

# Predictive Modelling of Corrosion Rates of Jetty Components in Port Harcourt Environment

Jinyemiema, Tamuno K<sup>1</sup> & Chiejine, Chinedu M.<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, Rivers State University, Port Harcourt.

Department of Electrical Engineering, Admiralty University of Nigeria, Ibusa, Delta State.

Corresponding Email: [kurotamuno.jinyemiema@ust.edu.ng](mailto:kurotamuno.jinyemiema@ust.edu.ng),

## Abstract

**Introduction:** This study examined the effect of corrosion on structural integrity and longevity of jetty components in Port Harcourt environment. The assessment focused on depreciation of handrails, piers and concrete-embedded rods within these Jetties.

**Objectives:** the objective of this research is to develop a predictive model for jetties for effective management and monitoring of jetty

**Methods:** The research used results obtained by recent investigation on corrosion rate of steel components of the Jetties to a developed a model expressed in terms of seawater pH, depreciated thickness and time. This was complemented by analytical modelling approach to evaluate the effect of corrosion rate on the lifespan of the jetty components. The corrosion rate of steel materials of the jetties was modelled in terms of seawater pH, weight loss of the steel material, and duration of immersion of the structure in seawater. To achieve this, multiple regression analysis was utilized to evaluate the model coefficients

**Results:** The regression analysis of the corrosion rate model demonstrates a high degree of correlation between the independent variables (measurement time, seawater pH, pier thickness depreciation) and the dependent variable (corrosion rate). The regression statistics show a very strong relationship, with a multiple R of 0.9998 and an R-square value of 0.9996, indicating that the model explains 99.96% of the variance in the corrosion rate data. The constant of the model was determined as -0.05929, while the coefficients for time,  $t$ , seawater pH and pier thickness depreciation,  $\delta$  are determined as -1.00257, 0.041652 and 1.001968, respectively

**Conclusions:** There is high degree of correlation between the independent variables (time, seawater pH, and depreciated pier thickness) and corrosion rate, with 99.96% of measured corrosion rate explained by the predictive model. The developed corrosion model can serve as useful tool in managing corrosion risks associated with jetties and other infrastructures built within seawater surroundings.

**Keywords:** concentration, seawater, chlorine, samples, salts, organism, values.

## 1.0: Introduction

Corrosion is the continuous destructive phenomenon of a material or its properties through the effects of unwanted chemical or electrochemical reactions with its environment, which may cause deterioration of the surface and structural properties of the material component. It depends on the pH, temperature and concentrations of many inorganic and organic species at the metal-water interface. Seawater covers 70% of the earth's surface and is a highly complex medium that contains almost every element in the periodic table and a multifarious plethora of living organisms. It contains on average 3.5 to 4% of dissolved salts, mainly sodium chloride (Sylvester *et al.*, 2020). The corrosion process can be split into two stages; the corrosion initiation

stage, between the penetration initiation of chloride ion and the CO<sub>2</sub> into concrete cover and the initiation of the reinforcement corrosion; and the corrosion propagation stage, characterized by a loss of cross-sectional area of the material (Sousa *et al.*, 2020).

Marine corrosion can exist in several forms such as pitting, galvanic, stray current and cavitation corrosion. The high salt concentration in most marine environments combined with high electrical conductivity makes marine bodies a highly conducive environment for corrosion to occur on metal surfaces. The marine structures such as ships and aquatic platforms are under continuous attack from their surrounding environment, and are sometime allowed to corrode. The seawater mostly contains two ions

which are chloride and sodium. These two ions make up over 90% of all dissolved ions in seawater. The chloride ions continuously react with marine structure in contact of water and damage the structure.

Understanding how marine jetty constructions deteriorate is critical for guaranteeing their long-term integrity, safety, and sustainability (Dhairiyashil and Rasal, 2023). The corrosion of jetty structures initiated by chloride ion attack upon the passive layer of steel, is the dominant cause of premature deterioration of marine and aquatic structures in the chloride-laden Niger Delta region of Nigeria.

