

CORROSION RATE THROUGH MATHEMATICAL MODELS

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ABSTRACT

In any system which involves several variables, it is essential to examine the true functional relationship between response variable and independent variables. Such relationships may be linear, polynomial or exponential. The system involved in marine corrosion is rather enigmatic and is dependent on several parameters. The predictability of corrosion rate in a particular area is based on the understanding of the total system including quantitative relationship. The physico-chemical parameters like dissolved oxygen, salinity, temperature, pH are correlated with corrosion rate by multiple regression analysis for sea water and for marine atmosphere of Goa harbour area. The analysis has given a fairly high coefficient of correlation in both the cases, thus suggesting the compatibility of corrosion rate with synergistic changes in sea water and atmospheric milieu.

INTRODUCTION

A probe into the true functional relationship between response variable and independent variable is essential in any system which involves several variables. Such relationships among dependent and independent variables can be represented by a mathematical model of simple linear, polynomial or exponential type. It is deemed that, such mathematical models would be of immense help in predicting the influence of independent variables on the response variable under certain limitations.

THE MODEL

The system involved in marine corrosion is rather enigmatic and is dependent on host of parameters. The predictability of corrosion rate in a particular area is based on the understanding of the total system including the quantitative relationship between the environmental factors. Hence corrosion rate of a structural material in marine environment can always be represented in a functional form which involves the most significant parameters. The functional form for seawater corrosion may be of the form

$$C^{\circ} = \frac{dc}{dt} = f(O_2, T, S, V, pH, t) \quad \dots (1)$$

where,

- C° = Corrosion rate of steel (Mills/year)
- O_2 = Dissolved Oxygen content (ml/L)
- T = Temperature of seawater ($^{\circ}C$)
- S = Salinity of seawater (P_{pt})
- pH = Acidity/basicity of the corrosive medium
- t = Duration of exposure
- V = Velocity of surrounding seawater

And the functional form for marine atmospheric corrosion may be of the form :

$$C^{\circ} = \frac{dc}{dt} = f(S, R, T, P, t, V) \quad \dots (2)$$

where,

- S = Salt content in air (mgs/m²/day)
- R = Relative humidity (%)
- T = Temperature ($^{\circ}C$)
- P = Pollutant Concentrations
- t = Duration of exposure
- V = Wind velocity

However, the mathematical models presented herein, involve the most important parameters for the initial corrosion behaviour of mild steel.

MODEL FOR UNDER WATER CORROSION

The mathematical model proposed for the corrosion rate of mild steel in the submerged zone of Bombay High area is of the form :

$$C^{\circ} = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \quad \dots (3)$$

where,

a, b_i = Regression Coefficients

x₁ = Parameters that influence corrosion rate

The Parameters considered are,

x₁ = Oxygen content of seawater (ml/L)

x₂ = Salinity of seawater (Ppt)

x₃ = Temperature (°C)

x₄ = pH value

Data for the Analysis

The environmental parameters of Bombay High area and corrosion rate of mild steel are obtained from the Biofouling and Corrosion section, NIO, GOA. The corrosion rate of mild steel was determined for the depths of 2m, 22m, 42m and 62m in Bombay High area by exposing the mild steel specimens. The monthly corrosion rate for nine months (July '83 to March '84) were obtained for all depths. The physicochemical parameters like dissolved oxygen, salinity, temperature, pH of the corresponding depth were determined at the site for all the nine months. These values are correlated with the corrosion rate by multiple regression analysis.

MODEL FOR CORROSION RATE IN ATMOSPHERIC ZONE

Corrosion rate of mild steel in marine atmosphere depends on many factors as stated before. The relative humidity of marine atmospheres will be always above the critical value which is necessary for salt condensation (Sereda, 1974). Hence, it is felt that, the presence or absence of salt (However small the quantity may be) in marine atmosphere is a key factor in the onset of corrosion and also in controlling the corrosion rate. Moreover, the extent of chloride content in the atmosphere has a direct influence on the susceptibility of metals to stress corrosion cracking and severe pitting of steel (Khanna et al, 1986). Many failures in steel structural components, exposed at Reactor Research Centre, Kalpakkam, either in installed condition or during pre-installed conditions were attributed to the atmospheric salinity (Dayal and Gnanamoorthy, 1981). Hence it is necessary to know the salt content of the atmosphere and its functional relationship with the rate of corrosion.

A two variable linear Regression Analysis has been proposed for the atmospheric corrosion of mild steel.

