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Abstract: The estimation of zinc protective layer thickness (or corrosion life) on steel substrate provides a key part for the optimum selection of zinc coating thickness that is tailored to the specific outdoor environmental conditions at the location for the requisite design life of steel structures. In this study, the estimation of first-year corrosion rate and/or corrosion thickness loss of zinc protective layer on steel substrate has been done using the methodology outlined in ISO 9223 and 9224 based on dose-response function for sixteen sites representing diverse outdoor atmospheric conditions. The results apparently revealed that the estimated first-year corrosion rate of zinc was lowest in the rural atmosphere followed by the urban-industrial, mixed, and marine atmosphere; however, it is not so for every site and in every case due to the stochastic character of corrosion as it depends on various environmental factors. The comparative analysis of estimated and observed first-year corrosion rate of zinc layer revealed that the variation was within ±13% (-0.36 to +0.17 µm) at 26.67% sites, ±45% (-0.22 to +0.46 µm) at 33.33% sites and ±87% (-0.23 to +1.98 µm) at 20% sites; and very high observed corrosion rate up to 213% (-5.84 to -1.01 µm) at 13.33% sites and up to 750% (-2.90 µm) at 6.67% sites. Thus, about 60% of the sites have an uncertainty level of zinc within expected and acceptable limits as per ISO 9223. Further, based on the estimated first-year corrosion rate of the zinc layer, atmospheric corrosivity categories have been assigned to the sites as per ISO denomination. Thereafter, the corrosion thickness of the zinc layer required for steel structures has been estimated on a short- and long-term (>20 years) basis for the sites.

Keywords: atmospheric corrosion; steel structures; zinc protective coating; ISO 9223 and 9224

1. Introduction

Occupational Steel structures have wide application in infrastructural development due to their constructability, fire resistance and high strength-to-weight ratio. Apart from its conventional application in the areas of structural buildings[1], bridges, automotive frame parts, trains, ships, pipes, machines and/or their parts, etc., steel has adapted to the speed of innovations in the telecommunication and energy sectors as well that includes tower structures for power transmission and cellular networks, windmills, wave power systems, solar panels and panel mounting structures[2], transformation stations, etc. Despite the wide applicability, the infrastructural damage of steel structures due to the natural phenomenon of atmospheric corrosion is a serious problem that results in huge economic losses to the tune of about USD 2.5 trillion per year which is about 3.44 % of global GDP[3), 4), 5)]. The most significant effects of corrosion include catastrophic structural/equipment failures – such as the Genoa bridge collapse in Italy, the sinking of Erika oil tanker, Bhopal tragedy due to escape of toxic gases, etc.[6), 7)]; deterioration of historic monuments – such as Eiffel Tower: Paris (France), Brooklyn Bridge: New York (USA), Sydney Harbour Bridge (Australia), Howrah Bridge: Kolkata (India), and many more; increased carbon footprint of steel – corroded steel represents about 4-9% of steel's carbon footprint[8)]; and social losses including wastage of human effort[9)].

Corrosion, in general, is the deterioration of a material (generally a metal) due to the chemical reaction of the material with its environment; whereas atmospheric corrosion refers to the corrosion of a material that occurs in the presence of air and moisture, which are commonly found in the atmosphere, that is natural outdoor environment[10)]. Corrosion reduces the effective cross-section of structural components that in turn reduces the axial, and flexural strength of elements, and makes them structurally weak[11), 12)]. This implies that environmental conditions conducive to atmospheric corrosion are detrimental to the functionality of steel structures[13)] by corroding them much before reaching their design life in the absence or lack of protection against corrosion. In order to minimize corrosion damage and resultant economic and environmental costs, it is necessary to use a protective coating on steel substrate of suitable material having excellent metallurgical properties including corrosion behaviour[14), 15)]. Galvanized steel (steel with a protective coating of zinc to prevent rusting) is widely used to ensure longevity of the steel structures that are vulnerable to atmospheric corrosion due to their constant exposure to corroding elements – temperature, humidity, precipitation, time of wetness[16)], and atmospheric pollutants such as sulphur dioxide, chloride and nitrogen oxides[17)]. Zinc protective coating provides a two-fold protection of steel substrate. Firstly, it forms a physical barrier around the steel substrate and thus protects its rusting from atmospheric corroding elements. Secondly, it provides galvanic protection at defects, cut-edges, breached or punctured areas extending through zinc coating[18), 19)] due to the formation of compact zinc corrosion products[20)] that adhere to the steel substrate and protect it from atmospheric corrosion. Additionally, zinc coating is cost-effective[21)], has ease of manufacturing and workability, low toxicity[22)], is available in a wide range of different finishes from bright gleam to textured surfaces, and ideal primer layer for painted components[23), 24)].

