# CORROSION PROTECTION OF REINFORCEMENT FOR CONCRETE STRUCTURES

## 1. INRODUCTION

There are numerous examples, around the world, of "spalling concrete" found on structures within marine and inland urban and industrial environments. Clearly, there is a need to implement effective corrosion control methods in order to extend the long-term durability of steel reinforced concrete.

Methods proposed for the corrosion protection of reinforcement do not, in any way, replace or usurp the importance of good quality concrete as the primary source of "barrier protection" against corrosive attack of steel reinforcement. What is proposed in this paper is a "belt and braces", cost effective and site practical method, of improving corrosion protection of embedded reinforcement, before actual placement within a structure, i.e. prior to, during delivery to site and final installation. In short, "prevention is better than cure".

*The cost of adequate prevention carried out during the stages of design and execution are minimal compared to the savings they make possible during the service life and even more so, compared to the cost of rehabilitation, which might be required at later dates. The so-called De Sitter's "law of five" can be stated as follows: one dollar spent in getting the structure designed and built correctly is as effective as spending $5 when the structure has been constructed but corrosion has yet to start, $25 when corrosion has started at some points, $125 when corrosion has become widespread. Ref No.3.*

There are several methods of corrosion protection, such as, but not limited to the following:
❖ The use of membrane-type coatings applied to the surface of concrete structures.
❖ Painting the outer concrete surface to provide barrier protection.
❖ Addition of corrosion inhibitors to concrete.
❖ The use of stainless steel or 3CR12 as a substitute of normal carbon steel reinforcement.
❖ Cathodic protection of the reinforcement.
❖ Application of a coating to the reinforcement itself, i.e. epoxy coatings and specifically zinc in the form of hot dip galvanizing.

While these various methods provide varying degrees of success, this paper will examine the specific aspects of corrosion protection by the application of hot dip galvanizing for "barrier protection" ($2^{ND}$ line of defence) with the added benefit of cathodic protection ($3^{RD}$ line of defence) achieved by the fact that zinc is electro-negative to carbon steel. The main "barrier protection" ($1^{ST}$ line of defence) is of course the concrete cover of the embedded reinforcement.

It is abundantly clear that many misconceptions persist with regard to the use of hot dip galvanizing as a corrosion protection system for reinforcement.

This paper addresses many of these issues in order to facilitate informed decision making, during the design stage for projects where reinforced concrete is to be used as a structural component.

It is known from practical experience and site investigations, around the world and specifically along the Southern African coastline, as well as at numerous inland locations that **"The life to the first maintenance of an uncoated steel bar reinforced concrete structure which has failed by concrete spalling after approximately 10 years, could have been extended to over**

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**30 years if the re-bar had initially been hot dip galvanized".** This postulation assumes a quality concrete cover of 40mm minimum with >40 MPa strength concrete (ordinary Portland Cement). *Ref No.1.*

It is generally accepted that such concrete quality as well as correct site placement, presents practical difficulties that cannot always be avoided. A zinc coating, in the form of hot dip galvanizing, is suggested as a practical, and economical approach aimed at enhancing the durability of reinforced concrete.

## 2. FACTORS AFFECTING DURABILITY OF REINFORCED CONCRETE STRUCTURES

### 1. Environment

Corrosion attack and hence, ultimate service life of any material, is dependent on the environment in which such components are situated. The external environment is a major factor to be considered when designing all types of structures, and reinforced concrete is no exception.

It is the environment that carries the corrosive inducing elements and compounds such as oxygen, chlorides, sulphur dioxide and water to name but a few. Structures located along the coastline, which are exposed to prevailing winds from off the sea, are subjected to a greater degree of corrosion attack than at most inland sites. This applies particularly in the spray zone because of the presence of chloride containing moisture in an oxygen rich environment. Sulphur dioxide containing atmospheres encountered in polluted industrial areas can be even more severe. It is essential to assess the degree of corrosion pertaining at each specific site whether inland or in a coastal region. Determine the microclimatic conditions, whether coastal or inland.

There are many examples of the effective use of hot dip galvanized reinforcement in corrosive marine and industrial environments both in Southern Africa and throughout the world. Many of these examples date back to the late 1950s and early 1960s.

### 2. Quality of Concrete

The quality and permeability of concrete represents the most important or critical factor to be considered when reviewing corrosion control and/or protection of the embedded reinforcement. Concrete permeability ($1^{ST}$ line of defence) is influenced by the following factors, referred to as the four **C**s.

