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Steel Corrosion Map of Vietnam

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In the framework of an International cooperation program in Australia-Asia, the atmospheric corrosion of metals in five nations located in this tropical zone: Australia, Vietnam, Thailand, Philippines and Indonesia was investigated. In this program, mild steel, zinc and copper were tested on a set of sites, representative for different climatic conditions: severe marine, marine, industrial, urban and rural, simultaneously with the collection of climatic parameters and pollutants. Based on the data obtained in the Program and referring to the bank of data collected in the Vietnam National Projects, modeling was used to construct a corrosion map of steel for Vietnam. The correlation of the data derived from the map compared with those from National Projects is very high, in most cases, differing by less than 2-3%.

Keywords *: corrosion, natural testing, site, corrosion modeling, corrosion map*

1. Introduction

In humid tropical countries such as Vietnam, metal corrosion caused by the natural atmospheric environment is a problem that results in large costs to the national economy. The Natural Institute of Vietnam was established in 1960; and as early as 1963 samples for a corrosion study were tested in a number of sites in North Vietnam. Since then, there have been several National and Ministerial Projects also focused on the investigation of metal corrosion. The first attempt to construct a corrosion map for Vietnam was carried out in the atmospheric corrosion group, at the Institute for Tropical Technology of Vietnam. P. T. San, N. V. Hue and L. T. H. Lien published the first paper in this direction in APCCC-9 in Kaoshung, Taiwan, 1995.[1)] In this paper, based on the testing results obtained in the National Project numbered 48.08.01 and others,[2)] the mathematical terms and corrosion modeling were developed and used to construct the corrosion map for North Vietnam. The map constructed corresponded adequately to the corrosion rates of mild steel in the Vietnam environment.

In the International Program of Australia - Asia, atmospheric corrosion of mild steel, zinc, and copper in twenty sites over 5 countries: Australia, Vietnam, Thailand, Philippines and Indonesia, was investigated.[3)] The aim of the Project was to develop the understanding of the fundamental mechanism of corrosion in tropical climates. This is done by studying the level and characteristics of corrosion of common metals in the geographic zone; and the surface morphology of samples after testing in order to determine the relationship between the chemistry of corrosion products and environmental factors. Based on the results obtained, a model of the corrosion process is created for assessment of corrosion kinetics and construction of a corrosion map.

2. Experiments

2.1 Testing samples and testing procedure

To select the data for corrosion mapping, metal coupons of mild steel (bellow - steel), zinc and copper, sized 10 x 16 x 1 (mm) were prepared at CSIRO. Coupons were exposed at 45° to the vertical and faced towards the sea. The testing period was 1, 3, 6, 9, 12, 24 and 36 months (3 samples/site/time/metal). Samples after testing were treated and analyzed at CSIRO. Analysis consisted of mass loss determination, and Fourier Transform Infrared Spectroscopy - FTIR, Field Emission Scanning Electron Microscopy - FESEM and Scanning Electron Microscopy - SEM to determine the nature of the corrosion products..

Atmosphere/surface temperature, humidity, rainfall, solar radiation, and sunlight total time were recorded continuously by Datalogger and downloaded to computer.

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Salinity and soluble particulates in the atmosphere were collected by the wet candle technique, SOx and NOx were measured by passive gas.[4),5)] Sites in Vietnam were Hanoi (Phuthuy), Doson, Hue, Nhatrang and HoChiMinh City. These were selected as being representative for different climatic conditions: severe marine, marine, industrial, urban and rural.

2.2 Basic disciplines for corrosion mapping

Corrosion maps are traditionally constructed using two basic methods. Both methods are based on the field observation from a set of sites distributed within the study area and located in such a way that they are representative of the variability of the corrosion rates within the study area.

If enough data points are available, the most straightforward approach is to construct a contour consisting of lines of equal corrosion rate. In this approach, arranging the sites in some sort of grid pattern is desirable. This approach was used in producing corrosion maps for Australia and other countries (eg. Spain, Japan, Czech Republic, Korea) 6-9]. Unfortunately this approach is very costly both in financial terms and in the time taken. Where there are not enough data points to adequately cover the spatial extent of the study area, an alternative approach is to construct a statistical or parametric model. Some examples of this approach include:

1) Corrosion as a hyperbolic function of distance from the coast (G. King)[10)]
2) Corrosion as a function of distance from the coast and level of sulfur dioxide (G. Trinidad)[11)]
3) Corrosion as a function of distance from the coast, climatic factors, level of salinity and geometrical parameters (P T San)[1),9)]
4) Corrosion as a function of distance from the coast, relative humidity and temperature (and salinity) (I. Cole).[12)]

Selecting the set of variables to be considered is difficult and could vary from one case to another. To overcome these difficulties, a new approach to the construction of corrosion maps should be investigated.