There have been studies on atmospheric corrosion in general and also on the evaluation of the corrosion rate of zinc coating on steel substrate under laboratory and actual conditions. Galvanized steel corrosion behaviour was examined by Pokorny et al.[25)] in simulated real-world atmosphere exposure, and recommended for enhanced zinc coating compositions for the longer service life of steel structures. Pop et al.[26)] studied the corrosive behaviour of zinc coatings for corrosion protection and steel substrates under various exposure scenarios using low-carbon steel specimens. Gocal and Odrobinak[27)] in their study of riveted steel bridges reported a practically linear course of decreasing cross-sectional area and load-carrying capacity of steel bridge elements due to increasing corrosion losses over the period. The experimental study, at a laboratory scale using weight loss technique and polarization measurement, reported that corrosion performance depends on the initial thickness of zinc coating and the corrosion rate of mild steel increases with a decrease in zinc coating thickness in a marine environment[24)]. Thierry et al.[18)] studied the performance of hot-dipped galvanized (HDG) steel and Zn-5%Al-coated steel at ten worldwide locations exposed to different atmospheric weathering conditions, and reported that Zn-5%Al protective coating was more effective than HDG over the period of six years of exposure, and was less dependent on environmental conditions (such as temperature, relative humidity and chloride deposition). The corrosion effects study of road or railway steel bridges, twelve in the Zilina region of Slovakia and eleven in the Silesia region of Poland for six and three years respectively, observed that polluted air was more aggressive in causing corrosion coupled with the impact of average temperature and rainfall; and emphasized on the long-term studies[28)]. Atmospheric corrosion of painted galvanized and Zn-55%Al steel sheets was studied for twelve years of exposure to the urban atmosphere at the La Plata site in Argentina[29)]. The Ibero-American Map of Atmospheric Corrosiveness (MICAT) project, covering 75 sites in fourteen countries, was the landmark study in the area of atmospheric corrosion that covered a broad spectrum of atmospheric conditions – climatological and air pollution conditions, for the study of corrosion specimens of mild steel, zinc, aluminium and copper exposed for one year in different rural, urban and marine environment[30)]. Despite all the efforts and work in the field of atmospheric corrosion, it is very difficult to carry out experimental studies on a long-term basis in diverse atmospheric/environmental conditions due to practical constraints. Therefore, the estimation/prediction of zinc protective layer thickness (or corrosion life) on steel substrate provides a key part for the optimum selection of coating thickness for steel structures that are tailored to the specific outdoor environmental conditions at the location for the requisite design life of steel structures. Most of the methods or models developed to estimate the life of galvanized steel in outdoor environmental conditions are based on the Geographic Mapping Method or Regression Models. The Geographic Mapping Method is the most reliable being based on field data but its utility is limited to the area suitably mapped for the purpose[31)]. Regression Models are based on historical meteorological and air pollution data but their utility is generally limited due to the diversity of outdoor environmental conditions and paucity of data of multiple parameters[32), 33)]. All the models used in the estimation/prediction of zinc protective layer thickness (or corrosion life) on steel substrate have the inherent drawback in the form of lack of data over a long period in diverse atmospheric environments[34)].

In the present study – (i) a quantitative estimation of annual and long-term corrosion loss of protective zinc layer under varying location-specific outdoor environmental conditions has been carried out for selected sites by using methodology outlined in ISO standards[35), 36)]; and (ii) a comparison of observed and estimated first-year corrosion rate of zinc protective layer in view of level of uncertainties has been presented. The paper also focuses on the utility of estimation of zinc protective layer by ISO methodology based on dose-response function from the atmospheric (meteorological and pollution) data that include temperature, humidity, sulphur dioxide deposition/concentration, and chloride deposition.