❖ *Concrete Mix* - Low concrete permeability is a function of the bonding between the aggregate and the cement, water/cement ratio and size and grading of the aggregate.
❖ *Compaction* – Adequate and controlled compaction has an influence on both the quality of the concrete and its permeability.
❖ *Curing* – Site curing procedures influence permeability and ultimately concrete quality and strength.
❖ *Depth of Cover* - Depth of cover over the embedded reinforcement is of major significance when corrosion prevention of steel is being considered. Notwithstanding the depth of concrete cover required in terms of the specification, the final cover is often determined or limited by practical considerations at the time of the actual placing or pouring of the concrete. The reinforcement could shift within the shuttering or formwork and this could remain undetected due to practical restrictions during the pouring process. Practical aspects encountered during construction could compromise final depth of covers.

Indications of the reduction of the initiation time of corrosion due to local reductions in the thickness of the concrete cover in some areas of the structure is halved with respect to its nominal value, in these areas the initiation is reduced to less than one quarter of that predicted. This analogue is only valid when concrete is exposed to chlorides. *Ref No.3.*

In other words considering a chloride environment the following is possible.

❖ 24mm nominal concrete cover estimated 100years to initiation of reinforcement corrosion.
❖ With the reduction of the nominal concrete cover to half, (12mm) estimates reduce to 15 years to initiation of reinforcement corrosion. Refer to annex C.

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From the above, it is clear that the structural performance of reinforced concrete and the onset of corrosion of the reinforcement is largely determined by the quality of the concrete and practical placement of the embedded steel reinforcement. It is therefore clear that provision of corrosion protection to the reinforcement, by hot dip galvanizing, does not replace the requirement for good quality concrete. The purpose of corrosion protection of reinforcement is to extend the ultimate service life of the structure once the corrosive agents, present in an aggressive environment, have penetrated the concrete cover. Consider *Fig No.1*.



*Fig No.1*
While minimum cover may be specified the actual cover ultimately achieved is frequently dependant on practical site considerations.

## 3. STRUCTURAL FAILURE DUE TO CORROSION

In order to place the need for hot dip galvanizing of reinforcement into context, we must first discuss a typical failure of a reinforced concrete structure, due to corrosion of the reinforcement.

The following photographs illustrate the sequence of events leading to the ultimate failure of a reinforced concrete structure. *Fig No.2a to 2d.*



*2a*
Ingress of corrosive substances, is first indicated by **Rust Staining**



*2b*
**Cracks appear**

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**2c**
**Spalling concrete**



*Fig2d*
**Potential structural failure**
Once spalling has occurred, it becomes very difficult and expensive to repair.

The service life of a structure can be defined as the period of time in which it is able to comply with the given requirements of safety, stability, serviceability, and function, without requiring extraordinary costs of maintenance and repair. *Ref No.3.*

Hot dip galvanized steel reinforcing can be used to control corrosion in reinforced concrete exposed to the following conditions:

❖ Carbonation;
❖ Chloride and sulphate ion intrusion;
❖ Atmospheric pollution;
❖ A combination of chlorides and sulphates constituents;
❖ Freezing and thawing; and
❖ Expansive reactions e.g. alkali-aggregate reactions. *(Ref No.4)*

Hot dip galvanized reinforcement offers significant advantages compared to uncoated carbon steel under equivalent circumstances. These include: an increase of initiation time of corrosion; greater tolerance for low cover, e.g. in slender (architectural) elements, and corrosion protection is offered to the reinforcement prior to it being embedded in concrete. *Ref No.3.*
The structural integrity and longevity of bridges, tunnels, coastal buildings, industrial chimneys and cooling towers, as well as many inland industrial installations can be effectively and economically improved by the use of a zinc coating in the form of hot dip galvanizing to protect the embedded reinforcement.

Before continuing, let us briefly review the hot dip galvanizing process. What do we know of hot dip galvanizing, how does zinc protect and what constitutes the zinc coating?