Data for the Analysis

Data were collected by experimentation. The specimens were exposed at four different levels in the marine atmosphere of Goa Harbour area (Fig. 1a & 1b). The specimens were exposed in triplicates over a wooden rack kept on horizontal surface of laterite rock at an angle of about 45° facing west. The specimens were tightly secured to wooden rack by P.V.C. nuts and bolts. The salt concentration of the atmosphere at all the four levels were evaluated during the exposure period. The salt trapping equipment was devised on the lines suggested by Ambler and Bain (1955), Roy (1983), Khanna et al (1986).

MULTIPLE REGRESSION ANALYSIS

Regression Analysis is made in the following order.

- (a) Estimating regression equation, which in turn involves the evaluation of regression coefficients a and b_i. The coefficients indicate the effect on corrosion rate due to change in the accompanying independent variable. One object of such an equation is to make an estimate of one variable from another.
- (b) Measure of the divergence of the actual values of the field observations from their estimated or computed values. This measure is analogous to a standard deviation and gives an idea, in absolute terms, of the dependability of estimates. It is called the "Standard Error of Estimate".
- (c) Measure of the degree of relationship or correlation between the variable expressed as "Correlation Coefficient"(r). This coefficient is independent of the units or terms in which the dependent and independent variables are originally expressed.

RESULTS AND DISCUSSIONS

The results of the Multiple Regression Analysis for mild steel at immersed zone is presented in Table 1. This table shows a fairly high order correlation between the corrosion rate and the dissolved oxygen content of seawater. The multiple correlation coefficient is also fairly high. The trustworthiness of the estimated regression line is checked through the analysis of variance, viz. Table 2. In this table, the source of variation is broken down into two components. One variation is explained as partly due to the fitment line

(attributable to regression) and the other variation is explained by points outside the fitment line (deviation from regression). Finally, Fishers Value (F-Value) is computed and is compared with the table F-Value at 95% confidence level. Since the calculated F-Value exceeds the table F-Value the regression value is satisfactory. A similar type of analysis is done by Suryanarayana Raju (1986).

Tables 3 and 4 show similar analysis for the mild steel in atmosphere zone. The correlation coefficient is very high suggesting the key role of the salt content in air on the atmospheric corrosion. The calculated F-Value is far more than the table F-Value. Altekar et al (1977), have established a linear relationship between the salt content of air and the corrosion rate for the marine atmosphere of Digha (West Bengal). Their analysis have given fairly good correlation coefficient and the scattering of the observed values over the regression line established by them may be due to less number of observations.

Fig.2 shows a plot of Predicted V/s actual corrosion rates in the immersed zone and Fig.3 shows the fit line for atmospheric corrosion.

CONCLUSION

It can be concluded by the analysis that the corrosion rate in the submerged zone and the atmospheric zone is compatible with the synergetic changes in the respective milieu.

The scattering of computed values from the observed corrosion rate values in both cases suggests that, for under water corrosion of materials, other parameters like microfouling water current velocity should be considered. Regarding atmospheric corrosion the model can be improved if parameters like relative humidity, pollutant concentration and distance of the panel from the ocean are incorporated.

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Table 1 : RESULTS OF MULTIPLE REGRESSION ANALYSIS (FOR SUB-MERGED ZONE)

Parameter	Correlation coefficient between individual parameter and corrosion rate (C^o and x_1)	Regression coefficient evaluated (a and b_1)	Multiple correlation coefficient	Standard error of estimate as a percentage of mean response
		341.7475		
Oxygen content (x_1) ml/L	0.9425	-0.5376		
Salinity of Seawater (x_2) Ppt	-0.6295	-9.1654	0.8451	5.32
Temperature (x_3) (o C)	-0.0916	-0.0111		
pH (x_4)	-0.4005	-0.2307		

Table 2 : ANALYSIS OF VARIANCE

Source of variation	Degree of freedom (D.O.F.)	Sum of Squares (S.Sq)	Mean Square = S.Sq/D.O.F.	Calculated F-Value	Table F-Value
Attributable to Regression	4	2550.35	637.50(a)	19.37	F(4,31)=2.68
Deviaton from Regression	31	1020.20	32.90(b)		
Total	35	3570.55			

Table 3 : RESULTS OF MULTIPLE REGRESSION ANALYSIS (FOR ATMOSPHERIC ZONE)

Parameter	Correlation coefficient	Regression Coefficient evaluated	Standard error of estimate as a percentage of mean response
-	-	6.68	2.88
Salt content of Air mg/100 cm ² /day	0.9941	21.78	