2. Materials and methods

2.1 Exposure sites

In the present study, 16 sites have been selected for analysis and evaluation which were part of the 75 atmospheric exposure test sites under the Ibero-American

Map of Atmospheric Corrosiveness (MICAT) project during the period August 1988 to December 1994. The sixteen sites are selected such that they represent various types of outdoor atmospheres (Table 1) as defined by Morcillo et al.[30] and are based on deposition rates of chloride and sulphur dioxide as per ISO 9223 denomination[30]. The atmospheric environments (S_xP_y) are classified in ten categories by Morcillo et al.[30] by sub-dividing the four broader types of atmosphere classified by ISO so as to cover a broad spectrum of climatological and pollution conditions. In the present study, the selected 16 sites represent eight types of atmosphere (Table 1). The sites having S_2P_2 and S_3P_0 types of atmospheres, representing extreme marine and mixed atmospheres respectively, were not considered due to lack of data availability of such sites. However, marine atmosphere is being represented by S_1P_0 (3 sites) and S_2P_0 (1 site); and mixed atmosphere is being represented by S_1P_1 (4 sites), S_1P_2 (1 site) and S_2P_1 (1 site). The locations of the 16 Ibero-American sites (13 in Central and South America, and 03 in Western Europe) are presented in Fig. 1.

2.2 Data source

The temperature and relative humidity data of the studied sites for the period 2001 to 2013 was obtained from Global Weather Data, the SWAT tool developed by the National Centers for Environmental Prediction (NCEP) that carries out Climate Forecast System Reanalysis (CFSR), by taking permission for accessing and downloading the required weather data[37].

Ibero-American Map of Atmospheric Corrosiveness (MICAT) database[30] has been referred for the annual daily deposition rates of sulphur dioxide (SO_2) and chloride (Cl^-) in $mg/m^2.d$.

The data was organized and structured so that it can be integrated into the dose-response functions for computing corrosion rate and corrosivity estimation in a systematic way as per international standards, namely ISO 9223[35] and ISO 9224[36].

Table 1. Type of atmosphere as classified by Morcillo et al.[30] based on ISO 9223[35] denomination.

Type of Atmosphere	Denomination as per ISO 9223	Deposition Rate $[mg/(m^2 \cdot d)]$	
	S_xP_y	Cl^- (S_d)	SO_2 (P_d)
Rural atmosphere	S_0P_0	≤3	≤10
Urban and Industrial atmospheres	S_0P_1	≤3	10<P_d ≤35
	S_0P_2	≤3	35<P_d ≤85
Marine atmospheres	S_1P_0	3<S_d ≤60	≤10
	S_2P_0	60<S_d ≤300	≤10
	S_3P_0	300<S_d ≤1,500	≤10
Mixed atmospheres	S_1P_1	3<S_d ≤60	10<P_d ≤35
	S_1P_2	3<S_d ≤60	35<P_d ≤85
	S_2P_1	60<S_d ≤300	10<P_d ≤35
	S_2P_2	60<S_d ≤300	35<P_d ≤85

2.3 Methodology

The atmospheric corrosion of the zinc layer or any metal at a specific location depends on four key factors, namely temperature, relative humidity, and dry depositions of sulphur dioxide and chloride[35]. The first-year corrosion rate of zinc at each of the sites is estimated by following the ISO methodology[35] based on dose-response functions using the following equations:

$$r_{corr,est} = 0.0129 \cdot P_d^{0.44} \cdot \exp(0.046 \cdot RH + f_{Zn}) + 0.0175 \cdot S_d^{0.57} \cdot \exp(0.008 \cdot RH + 0.085 \cdot T) \quad (1)$$

$$f_{Zn} = 0.038 \cdot (T - 10) \quad \text{when } T \leq 10°C \quad (2a)$$

otherwise,

$$f_{Zn} = -0.071 \cdot (T - 10) \quad \text{when } T > 10°C \quad (2b)$$

Zinc specimen details: N=114 (model number); R2=0.78

Fig. 1: Locations of studied Ibero-American sites.

where,

$r_{corr,est}$: estimated first-year corrosion rate of zinc, in micrometres per year ($\mu m/a$);

T : annual average temperature, in degrees Celsius (°C);

RH : annual average relative humidity, in percentage (%);

P_d : annual average SO_2 deposition, in milligrams per square meter per day [$mg/(m^2 \cdot d)$];

S_d : annual average Cl^- deposition, in milligrams per square meter per day [$mg/(m^2 \cdot d)$].

Based on the first-year corrosion rate of zinc at a specific location, the corrosivity of the atmosphere is categorized into six categories from C1 to CX by ISO 9223 standards[35] as shown in Table 2.

Table 2. Categories of corrosivity of the atmosphere for zinc as per ISO 9223[35].