4.   HOT DIP GALVANIZING PROCESS

    Hot dip galvanizing is a metallurgical process whereby perfectly cleaned steel is totally immersed into molten zinc at a temperature of approximately 450°C. During this process the carbon steel metallurgically reacts with the molten zinc forming a series of zinc/iron alloys together with a top pure zinc layer, chemically bonded to the parent steel. The micrograph *(Fig No.3)* is an illustration of a typical hot dip galvanized coating in which one can identify the various coating layers. Hot dip galvanized coatings provide "barrier protection" as well as "cathodic protection" of minor uncoated areas (handling damage), and micro-cracks that may be present, should cold bending be carried out after zinc coating. Corrosion creep from an uncoated area is not possible as is the case with an epoxy coating, which is pure barrier protection. While

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zinc and/or iron/zinc alloys are present the zinc will "sacrifice" itself to protect the carbon steel. We therefore refer to zinc as a "wasting protector" due to the fact that it is electro-negative to carbon steel in terms of the galvanic series of metals.
i.e. Zinc is anodic to cathodic carbon steel and will therefore provide "cathodic protection" of small-uncoated areas.

**Typical Coating Thickness range between 70 to 100μm**
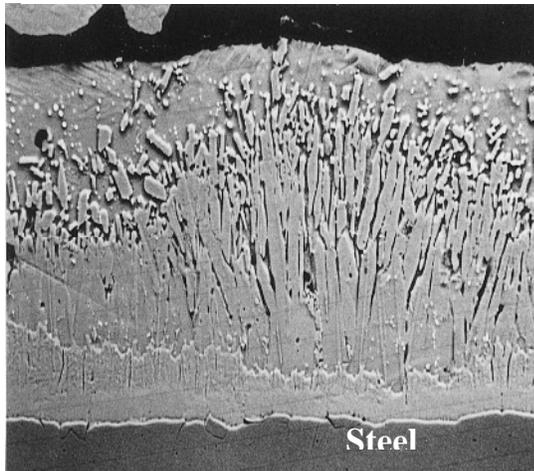


Pure Zn Layer
(eta ±15μm)

Fe/Zn layers

(delta & zeta

layers ±75μm)

Gamma
Layer
(± 6μm)

*Fig No.3*
Typical Hot Dip Galvanized coating showing the metallurgical bonded layers of iron/zinc with a pure (eta) top layer

Hot dip galvanized coating thicknesses are dependent on factors such as immersion time, zinc temperature, speed of withdrawal and chemical analysis of the carbon steel reinforcement. It is possible that the chemical composition of the steel could result in coating thicknesses as much as 200μm. While such coatings improve corrosion protection, estimated at +30% better than pure zinc, it is advisable to limit the coating thickness to <200μm and avoid excess brittle alloy layers and potential for coating flaking. While excessive zinc/iron alloys need to be controlled, they do provide additional benefits of increased corrosion protection and abrasion resistance. Coatings should be restricted to <200μm by due care and controls during the hot dip galvanizing process.

The final operation, within the hot dip galvanizing process, steel is processed through a passivating solution (0.5% to 1% sodium di-chromate). While this process is aimed at the restriction and formation of zinc oxidise/hydroxide (white rust) during storage and in transit to site, it has the added benefit, of passivating the hot dip galvanized zinc coating when exposed to high alkaline and reactive "wet" concrete. We will again refer to this issue later in this paper.

## 5.   ZINC REACTION WITH NEWLY POURED CONCRETE

In order to place the question of hot dip galvanized reinforcing bars into context, we need to consider what transpires when reinforcing is cast into concrete. How does the zinc coating react with the newly poured and curing concrete? What reactions take place when corrosion induced substances penetrate through to the reinforcement?

a.  Zinc in a varying pH environment

From the diagram of the relative corrosion rates of zinc in terms of the pH scale, *Fig No.4*, we see that zinc is attacked in an acid environment (pH <6) and again in highly alkaline conditions (pH > 12.5). The fact that zinc corrodes at pH levels >12.5, gives rise to the misconception regarding the performance of hot dip galvanized reinforcement in contact with newly poured "wet" concrete.

Freshly poured "wet" concrete has a pH >12.5, which will cause it to react with zinc. In practice, the pH of the pour solution in concrete is usually below 13.3 during the first few hours after mixing, due to the presence of sulfate ions from the gypsum added to the Portland cement as a regulator.

This reaction progressively ceases whilst the concrete is curing, and is largely inhibited when the galvanized reinforcement is chromate passivated, as is normal practice, within the hot dip galvanizing process. Refer to paragraph 4 above.