2.2.1 Method based on the humidity temperature complex

Studies on atmospheric corrosion showed that humidity, temperature, salinity, and sulfur content all have an effect on the corrosion of metals, particularly steel. In the developing countries and eastern European countries, sulfur dioxide content in the atmosphere may be high, in Prague (Czech Republic) the level is about 67 mg/m^3,[8)] whilst humidity and salinity is low, so the sulfur content is the main factor affecting the metal corrosion. In the countries surrounded by sea (for example Cuba) the salinity is very high (at Havana: 200 mg/m^2/day) and distributed far from the coastline, so the salinity in the atmosphere is the determining factor for metal corrosion.[13)]

According to[14)] and data obtained in the AusSEA Project, the salinity in the Vietnam atmosphere is relatively low, with chloride levels of about 2-3 mg/m^2/day in the North and 40 mg/m^2/day in the South at a distance of 1-3 km from the coastline. Elsewhere the salinity is negligible. (For comparison at Australia's coastline, chloride levels are about 110 mg/m^2.day). However sulfur dioxide levels are also very low with the highest values found at Hanoi is 7 mg/m^3 while the level at Nhatrang: 0.3 mg/m^3. Based on these findings, it is suggested that the humidity and temperature combination is the prime factor controlling corrosion in Vietnam with some influence of salinity.

2.2.2 Method based on holistic model

To reduce the dependence on expensive, and sometimes impractical, field experiments, corrosion rates will be estimated by simulating the corrosion process itself.

As an initial calculation, I. Cole and colleagues[14),15)] have suggested that the corrosion rate in a particular site is computed using the following steps:

1) The coastline is represented as a series of points (x, y).
2) Each point is associated with a particular coast type in order to reflect surf and ocean salt production.
3) The study area is partitioned into wind regions such that the wind pattern within a region is uniform.
4) Each region is associated with one or more wind rosettes.
5) A particular site is associated with the nearest wind rosette associated to wind region where the site belongs
6) A particular site is associated with a set of coastline points by performing a radial search using a pre-determined threshold distance. For example, if the threshold distance is set to 1000 km, a circle with a 1000 km radius is drawn around the site and all coastline points within this circle are associated with the site.
7) Each of the coastline points associated with a site could possibly contribute to the amount of salt that can be transported from the coast to the site.
8) The amount of salt transported to the site is estimated using the distribution pattern of both wind direction and speed as derived from the selected wind rosette. The only other factor that is considered aside from the wind is distance. The form of topography is ignored (flat land is assumed). The effect of topography and climate in salt transport will be considered

in the next stage.

After estimating the amount of salt transported to the site, the available moisture is estimated using relative humidity, temperature, wind speed and rainfall at the site. Note that relative humidity, temperature and rainfall are related to the amount of moisture while wind speed and temperature are related to the rate of drying. Other factors such as condensation and cloud cover will be considered in the next stage of the modelling.

3. Results and discussion

3.1. Steel corrosion map construction

Based on these principles, the data were processed and steel corrosion maps for Australia and Vietnam were constructed. These are shown in Fig. 1 and 3. The Australia map is computed for steel at each of the 10,000 selected Australia towns. The resulting map is compared with known data points (75 sites). The corrosion map for Vietnam is based on the data selected from 8 sites.

The corrosion rate derived from the map is satisfactory, but with some unexpected results. For example, in the Mekong River Delta, the corrosion is in a similar high category to that found near the coastline. Subsequently, the high corrosion rate in this region was confirmed by the testing Project described by Corrosion Department in National University of HoChiMinh City.[16)]

To improve the accuracy of the map making, a new principle for corrosion mapping based on so-called "Dimensional Spatial Interpolation for Corrosion" was developed.

It was also observed that a simple spatial interpolation technique could possibly approximate the result of the holistic model if there are enough available data points. The method is essentially "Inverse Distance Weighting - IDW" with boundary clipping. The principles are as follows:

1) A set of 5 x 5 km grids is constructed (>80,000 grids are needed to cover Australia).
2) The value of each grid, Gi is computed as:

$$G_i = \frac{\sum_{i=1}^{n} \frac{P_j}{(d_{i,j})^{\beta}}}{\sum_{j=1}^{n} \frac{P_j}{(d_{i,j})^{\beta}}}$$

Where P_j is the value at data point j, $d_{i,j}$ is the spherical

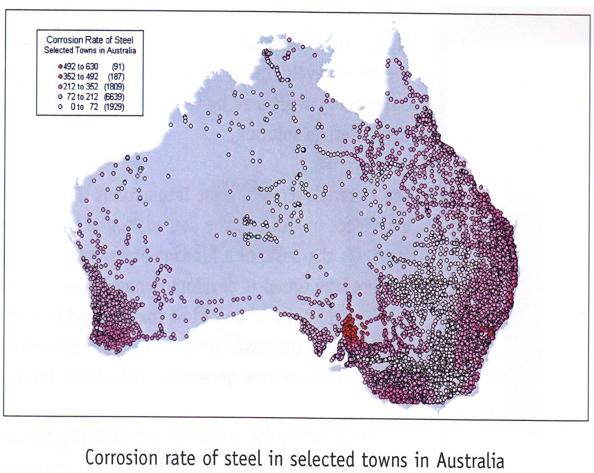

Fig. 1. Corrosion map of Australia by statistic model.