Category	First-year corrosion rate (r_{corr}) [$\mu m/a$]	Corrosivity
C1	$\leq$ 0.1	Very low
C2	0.1 < r_{corr} $\leq$ 0.7	Low
C3	0.7 < r_{corr} $\leq$ 2.1	Medium
C4	2.1 < r_{corr} $\leq$ 4.2	High
C5	4.2 < r_{corr} $\leq$ 8.4	Very High
CX	8.4 < r_{corr} $\leq$ 25	Extreme

The total attack (D), expressed as penetration depth or mass loss per unit area is estimated by following the ISO methodology[36] using the following equations for short-term (up to 20 years) and long-term (beyond 20 years) exposures:

$D = r_{corr,est} \cdot t^b$ when exposure is up to 20 years. (3a)

$D = r_{corr,est} \cdot [20^b + b \cdot (20^{b-1}) \cdot (t - 20)]$ (3b)
when exposure is greater than 20 years.

where,

D : corrosion thickness loss of zinc layer, in μm [also expressed in Mils, 1 Mils~ $(1\mu m/25.4)$];

$r_{corr,est}$: estimated corrosion rate experienced during the first-year, in micrometers per year ($\mu m/a$), in accordance with ISO 9223[35];

t : exposure time, in years; and

b : metal-environment-specific time exponent (taken as 0.873 for zinc alloys as per IS 9224[36]).

The estimated total mass loss per unit area or penetration depth (D), coating in terms of 'zinc thickness' is applied to protect the steel structure exposed to the natural outdoor atmosphere for a total period of project life.

3. Results and discussion

For systematic analysis, the dose-response functions or input parameters were used to estimate first-year corrosion loss (r_{corr}) for the zinc layer followed by estimation of short-term and long-term coating thickness loss (D) of the zinc protection layer.

3.1 First-year corrosion loss for zinc protection layer

The estimated first-year corrosion loss ($r_{corr,est}$) by using Eq. (1) for the studied sites is presented in Table 3 along with the type of atmosphere ($S_x P_y$) as categorized by Morcillo et al.[30] based on ISO 9223 denomination[35], observed first-year corrosion loss ($r_{corr,obs}$) by Morcillo et al.[30], dose-response functions or input parameters for Eq. (1), and atmospheric corrosivity category of the sites based on estimated first-year corrosion loss ($r_{corr,est}$) as per ISO 9223 categorization[35].

A glance at the results (Table 3) reveals that the estimated first-year corrosion rate ($r_{corr,est}$) of zinc was lowest in the rural atmosphere (S_0P_0) followed by the urban industrial atmosphere (S_0P_1 and S_0P_2), mixed atmosphere (S_1P_1, S_1P_2 and S_2P_1) and marine atmosphere (S_1P_0 and S_2P_0). However, it is not so for every site and in every case. This is due to the stochastic character of corrosion as it depends on various environmental factors, such as average temperature, relative humidity, precipitation, air pollutants (particularly chloride and SO_2) characteristics and concentration, etc. The estimated first-year corrosion rate of zinc is in line with the observed first-year corrosion rate of zinc by Morcilloo et al.[30] as shown in Table 3.

Based on ISO 9223[35] categories, three sites having rural atmosphere (S_0P_0) fall under C2 atmospheric corrosivity category accounting for r_{corr} =0.32-0.56 $\mu m/a$; whereas, the La Plata (Argentina) site falls under C3 category ($r_{corr,est}$=0.85 $\mu m/a$) due to higher SO_2 deposition rate possibly due to some industrial activity around the site. The two sites having an urban industrial atmosphere, namely Potosi, Mexico (S_0P_1) and Sao Paulo, Brazil (S_0P_2) fall under the C3 category having $r_{corr,est}$=0.76 and 1.63 $\mu m/a$ respectively. The three sites having a marine atmosphere of type S_1P_0 exhibited diverse first-year corrosion rates ($r_{corr,est}$=0.52-2.28 $\mu m/a$). Coro, Venezuela site (S_2P_0 type atmosphere) showed a higher corrosion rate and falls under corrosivity category C4, in comparison to the other two sites having similar type of atmosphere probably due to relatively higher exposure to the marine environment. Limon, Costa Rica site having S_2P_0 type marine atmosphere showed the highest corrosion rate of 6.09 $\mu m/a$ falling under very high corrosivity category C5 due to high exposure to marine environment as is reflected from very high Cl^- deposition rate of 220 $mg/(m^2 \cdot d)$ and may also be due to high time of wetness (TOW) as pointed out by Morcillo et al.[30]. Three sites having mixed atmosphere (S_1P_1) fall under C3 atmospheric corrosivity category accounting for $r_{corr,est}$=1.02-1.52 $\mu m/a$ due to industrial activities; whereas, the V. Salvador (Peru) site falls under high corrosivity category C4 having $r_{corr,est}$ of 2.35 $\mu m/a$ possibly due to exposure to marine environment as well. Petrox, Chile site having a mixed atmosphere of type S_1P_2 falls under high corrosivity category C4 mainly due to

Table 3. Site Characteristics including dose-response functions, along with estimated first-year corrosion loss and atmospheric corrosivity category. (Data source: Morcillo et al.[30] for data in column 3,4 and 5; and Global Weather Data[37] for data in column 6 and 7).