The passive film that forms on zinc not only reduces the rate of the anodic process (zinc dissolution), but also even hinders cathodic reactions of oxygen reduction and hydrogen evolution. *Ref No.3.*
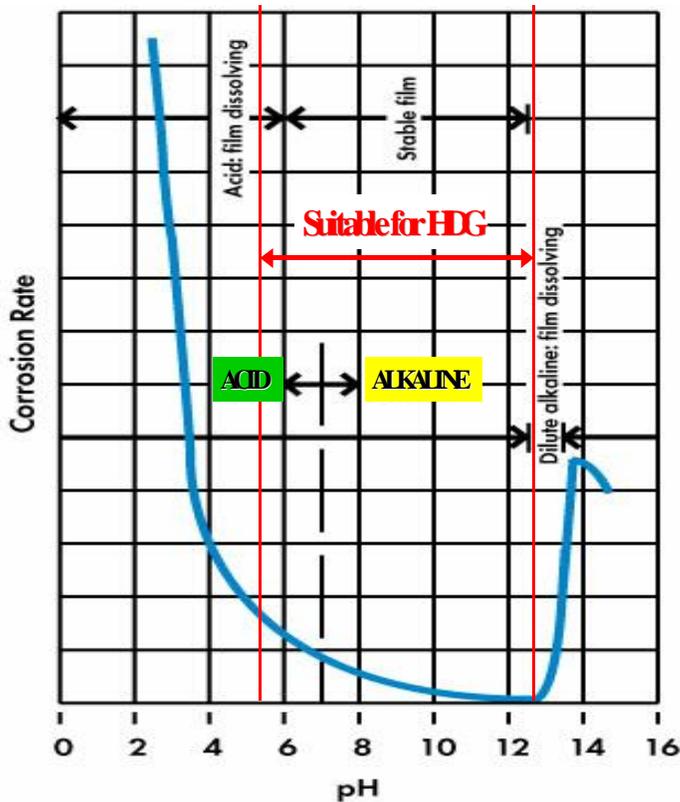


*Fig No. 4*

The relative corrosion rates (y axis) of zinc in terms of the pH scale (x axis)

During initial contact between hot dip galvanized reinforcement and wet concrete, the outer zinc layer of the galvanized coating reacts to form zincates, (calcium hydroxyzincate). The zincates formed, consuming between 5 to 10µm of the outer zinc (eta) layer in the establishment of a passivated layer. This reaction ceases as the concrete hardens leaving a coating of stable zincates and the remaining (approximately 75 to 85µm) original zinc and zinc iron alloys intact and able to provide corrosion protection, both barrier and cathodic.
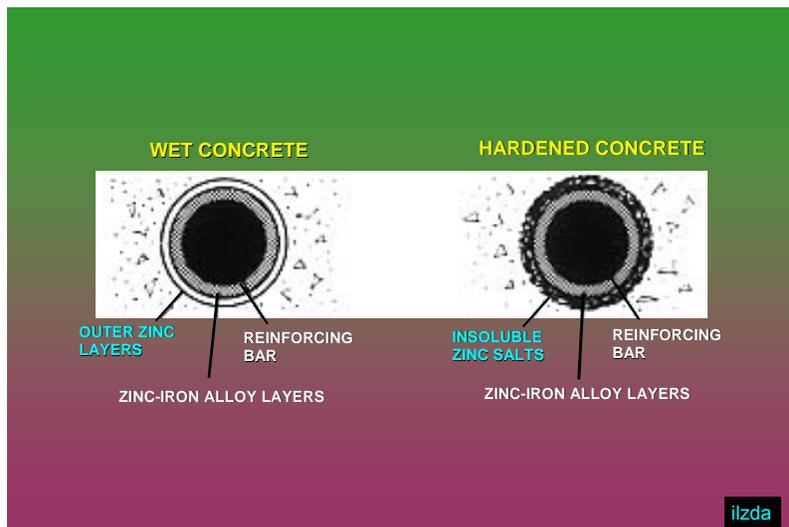


*Fig No.5*
Evolution of the hot dip galvanized coating from the "wet" concrete pour to that of the "hardened" concrete at 7 to 10 days.

