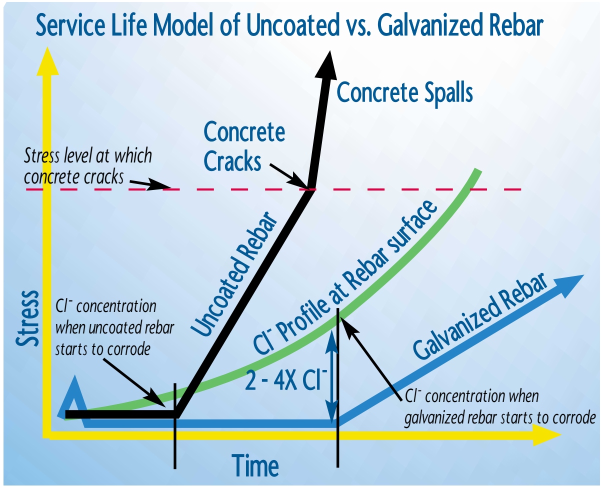
Corroding concrete piling

Economics of Galvanized Reinforcement

Hot dip galvanizing is a small but important investment. It is used extensively throughout the world annually to protect millions of tons of steel against corrosion. Hot dip galvanizing is therefore a widely available service that is cost competitive with other rebar protective coating systems. When measured against total building and construction costs, and the enormous potential costs associated with premature repair of damaged concrete, or failure of the structure, the premium paid for galvanized rebar is very small and easily justified.

Codes of Practice and Standards

The specification for hot dip galvanizing of steel reinforcing bars is handled in different ways around the world. Some countries treat steel reinforcing bars in the same way as any other steel product, and the hot dip galvanizing of rebar falls under a general galvanizing standard (Table 2). Several other countries have developed product specific standards for the hot dip galvanizing of steel reinforcing bars. These are also listed in Table 2.



Zinc coatings have a higher chloride (Cl^-) corrosion threshold (2-4 times) than that of uncoated steel, significantly extending the time until corrosion initiation. Once corrosion of the zinc coating does occur, the properties of the corrosion products and their ability to migrate into the concrete matrix reduces stress generation in the surrounding concrete, further extending the life of the reinforced concrete structure.

Summary

Over a long period of time, hot dip galvanizing has proven to provide cost effective and reliable corrosion protection to steel in concrete in a variety of exposure conditions. Hot dip galvanizing is one of a number of corrosion protection measures used to improve the overall durability of reinforced concrete. The convenience of manufacture and supply of the product, the ease of handling, transportation and installation, its proven durability and the fact that no special design requirements are needed, means that hot dip galvanized steel has been accepted in many countries worldwide for a wide range of concrete construction.

Bridge deck

ASER Tower, Adelaide, Australia

Examples of Prominent Structures Utilizing Galvanized Reinforcing Steel

Australia / New Zealand

Sydney Opera House: 35 mm thick panels for cladding of sails and seawall units
Hydro-Electricity Commission, Hobart: clad with 950 galvanized precast panels
Telecom Exhibition Exchange, Melbourne: clad with precast panels
Intercontinental Hotel, Sydney: 1549 precast windows and fascia units
Library Tower, Sydney: galvanized bar in external columns and panels
High Court and National Gallery, Canberra: galvanized bar in critical areas
New Parliament House, Canberra: 1800 galvanized cladding panels
National Tennis Centre, Melbourne: precast stadium support beams
New Zealand Parliament House, Wellington: clad with precast fascia panels

Asia

The Lotus Temple, India: galvanized rebar in white precast fascia panels
Offshore piers at Ominichi, Japan: galvanized reinforcement throughout
Deep Tunnel Sewage System, Singapore: 10,000mt of galvanized rebar