Site	Type of Atmos-phere	Observed First-year Corrosion Rate of Zinc[30] $(\mu m/a)$	Dose-Response Functions (Input Parameters)				Estimated First-year Corrosion Rate of Zinc as per Eq. 1 $(\mu m/a)$	Atmospheric Corrosivity Category
			Annual Average Deposition Rate[30] $[mg/(m^2 \cdot d)]$		Annual Average Temperature[37] (℃)	Annual Average Relative Humidity[37] (%)		
	S_xP_y	$r_{corr,obs}$	Cl^-	SO_2	T	RH	$r_{corr,est}$	
1	2	3	4	5	6	7	8	9
La Plata, Argentina	S_0P_0	0.91	2.5	6.9	17.56	77	0.85	C3
San Pedro, Colombia		3.29	0.7	0.6	19.31	83	0.39	C2
Guayaquil, Ecuador		0.21	1.5	3.0	24.89	75	0.56	C2
Trinidad, Uruguay		0.55	1.5	0.7	17.37	68	0.32	C2
Potosi, Mexico	S_0P_1	1.77	2.6	18.9	20.53	66	0.76	C3
Sao Paulo, Brazil	S_0P_2	1.21	2.4	57.8	21.44	79	1.63	C3
Melo, Uruguay	S_1P_0	0.69	3.8	0.7	18.74	75	0.52	C2
Coro, Venezuela		0.30	27.5	6.5	27.79	67	2.28	C4
Pego, Portugal		1.15	6.0	7.9	16.61	73	0.93	C3
Limon, Costa Rica	S_2P_0	…….	220.0	3.5	23.7	86	6.09	C5
Bauta, Cuba	S_1P_1	1.22	6.4	16.4	24.57	80	1.39	C3
Panama, Panama		1.06	9.8	21.7	27.78	69	1.52	C3
V. Salvador, Peru		2.46	38.0	18.0	17.02	82	2.35	C4
Barcelona, Spain		0.56	4.4	16.7	15.42	70	1.02	C3
Petrox, Chile	S_1P_2	8.58	12.8	65.2	12.55	77	2.74	C4
Sines, Portugal	S_2P_1	4.03	203.0	27.0	17.48	71	3.67	C4

high industrial activities; whereas, Sines, Portugal having a mixed atmosphere of type S_2P_1 also falls under high corrosivity category C4 but mainly due to marine environment as is evident from very high Cl^- deposition rate of 203 $mg/(m^2 \cdot d)$. The above results, that is variation in zinc corrosivity rates at different sites, approve the randomness of corrosion[28].

The determination of the corrosivity of atmospheric environments can be based either on the exposure of metal specimens or by estimation based on environmental parameters and the use of the dose-response function. So, two different levels of uncertainties – low uncertainty (observed exposure of specimen) and high uncertainty (estimation by dose-response function) are expected. As per ISO 9223[35], the level of uncertainty for zinc are – low uncertainty: ±5% and high uncertainty: -33% to +50%. Further, the environmental parameters vary with time due to natural and anthropogenic factors. In view of this, the observed first-year corrosion rate ($r_{corr,obs}$) by Morcillo et al.[30] and estimated first-year corrosion rate ($r_{corr,est}$)