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It is noteworthy that within a short time, pH levels within concrete are reduced into a range of 8 to <12, due to the inevitable ingress of carbon dioxide ($CO_2$), referred to as carbonation. In this pH range, zinc performs exceptionally well, while the rate of corrosion of unprotected steel increases due to the loss of a protective oxide passive film on steel. It could be argued that the formation of the zincates (calcium hydroxyzincate) is an additional corrosion protective barrier, which is perhaps debatable.

b. Evolution of Hydrogen

It is known that when the wet concrete pour is exposed to zinc, a reaction takes place between the zinc and the cement paste or $Ca(OH)_2$ formed because of cement hydration. This corrosion reaction is controlled by diffusion processes and results in the evolution of hydrogen and the transformation of zinc into calcium hydroxyzincates, as shown by the following chemical formula. *(Ref No.4)*.

$$2Zn + Ca(OH)_2 + 6H_2O \quad Ca[Zn(OH)_3]_2\,2H_2O + 2H_2$$

The resultant hydrogen, so formed, is believed to reduce the bond strength between the reinforcement and the concrete. However, this zinc corrosion reaction is only active during the initial curing period of between 6 to 10 days. During this period, as already stated, approximately 5 to 10µm of the pure zinc (eta) outer layer is consumed, leaving the remainder of the eta and all of the zinc/iron alloy layers unaffected. Subsequent loss of zinc (eta) and alloy (gamma, delta & zeta) layer, due to continued reaction, is no more than about 2µm per year although, in carbonated concrete, this may increase. *(Ref No.4)*. Depending on the coating thickness a further 60 to 90 years or more can be expected before all the zinc is sacrificed in the protection of carbon steel.

Notwithstanding the above, the corrosion rate between zinc and fresh concrete can be controlled by the presence of chromates. Such chromates are provided by way of the sodium di-chromate applied during the hot dip galvanizing process or alternatively as potassium dichromate as an additive to the concrete mix. In addition, naturally occurring chromates, present in most Portland cements, can be relied upon to provide adequate passivation with no reduction in bond strength.

6. BOND STRENGTH OF CONCRETE TO HOT DIP GALVANIZED REINFORCING BARS

A further misconception that arises is that due to the formation of insoluble zinc salts and the evolution of hydrogen formed at the interface between the newly poured (wet) concrete and the hot dip galvanized reinforcement, is the reduced bond strength.

Extensive programmes of pullout tests conducted by a number of research organisations around the world including a series of local tests conducted by Dr. R.G.D. Rankine of the School of Concrete Technology. Results show conclusively that the bond strength is not reduced when compared with uncoated reinforcement. In fact, an actual increase in the bond strength has been observed. The graph, illustrated in *Fig No. 6*, reflects the results obtained during the tests conducted by Dr. R.D.G. Rankine. *(Ref. No.2)*.

Generally it is believed that during the early stages (6 to 10 days) of the concrete curing, the bond strength may be temporarily reduced due to the issues of hydrogen evolution and the formation of calcium hydroxyzincate etc. However, as the concrete hardens, the bond strength increases and there is no difference between uncoated reinforcement and that of the hot dip galvanized material. In fact there is evidence to suggest that bond strength improves and is higher than that of uncoated reinforcement. Evolution of hydrogen is believed to be very short lived and may well cease within approximately 1 hour. *(Ref No.4)*.

**Local Pull out Tests**
**(by Dr. R.D.G. Rankine)**



Sample No.

- Uncoated Steel
- HDG Steel
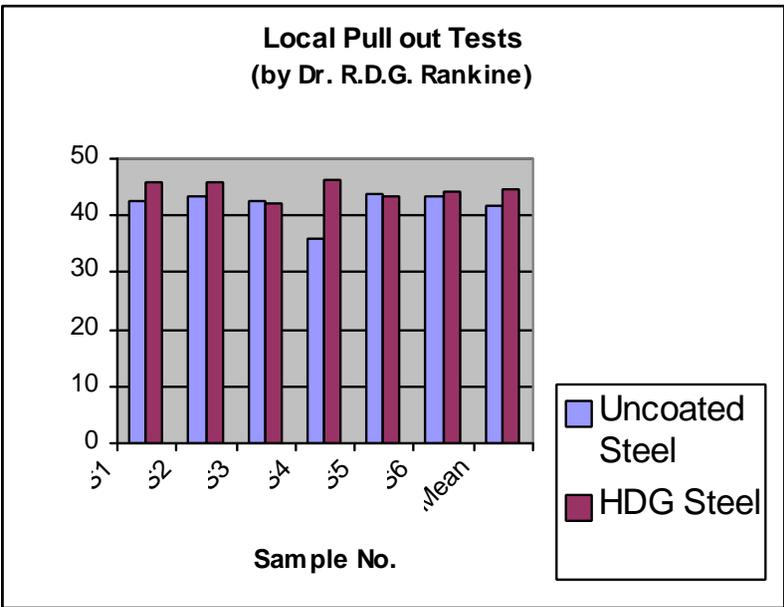
*Fig No.6*
Bond Strength Tests Conducted by the School of Concrete Technology, including six samples labelled S1 through to S6