### **1.2: Importance of Modelling Corrosion Rates**

Various groups have developed corrosion prevention strategies in order to protect corrosion prone-materials. A comprehensive study on corrosion inhibitors can be accessed in the recent works of Al-Amiery *et al.* (2024) and Yadav *et al.* (2024). In the early days, paints, pigments, and organic coatings were developed to prevent metal corrosion, but advanced and effective methods are now available (Amjad *et al.*, 2023). Consequently, cathodic protection, conjugated polymers, epoxy resin, phenolics, acrylic polymers, and many thermoplastics as well as thermoset resins have been used to inhibit corrosion (Bairagi *et al.*, 2024).

Nanofillers such as fullerene, nano-diamond, graphene, graphene oxide, carbon nanotube, carbon black, nano clay, and inorganic nanoparticle have also been introduced as corrosion prevention mechanisms (Kausar *et al.*, 2023). In recent times more environmentally friendly Agricultural-based inhibitors are gaining significant interest in area of corrosion prevention of steel materials in harsh corrosive environment (Alibakhshi *et al.*, 2018; Verma *et al.*, 2018).

The cathodic protection method is another most widely used method of protecting material from corrosion in marine environment. This is an electrical anticorrosion method that protects many surface structures especially underground storage tanks, lock gates and dams, water treatment facilities, well casings, rubbish racks, bridge decks, steel pilings, ship-wetted hulls buried in soil or immersed in water (Tezdogan & Demirel, 2014).

While these corrosion prevention methods are effective, monitoring and maintenance of existing

infrastructures remained a productive approach to corrosion management. Hence, in achieving an effective corrosion management, mathematical modelling can be adopted to predict the rate of depreciation or thinning of steel materials due to corrosion effects. Several corrosion studies have used mathematical models to predict the depreciation of materials. For instance, Vazquez *et al.* (2022) used mathematical models to predict the corrosion of marine structures with accuracy. Therefore, this study explored the efficacy of mathematical modelling approach to evaluate the depreciation level of Landing Jetty in selected locations in Rivers State, Nigeria by considering the effect of seawater on overall deterioration of Jetty through prediction of chloride diffusion into concrete slab and corrosion rate of steel components of the Jetties.

### **1. Objectives**

The objectives of this research are as follows;

- (i) To model the corrosion rate of steel component of the Jetties in terms of seawater pH, depreciated thickness and exposure period
- (ii) To predict the depreciation rate of jetty components
- (iii) To validate the predicted corrosion rate by comparing with experimental results
- (iv) To predict the long effect of seawater corrosion on jetty components
- (v) To suggest mitigation approaches to seawater corrosion on jetty components

### **2. Materials and Methods**

#### **2.1: Materials**

The materials used in this study include emery papers for cleaning of corroded steel surfaces, seawater, reinforced concrete structures, metal piers and handrails of the Jetties in the five case study locations.

The equipment used for measurement include:

- a. Ultra-sonic thickness gauge(D-meter)
- b. Electronic weighing balance

#### **2.2: Methods**

The research method used data collected by an earlier study in which measurements were taken from samples at the Jetties. The test was conducted from samples of seawater, reinforced concrete materials, metal piers, handrails and iron rods. These samples were tested at an average of seven weeks in triplicate. The samples were tested using relevant test methods and

equipment for corrosion analysis to investigate the effect of seawater on the corrosion behaviour of pontoon jetties. This was complemented by analytical modelling approach to evaluate the effect of corrosion rate on the lifespan of the jetties. The experimental investigation for this study includes:

- i. Visual inspection of the structure to assess the current state/health of the structure
- ii. Physicochemical test on the seawater samples
- iii. Corrosion analysis of the steel component of the jetties using the weight loss method
- iv. Chloride content analysis on the concrete component of the jetties

### 3.0: Modelling of Corrosion Rate

The corrosion rate of steel materials of the jetties was modelled in terms of seawater pH, weight loss of the steel material, and duration of immersion of the structure in seawater. To achieve this, multiple regression analysis was utilized to evaluate the model coefficients. Thereafter, the evaluated coefficient was plugged into the model equation and used to predict the corrosion rate for the given parameters. The corrosion rate model is expressed in terms of seawater pH and corrosion duration, as stated in Equation (1).

$$C_r = f(pH, \delta, t) \quad (1)$$

Where,  $C_r$ , is the corrosion rate (mm/yr), pH is the seawater pH value (-),  $\delta$  thickness loss (mm) and  $t$  is the immersion period (hr).