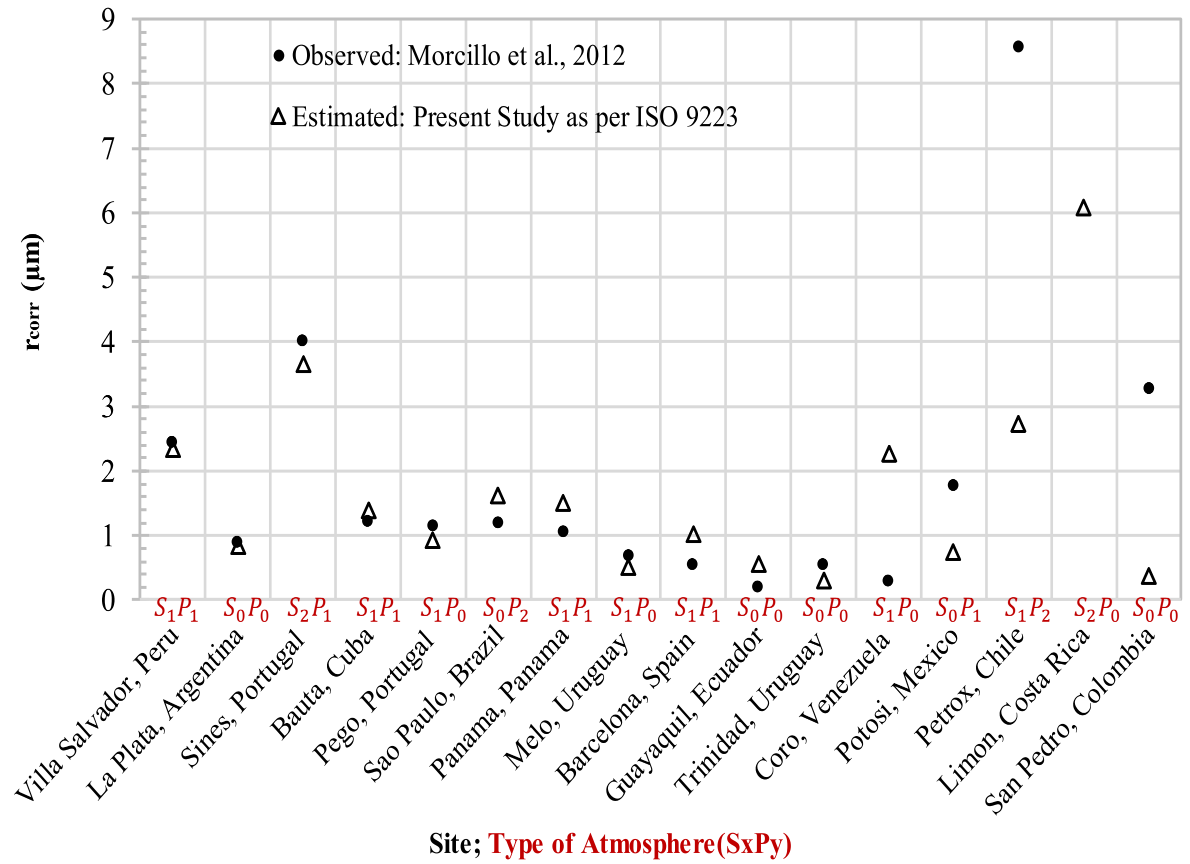

Fig. 2: Site-specific observed ($r_{corr,obs}$) and estimated ($r_{corr,est}$) first-year corrosion rate of zinc.

by Eq. 1 as per ISO 9223[35)], were compared as shown in Fig. 2. The comparative analysis of the 15 studied sites (observed data of 1 site: Limon, Costa Rica is not available in the data source paper) revealed that the variation was within ±13% (-0.36 to +0.17 µm) at 26.67% of the sites, ±45% (-0.22 to +0.46 µm) at 33.33% of sites and ±87% (-0.23 to +1.98 µm) at 20% sites; and very high observed corrosion rate up to 213% (-5.84 to -1.01 µm) at 13.33% sites and up to 750% (-2.90 µm) at 6.67% sites. Thus, about 60% of the sites have uncertainty of zinc within expected and acceptable limits as per ISO 9223[35)].

With respect to the type of atmosphere, $r_{corr,est}$ was in the range of -10 to +45 % for S_1P_1 and S_2P_1 sites having a mixed atmosphere, -24 to +87 % for S_1P_0 having a marine atmosphere, about +26% for S_0P_2 site having an urban industrial atmosphere, -72 to +63 % for S_0P_0 having rural atmosphere barring San Pedro, Colombia. The estimated first-year corrosion rate ($r_{corr,est}$) by ISO methodology (Eq. 1) is much less as compared to $r_{corr,obs}$ for three sites, namely San Pedro, Colombia (-743.59%) having rural atmosphere (S_0P_0), Petrox, Chile (-213.14%) having mixed atmosphere (S_1P_2) and Potosi, Mexico (-132.89%) having urban industrial atmosphere.