United States and Canada

Bank of Hawaii, Waikiki: thin decorative precast arches with galvanized bar
Financial Plaza of the Pacific, Honolulu: precast cladding panels
Crocker Building, San Francisco: galvanized reinforced structural elements
Levi Strauss Building, California: precast panels
University of Wisconsin: precast panels and in-situ concrete in numerous buildings
Wrigley Field Sports Arena, Illinois: precast panels in seating decks
Football Hall of Fame Stadium, Canton, Ohio: galvanized reinforcing steel
Georgetown University Law Center, Washington, DC: precast panels
US Coast Guard Barracks, Elizabeth City, NC: galvanized bar in 237 precast panels
Bridge decks and road construction in New York, New Jersey, Florida, Iowa, Michigan, Minnesota, Vermont, Pennsylvania, Connecticut, Massachusetts, South Carolina, Ontario and Quebec
Staten Island Community College, New York: brilliant white precast panels
IBM Data Processing Division, White Plains, New York: galvanized reinforcement in precast facade panels
Arkansas Civic Centre: galvanized reinforcement in slim external columns

Europe

National Theatre, London: over 1000t of galvanized bar in exposed parapet walls
Eastbourne Congress Theatre, UK: cladding panels and window mullions
Collegiate Buildings, University College, London: galvanized bar and mesh
University Sports Hall, Birmingham: 37 mm thick panels using galvanized bar
New Hall, Cambridge University: galvanized mesh in roof segments
Barclays Bank, City of London: galvanized precast window surrounds
Offices, Westminster Bridge, London: galvanized reinforced white facing panels
Dome of the Mosque, Rome, Italy: galvanized reinforcement
ANDOC North Sea Oil Rig: 2000t galvanized bar in roof of storage tank
Power Station, Spijk, Netherlands: fully galvanized reinforced cooling water ducts
Coke quenching towers, Dunkirk, France: galvanized structural reinforcement
Toutry Viaduct, St Nazaire Bridge and Pont d'Ouche Viaduct, France: galvanized reinforcing bars
Offshore piers Riva di Traiano, Rome, Italy: galvanized reinforcement throughout the structure

Court House, Townsville, Australia

The Lotus Temple, India

North American bridge decks

Deep Tunnel Sewage System, Singapore

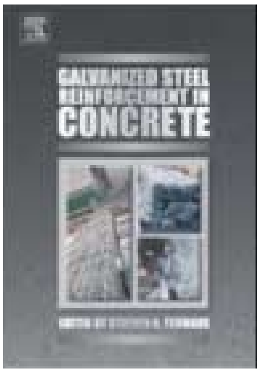
Table 2. Standards for Hot Dip Galvanizing of Reinforcing Steel.*

	Designation	Title of Standard
Hot Dip Galvanizing Standards		
Australia/ New Zealand	AS/NZS 4680	Hot dip galvanizing (zinc) coatings on fabricated ferrous articles
Canada	CAN/CSA G164	Hot dip galvanizing of irregularly shaped articles
South Africa	SABS ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles
Europe	EN ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles
International Standards Organization	ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles
Reinforcing Steel Hot Dip Galvanizing Standards**		
United States	ASTM A 767	Zinc-coated (galvanized) steel bars for concrete reinforcement
France	NF A35-025	Hot dip galvanized bars and coils for reinforced concrete
Italy	UNI 10622	Zinc-coated (galvanized) steel bars and wire rods for concrete reinforcement
India	IS 12594	Hot dip coatings on structural steel bars for concrete reinforcement specifications
International Standards Organization	ISO 14657	Zinc-coated steel for the reinforcement of concrete

* Further quidance and support in creating a hot dip galvanized rebar specification is available from regional galvanizing associations, as listed on: www.galvanizedrebar.com

**A new European standard "Steel for Reinforcement - Galvanized Reinforcing Steel" is currently under development. Also, a German national approval/quality specification exists Z-1.4-165 "Allgemeine Bauaufsichtliche Zulassung - Feuerverzinkte Betonstähle" in English "General approval by the building authorities - Galvanized reinforcing steel"

Further Information



For further information and details about hot dip galvanized reinforced steel, please visit: www.galvanizedrebar.com or contact galvrebar@iza.com

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www.galvanizedrebar.com

A website dedicated to advancing the knowledge of
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Technical questions can be directed to:

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Zinc Protects!

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