Using the approach by Farahani and Taghaddos (2020) and Melchers and Tan (2022), Equation (1) can be expressed as:

$$C_r = K(pH)^a \delta^b t^c \quad (2)$$

Where, a, b and c are constant coefficients of seawater pH, weight loss and immersion time, while  $K$  model constant, which accounts for the error.

Equations (2) can be expressed in linear form to obtain the constants coefficients by taking the natural logarithm of both sides of Equation (3) as follows:

$$\ln C_r = \ln K + a \ln pH + b \ln \delta + c \ln t \quad (3)$$

Substituting  $y = \ln C_r$ ,  $a_0 = \ln K$ ,  $a = a_1$ ,

$$x_1 = \ln pH, \quad a_2 = b, \quad x_2 = \ln \delta, \quad a_3 = c \quad \text{and}$$

$$x_3 = \ln t \quad \text{Equation (3) yields (Melchers \& Tan, 2022),}$$

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 \quad (4)$$

Equation (4) is detailed as follows (Farahani and Taghaddos, 2020).

$$\sum y = a_0 n + a_1 \sum x_1 + a_2 \sum x_2 + a_3 \sum x_3 \quad (4a)$$

$$\sum x_1 y = a_0 \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + a_3 \sum x_1 x_3 \quad (4b)$$

$$\sum x_2 y = a_0 \sum x_2 + a_1 \sum x_1 x_2 + a_2 \sum x_2^2 + a_3 \sum x_2 x_3 \quad (4c)$$

$$\sum x_3 y = a_0 \sum x_3 + a_1 \sum x_1 x_3 + a_2 \sum x_2 x_3 + a_3 \sum x_3^2 \quad (4d)$$

### 3.2: Methods of Data Analysis and Validation

The obtained experiment was analyzed using Microsoft Excel data sheets, while Equation (5) was solved using Microsoft Excel Analysis ToolPak. To assess the applicability of the models presented in this work for prediction of the corrosion induced failure of the case study, the model predicted results were compared with experimental results. Statistical tools were utilized to assess the correlation between the results.

### 3.3: Analysis of Variance

Analysis of variance (ANOVA) which comprises the degree of freedom (df), sum of square (SS), mean square (MS), f-value (F) and percentage contribution (P) will be conducted on the experimental results in order to study the percentage contributions of the different corrosion factors on the corrosion failure of the jetty materials. The level of confidence to be adopted for this analysis will be 95% and level of significance will be 5%. Also, the sum of square total (SST) for all ANOVAs will be calculated using Equation (5) (Iyasele, 2018).

$$SS_{Total} = \sum_{i=1}^n y_i^2 - \frac{1}{n} (y_i)^2 \quad i = 1, 2, 3, \dots, n \quad (5)$$

where,  $SS$  is the sum of square,  $n$  is the number of observation and  $y$  is the observations in  $i$ th sample.

### 3.4: Deviation analysis

The deviation of model-predicted corrosion rate ( $\Delta C_r$ ) from the corresponding experimental result will be obtained using the relation,

$$\Delta C_r = \left( \frac{C_r - C_{rm}}{C_r} \right) \times 100\% \quad (6)$$

where,  $C_r$  is the experimental corrosion rate (mm/yr) and  $C_{rm}$  is the model predicted corrosion rate (mm/yr).

### 3.5: Standard Error of Prediction

The deviation of the predicted results from the experimental results called standard error of prediction will be estimated using the relation;

$$E_s = \sqrt{\frac{\sum (C_r - C_{rm})^2}{N}} \quad (7)$$

where,  $C_r$  is the experimental corrosion rate (mm/yr),  $C_{rm}$  is the model-predicted corrosion rate (mm/yr) and N is the number of observations.

#### 4. Results

##### 4.1: Modelling Approach for Prediction of Corrosion Rate

The corrosion rate of steel component of the Jetties as a function of seawater pH, depreciated thickness of steel component and exposure time have been evaluated. However, to validate the model performance, the data obtained from the piers analysis across all the Jetties was used. Table 1 shows the statistical data generated from the regression modelling of the selected inputs and output parameters.