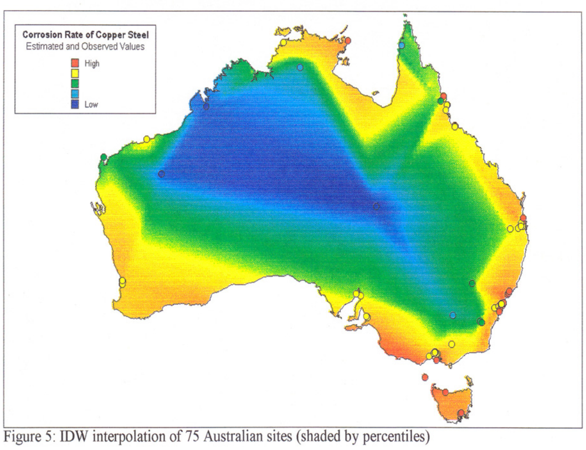

Fig. 2. Corrosion map of Australia by IDW model.

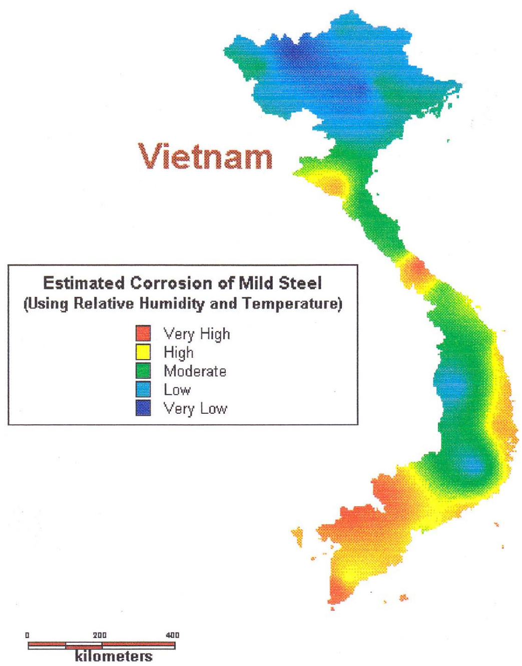

Fig. 3. Corrosion map of Vietnam by Holistic Model.

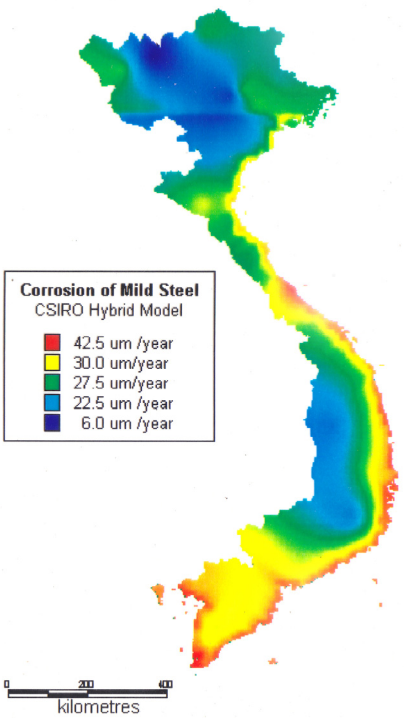

Fig. 4. Corrosion map of Viet nam by IDW Model.

Table 1. The comparison of data from map and other Projects

No	Site	Classification	Corrosion rate of steel after 1 year testing (μm/year)		
			From Map	48.08.01[2)]	KC-02[17)]
1	Vinhphu	Rural	22	21.8	-
2	Hanoi	Urban/Industry	26	25.3	-
3	Haiphong	Urban/Marine	30	24.4	30
4	Vinh	Rural/marine	35	33.2	34
5	Dalat	Rural	22	18.3	-
6	HoChiMinh	Urban/Industry	40	40	42
7	Kiengiang	Marine	40	39.7	-
8	Quangning	Marine	29	-	24
9	Danang	Marine	37	-	34
10	Nhatrang	Marine	40	-	24

distance between grid i and data point j, and β is the weighting power parameter.

3) A pruning strategy could also be included. For example, all data points that are farther than some prescribed distance will be ignored.

The corrosion map derived using a pruning distance of 2,000 km and setting $\beta = 2$ for Australia is shown in Fig. 2 and for Vietnam in Fig. 4.

3.2. A comparison between data from the map and from natural testing

For evaluating the accuracy of the corrosion maps, some corrosion rates in Vietnam conditions are taken from the map and from data summarized in the different National Projects as shown in Table 1.

It can be seen that the data taken from the map and selected from field tests are very similar, with a difference of less than 2-3%. In many cases the corrosion rates cited from the map compare very well with the ones from field tests, as at VinhPhu, Hanoi, HoChiMinh, and Kiengiang. In the case of Nhatrang, the large difference between the mapping estimation and field tests may be due to different locations being used for the testing sites. The new site is located in the Honchong area on a high hill and the old (used to construct the map) is located in the Meteorological Station close to the coastline.

4. Conclusions

For the first time, a corrosion map of steel in atmospheric conditions for the whole of Vietnam has been constructed. The corrosion rates from the map compare well with the reported results from field tests. The accuracy of the map could be improved by considering industrial development as this will affect pollutants., however, the map constructed is satisfactory and useful for the development of the Vietnamese economy and technology.

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