A higher bond with respect to bare steel could be obtained, due to the formation of calcium hydroxyzincate crystals that fill the interfacial porosity of the cement paste and act as bridges between the zinc coating and the concrete. *Ref No.3.*

## 6. INFLUENCE OF TEMPERATURE ON STEEL TENSILE STRENGTH

A further misconception is that due to the hot dip galvanizing temperature of 450ºC, the reinforcement will loose structural strength and its tensile integrity. This is not so, in that the transformation ranges of steel occurs between 700º to 900ºC, which is well above the hot dip galvanizing temperature. This fact is confirmed by laboratory tests as well as practical case studies with fasteners and structural steel components that have been hot dip galvanized.

## 7. CORROSION RESISTANCE

Two major factors cause corrosion of steel reinforcement and hence long-term performance of reinforced concrete structure. Both are influenced by the permeability of concrete cover.

a. **Carbonation**, i.e. the ingress of carbon dioxide ($CO_2$) from the atmosphere, and
b. **Chloride and sulphate ion intrusion**, again from the atmosphere or in other words the environment in which the structure is to function.

a. Carbonation

Carbon dioxide ($CO_2$) may well enhance the barrier protection of zinc by the formation of stable zinc carbonate ($ZnCO_3$), i.e. the reaction of zinc with carbon dioxide. At the same time, *Carbonation* is defined as a process whereby carbon dioxide in a moist environment reacts with hydrated cement paste to form an acid aqueous solution that tends to reduce the concrete's alkalinity.

Zinc is amphoteric, i.e. able to react as a base and an acid, between a pH range >6 to <12.5, refer to *Fig No.4.* As the pH is reduced, due to carbonation, into a range of 8 or 9, it is ideal for the corrosion protective properties of zinc, but less favourable in the case of uncoated steel. Hot dip galvanized reinforcement therefore presents an ideal solution to combat carbonation.
The passive film of hot dip galvanized reinforcement is stable ($ZnCO_3$), *Fig No.7,* even in mildly acidic environments, (pH of 6) so that the zinc coating remains passive even when the concrete is carbonated down to a pH of 8 or 9. In extreme cases, where all the calcium hydroxide is depleted, the value of pH may drop to as low as 8.3. *(Ref No.4).* Zinc coated reinforcement therefore remains passivated far longer than uncoated carbon steel where carbonation is encountered.

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The corrosion rate of hot dip galvanized steel in carbonated concrete is approximately 0.5 to 0.8µm/yr, therefore a typical 80µm hot dip galvanized coating would be expected to last over 100 years. The corrosion rate of hot dip galvanized bars remains negligible in carbonated concrete even if a modest content of chloride is present.
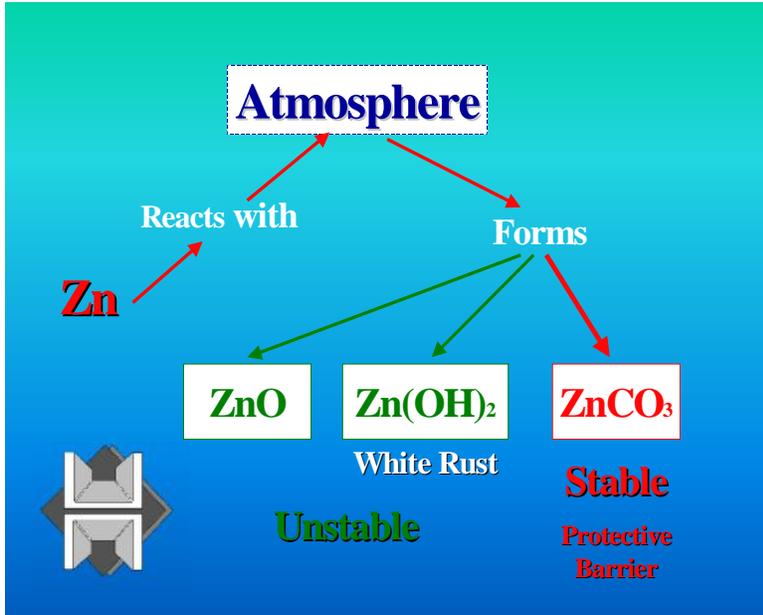


*Fig No 7*

The reaction between zinc (Zn) and the Atmosphere, including Oxygen, water moisture, and Carbon dioxide

b. Chloride attack

In chloride-contaminated concrete, which is the major reason for steel corrosion affecting the service life of reinforced concrete, the penetration of chloride ions can depassivate steel and promote active metal dissolution.