3.2 Short- and long-term estimation of corrosion loss for the zinc protection layer

In natural outdoor atmospheres, the corrosion rate of exposed metals and alloys (including zinc) is not constant and is usually observed to be linear. The short-term (≤ 20 years of exposure) and long-term (> 20 years of exposure) corrosion thickness loss of the zinc layer (D, in µm) is estimated by Eqs. 3a and 3b respectively for all the 16 sites, and presented in Fig. 3.

As a principle, the corrosion rate of all metals exposed to a natural outdoor environment is not constant with exposure time. To study the variation of corrosion rate, the short-term corrosion rate (exposure up to 20 years) and long-term corrosion rate (exposure more than 20 years) of the zinc coating layer (D) estimated by Eq. 3a and Eq. 3b respectively as per ISO methodology[35), 36)] is plotted against the exposure time in Fig. 4 for randomly selected six sites having different type of atmosphere category. Further, the corrosion rate trend with exposure time has been presented separately for short-term and long-term exposure for apparent analytical clarity. The progress of zinc layer corrosion is observed to be linear with exposure time – both in short-term and long-term exposure, but the corrosion rate will be higher during long-term exposure. The results are in line with the principle of corrosion rate of metals as outlined in ISO 9224[36)] and as a principle that

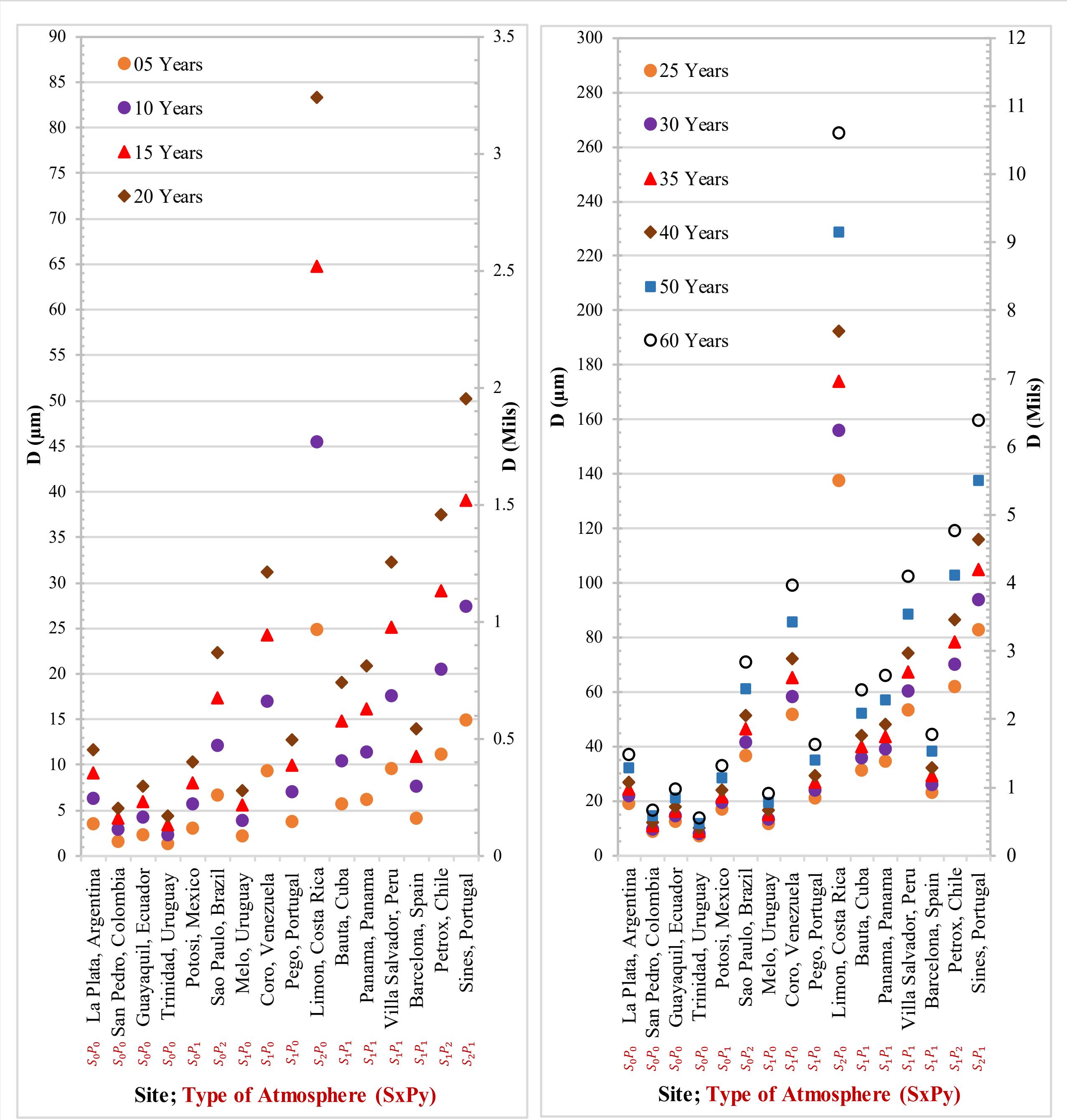

Fig. 3: Site-specific estimated corrosion thickness loss of zinc layer (a) short-term, (b) long-term.

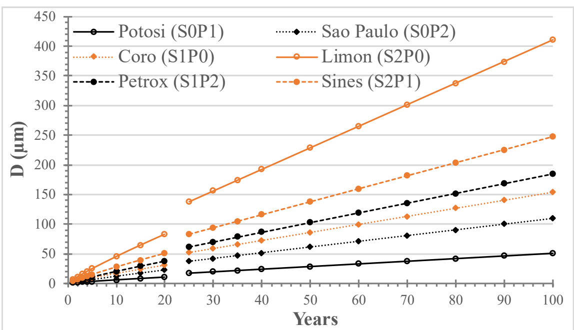

Fig. 4: Linear progress of zinc layer corrosion with exposure time.

the corrosion rate of metals exposed to a natural outdoor environment is not constant with exposure time. However, a linear corrosion rate in natural conditions is practically not possible. Despite the limitations and constraints posed by varying atmospheric/climatic conditions, the ISO methodology provides an approximation that needs to be monitored and regular maintenance of structures is suggested.

4. Conclusion

The Corrosion life prediction provides a key part of the optimum selection of zinc coating thickness for steel structures designed to serve for several decades in diverse and varying environments. The estimated first-year corrosion rate of zinc by ISO methodology is in line with the observed first-year corrosion rate of zinc at the studied sites. Both – estimated and observed first-year corrosion rates of