**Table 2: Analysis for evaluation of corrosion rate model constant coefficients**

SUMMARY OUTPUT					
<i>Regression Statistics</i>					
Multiple R					0.9998
R Square					0.9996
Adjusted R Square					0.9995
Standard Error					0.0153
Observations					15
ANOVA					
	<i>d</i>				<i>Significa</i>
	<i>f</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>nce F</i>
Regress		7.003	2.3343	9958.	3.66E-
ion	3	063	54	885	19
Residu	1	0.002	0.0002		
al	1	578	34		
	1	7.005			
Total	4	642			

#### 5. Discussion

The results presented in Table 2 showcase the statistical analysis conducted to evaluate the constant coefficients of the corrosion rate model equation for steel components in the jetties. This model was used to predict the corrosion rate based on the following factors, measurement time, seawater pH, and depreciation of pier thickness at different locations. The regression analysis of the corrosion rate model demonstrates a high degree of correlation between the independent variables (measurement time, seawater

pH, pier thickness depreciation) and the dependent variable (corrosion rate). The regression statistics show a very strong relationship, with a multiple R of 0.9998 and an R-square value of 0.9996, indicating that the model explains 99.96% of the variance in the corrosion rate data.

The ANOVA table provides insights into the significance of the regression model in predicting the corrosion rate of steel components. The high F-value and low significance level (p-value) indicate that the model is statistically significant and robust in explaining the variation in the corrosion rates observed in the experimental data.

The coefficients derived from the regression analysis represent the contributions of the independent variables to the corrosion rate model equation. The constant of the model was determined as -0.05929, while the coefficients for time, t, seawater pH and pier thickness depreciation,  $\delta$  are determined as -1.00257, 0.041652 and 1.001968, respectively. These coefficients indicate the magnitude and direction of the impact of each variable on the corrosion rate of steel components in the jetties as shown in Table 2 above.

The statistical analysis reveals that time and pier thickness depreciation have significant negative and positive correlations with the corrosion rate, as evidenced by the coefficients being close to -1 and +1, respectively. On the other hand, seawater pH has a relatively weaker positive correlation with the corrosion rate, as indicated by its coefficient being close to zero.

By plugging these coefficient values back into equation (2) with little rearrangement, the corrosion rate model was obtained as stated in equation (8).

$$C_r = 0.9424 \frac{(pH)^{0.042} \delta^{1.002}}{t^{1.003}} \quad (8)$$

Equation (4.1) was tested by predicting the corrosion rate of piers based on time, seawater pH and pier thickness depreciation. The predicted corrosion rate is shown in Table 3 in comparison to the measured corrosion rates. The percentage deviation and RMSE values for each Jetty were also shown in Table 3.

The comparison between the measured and predicted corrosion rates across the different Jetties reveals the efficacy of the corrosion rate model in estimating the deterioration of piers under the influence of environmental and operational factors, such as pH, time and material depreciation. The relatively low deviations and RMSE values across the different Jetties

indicate a satisfactory agreement between the model predictions and the actual corrosion rates observed in practice, highlighting the model's predictive capability. The model prediction accuracy emphasized the importance of data-driven modeling approaches in evaluating and predicting output parameters such corrosion behavior of steel components of Jetty exposed to corrosive seawater.

Generally, this predictive model can aid in assessing the deterioration of steel components of exiting infrastructures built in marine environment. With information obtained from the model, engineers can optimize maintenance schedules and implement corrosion prevention strategies to enhance the longevity and performance of Jetties in corrosive marine environments

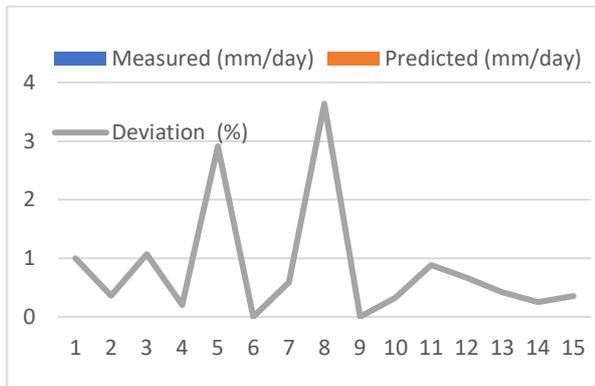


Fig 1: Plot showing daily measured and predicted corrosion rates against deviation