A combination of loss of alkalinity due to carbonation and the ingress or inclusions of chloride ions can act in combination and pose a serious destructive threat to the long-term stability of a concrete structure.

As chloride penetration of the concrete through to the embedded reinforcement is only possible through the concrete matrix, we can understand the significance of concrete quality and the need to ensure compliance to design and effective site management and supervision during construction.

Hot dip galvanized reinforcement can offer significant advantages over uncoated carbon steel in terms of substantial reduction or even total elimination of rust staining and greater tolerance to construction imperfections and greater resistance to chloride attack. Improved resistance to chloride attack is due, for a large part, to the lower value of free corrosion potential of hot dip galvanized steel.

It is worth pointing out that small-scale laboratory tests tend to indicate that hot dip galvanized steel is subject to corrosion in highly contaminated concrete. However, site experience and examination of several bridge decks exposed to chloride salts well in excess of the threshold value needed to induce corrosion of untreated steel, and of structures exposed to severe salt-water environments, have shown no evidence of corrosion or impaired performance of the concrete with no structural impairment due to lack of bond *(Ref No. 4)*.

Another interesting feature is that potassium chloride; also present in seawater, as opposed to sodium chloride, inhibits the corrosion of zinc. It is for this reason that totally immersed hot dip galvanized steel, as opposed to spray zone applications, will provide extended corrosion free life.

Even if pitting corrosion is initiated, the corrosion rate tends to be lower for hot dip galvanized steel, since the zinc coating that surrounds the pits is a poor cathode and thus it reduces the effectiveness of the autocatalytic mechanism that takes place inside the pits on bare steel. *Ref No.3*

Up to date information, both from laboratory tests as well as site inspections and observations over the past 20years, is provided in a book, published during 2004, which clearly confirms the long term benefits of hot dip galvanized reinforcing. *Ref No.4.*

In this publication, Professor Yeomans has proposed a schematic representation to illustrate the benefits of hot hip galvanized reinforcement on design and service life of reinforced concrete structures.

One of the major factors that contributes to the significant delay of the onset of corrosion of the base steel is the fact that the galvanizing provides a metallurgically alloyed coating of consistent quality that is highly resistant to damage during transportation, storage, site handling and concreting operations. *(Ref No 4 page 59).*

## 8. ECONOMIC CONSIDERATION OF HOT DIP GALVANIZING REINFORCEMENT

The cost of hot dip galvanizing reinforcement is insignificant compared to the cost of repairing spalling concrete that results from the corrosion of uncoated reinforcement. Refer to the *so-called De Sitter's "law of five"* quoted earlier.

Costs vary from place to place and are subject to many factors such as the price of concrete, price of steel, site location, contractor's overheads and so on. However, notwithstanding this, it is believed that the increase in the overall cost of placed reinforced concrete is in a range of 5% to 10%. If one were to continue with this analysis and consider the use of hot dip galvanized reinforcement in strategic locations, such as the exterior walls of a structure and for high-risk corrosion areas, the overall cost increase for a project could be as little as 0.5 to 3%.

Whatever the final cost incurred to hot dip galvanize, it is more economical than many alternative methods of corrosion protection, and perhaps more importantly for the project owner, the savings that will result over the life of the project, by the reduction in maintenance and rectification costs.

## 9. RECENT SITE VISITS AND OBSERVATIONS

The following photographs provide examples of sites where uncoated reinforcing bars were used in concrete that was undoubtedly required to conform to the specified standards for concrete quality and minimum depths of cover. In the case of one particular site, both hot dip galvanized reinforcement as well as uncoated re-bar was used. Where hot dip galvanized reinforcement was used no spalling was found, while the uncoated bars were corroding and spalling of the concrete had commenced.



Corroded reinforcement resulting in the "spalling off" of the concrete. Note the lack of concrete cover.

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Repairs to the concrete on this bridge structure proved to be unsuccessful in that the corroding reinforcing bars have again removed the concrete.

**Some Case Studies**

A recent case study resulting from a detailed investigation of a certain pedestrian bridge situated along the foreshore of Algoa Bay (Port Elizabeth South Africa) is briefly described.