Table 4 : ANALYSIS OF VARIANCE

Source of variation	Degrees of Freedom (D.O.F.)	Sum of Squares (S.Sq.)	Mean square = S.Sq/D.O.F.	Calculated F-Value a/b	Table F-Value
Attributable to Regression	1	31231.88	31231.88(a)	3493.49	F(1,42)=3.99
Deviation from Regression	42	366.56	8.94(b)		
Total	43	31598.53			

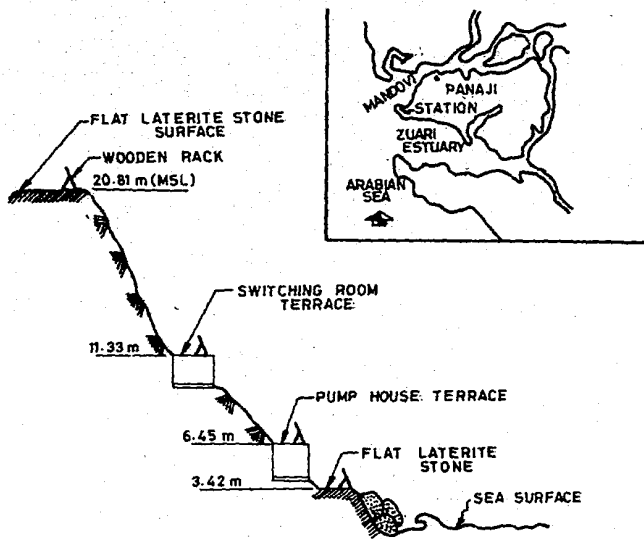


FIG. 1(a) MODE OF EXPOSURE AT VARIOUS HEIGHTS

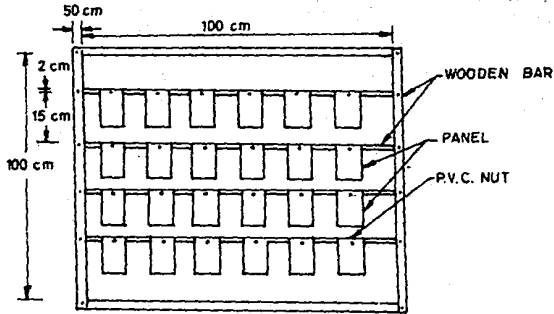


FIG. 1(b) ARRANGEMENT OF PANELS IN WOODEN RACK

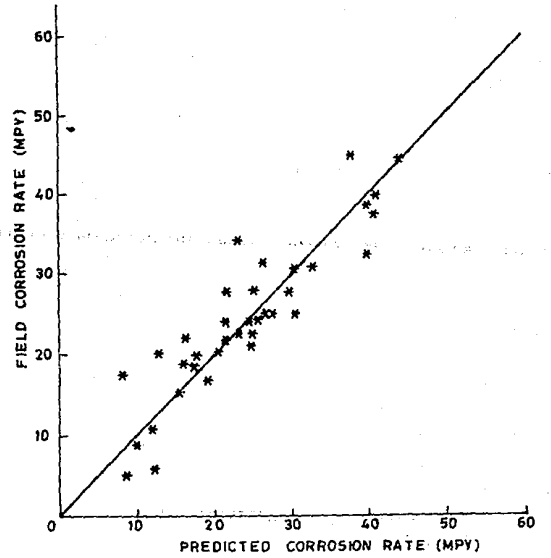


FIG. 2. FUNCTIONAL FIT FOR CORROSION DATA (SUBMERGED ZONE)

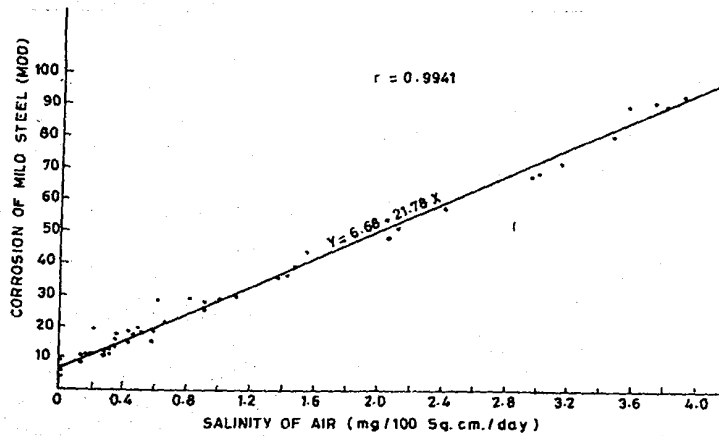


FIG. 3. MATHEMATICAL FIT FOR CORROSION OF MILD STEEL VS. SALINITY OF THE ATMOSPHERE