zinc were apparently lowest in the rural atmosphere (S_0P_0) followed by the urban industrial atmosphere (S_0P_1 and S_0P_2), mixed atmosphere (S_1P_1, S_1P_2 and S_2P_1) and marine atmosphere (S_1P_0 and S_2P_0). However, it is not so for every site and in every case. This is due to the stochastic character of corrosion as it depends on various environmental factors, such as average temperature, relative humidity, precipitation, air pollutants (particularly chloride and SO_2) characteristics and concentration, etc. The variation in the absolute values of estimated and observed first-year corrosion rate of zinc is due to two different levels of uncertainties – low uncertainty (observed exposure of specimen) and high uncertainty (estimation by dose-response function). The study exhibited the utility of estimating annual, short- and long-term atmospheric corrosion of zinc protective layer on steel substrate structures using the dose-response function-based methodology outlined in relevant ISO standards from the atmospheric (metrological and pollution) data under varying location-specific outdoor environmental conditions. However, the ISO methodology has certain limitations that needs to be addressed. Such as – the atmospheric environments (S_xP_y) needs to be sub-classified in more categories so as to cover a broad spectrum of climatological and pollution conditions; and additional metrological and air pollution parameters needs to be considered in the dose-response function. But despite the limitation and constraints posed by varying atmospheric/climatic conditions, the ISO methodology is widely used all over the world.

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Nomenclature

μm	micrometers
$\mu m/a$	micrometers per annum/year
℃	degrees Celsius
b	Metal-environment-specific time exponent
C1 to CX	Category of corrosivity of the atmosphere
d	day
D	Corrosion thickness loss of zinc layer, in μm or Mils
m^2	Square meters
mg	milligram
P_d	Annual average SO_2 deposition, in $mg/(m^2 \cdot d)$
r_{corr}	First-year corrosion rate of zinc, in $\mu m/a$
$r_{corr,est}$	Estimated first-year corrosion rate of zinc, in $\mu m/a$
$r_{corr,obs}$	Observed first-year corrosion rate of zinc, in $\mu m/a$
RH	Annual average relative humidity, in %
S_d	Annual average Cl^- deposition, in $mg/(m^2 \cdot d)$
S_xP_y	Type of atmosphere based on deposition rate of chloride and Sulphur dioxide
t	Exposure time, in years
T	Annual average temperature, in ℃

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