The site of the 40-year-old pedestrian bridge (No B776), due to be demolished. (April 2005). It was established that hot dip galvanized reinforcement was used in the approach stairway, which was on the sea facing side, indicated on the left of the photograph, with the sea some 50 meters further left.



Sample concrete cores were extracted from the sea facing side, top slab and landside of the structure. These samples were sent to an independent concrete diagnostic & durability laboratory with instructions to establish the ingress of chlorides, carbonation and quality of the concrete. The depth of reinforcement cover was confirmed as being 45 to 60 mm and a sample of hot dip galvanized bar was retrieved for examination.

**Chloride concentrations** (% as mass of cement) at a depth of 45 to 60 mm ranged between 0.15 & 0.65 on side facing inland, and 0.27 & 1.26 on the sea facing side. At a depth of 30 to 45 mm the chloride concentrations ranged between 0.19 and 2.6. Chloride levels at a depth of 15 to 30 mm rise to between 0.49 to 8.8 as a % of cement mass. Accepting that the typical limit is 0.1% chloride for uncoated reinforcement, it should be totally unacceptable to use plain reinforcing without additional corrosion protection in this environment.

**Carbonation** was found to be more severe on the landside of the structure, with penetration depths of 18 to 22 mm.

**Concrete durability** index testing results of oxygen permeability was as follows:- 1 sample "very good", 1 sample "good", 4 were "poor" and 1 "very poor". Sorptivity of 2 samples were excellent, 2 good and 2 were poor.

Examination of the hot dip galvanized reinforcing, after 40-years in service, revealed conclusive evidence that the zinc coating was providing excellent corrosion protection to the steel. Further details of this case study may be found by visiting the HDGASA web site, www.hdgasa.org.za.

Perhaps the most published and long-standing examples of the performance of hot dip galvanized reinforcement are the numerous reinforced concrete structures, on the island of Bermuda. For over 50 years hot dip galvanized reinforcement has been effectively employed with commendable results.

Reference to chapter 7 of the reference *(Ref No.4)* details the results of investigations of a number of installations dating back to construction in 1953 and 1968. These were:

❖ Dock wall in Hamilton Harbour.
❖ Jetty at the Royal Yacht Club.
❖ Dock wall at Pennon's Wharf, St. George's.
❖ An approach span of Longbird Bridge near the airport.

Generally the results are noteworthy and supportive of the motivation for this particular paper.



Sydney opera house successfully employed
hot dip galvanized reinforcements



Public sea front swimming pool in
Cape Town, using seawater



Johannesburg Civic Centre is an example of hot dip galvanized reinforcement being used as an architectural requirement to prevent rust staining on the slender (low concrete cover) fascia panels. Original construction period was from 1964 through to 1968. A recent inspection no sign of rust staining was evident.

## 9. CONCLUSIONS

Hot dip galvanizing of reinforcement is not a substitute for good quality concrete standards. It will, however, add value and longevity to concrete structures while compensating for practical difficulties in fully complying with the requirement of relevant specifications. Hot dip galvanizing of reinforcement is an economical and cost effective process that can be expected to substantially extend the useful service life of reinforced concrete structures in marine and other corrosive environments. The marginal cost increase (0.5% to 3%) of the total cost of a project is money well spent and will, without doubt, provide a justifiable and economical return on an investment.

Finally to quote from Mr. Neil D. Allan *(Chapter 7 of Ref No.4)*.

"Civil engineers are, by nature and training, analytical, logical and cautious. They usually need to have considerable confidence in any new product or technique before it is fully accepted. Galvanized reinforcement is slowly beginning to gain their confidence in the UK and USA. Galvanizing as a process has been around for over 100years *(175 years)* and is well proven to delay significantly the onset of steel corrosion. Despite this, it is quite mystifying why designers who would happily specify galvanized handrails appear to baulk at the thought of using galvanized reinforcement".

*References:*

1.      A review of Hot Dip Galvanized Steel Reinforcing in Concrete Structures Exposed to South African Coastal Marine Environments by Professor Dennis Twigg.

2.      Galvanized Steel Rebar in South Africa by Dr. Rod Rankine.

3.      Corrosion of Steel in Concrete by Luca Bertolini, Bernhard Elsener, Pietro Pedeferri and Rob Polder.

4.      Galvanized Steel Reinforcement in Concrete, edited by Professor Stephen R. Yeomans and Elsevier Science Ltd. in the UK. First edition.

5.      Hot Dip Galvanizers Association Southern Africa web site www.hdgasa.org.za.