Figure 1 shows the relationship between the predicted values against the measured (actual); it can be deduced from the chart that the deviations are minimal, the maximum deviation is 3.6% with respect to Bille Jetty

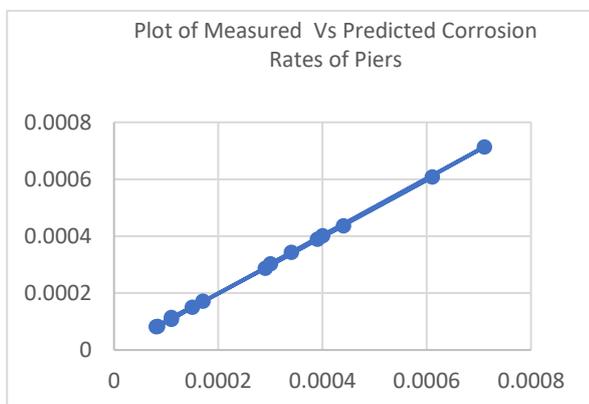


Fig. 2: Relationship Between Measured and Predicted Corrosion Rates of Piers

### 5.0: Conclusion

There is high degree of correlation between the independent variables (time, seawater pH, and depreciated pier thickness) and corrosion rate, with 99.96% of measured corrosion rate explained by the predictive model. The predicted corrosion rate compared well with the measured corrosion rate with a percentage deviation of less than 4% between both values. The percentage deviation and RMSE values between predicted and measured corrosion rate across the different Jetties are relatively low. These validated the model's predictive capability.

The overall findings underscore the importance of understanding and addressing the impact of saltwater on corrosion of steel components of the Jetties. The developed corrosion model can serve as useful tool in managing corrosion risks associated with jetties and other infrastructures built within seawater surroundings. Thus, the implementation of appropriate mitigation measures can enhance the durability, long-term sustainability and safety of marine structures.

Table 3: Comparison of Measured and Predicted Corrosion rate of Piers

	t (days)	pH	$\delta$ (mm)	Measured (mm/day)	Predicted (mm/day)	Deviation (%)
Abuloma Jetty	14	6.18	0.0061	0.00044	0.000436	1.0000
	28	6.04	0.0109	0.00039	0.000389	0.3590
	42	5.81	0.0121	0.00029	0.000287	1.0690
Bonny Jetty	14	6.24	0.0021	0.00015	0.000150	0.2000
	28	6.17	0.003	0.00011	0.000107	2.9091
	42	6.09	0.0034	0.000081	0.000081	0.0000
Bille Jetty	14	6.31	0.0024	0.00017	0.000171	0.5882
	28	6.22	0.0032	0.00011	0.000114	3.6364
	42	6.13	0.0035	0.000083	0.000083	0.0000
Marine Base Jetty	14	6.32	0.0085	0.00061	0.000608	0.3279
	28	6.23	0.0096	0.00034	0.000343	0.8824
	42	6.11	0.0127	0.0003	0.000302	0.6667
Okuru Jetty	14	5.74	0.01	0.00071	0.000713	0.4225
	28	5.44	0.0113	0.0004	0.000401	0.2500
	42	5.25	0.0119	0.00028	0.000281	0.3571

Table1: Corrosion Rate of Steel Component of the Various Jetties

	Corrosion rate (mm/day)									
	Handrail				Pier					R o d
Time (Days)	A b u l o m a	B o n y	B i l l e	M a r i n e B a s e	A b u l o m a	B o n y	B i l l e	O k u r u	M a r i n e B a s e	
0	0	0	0	0	0	0	0	0	0	0
14	0.00026	0.00013	0.00015	0.0008	0.00044	0.00015	0.00017	0.00061	0.00071	0.00041
28	0.00066	0.00096	0.00016	0.0009	0.00099	0.00011	0.00011	0.00034	0.00044	0.00035
42	0.00033	0.00071	0.00076	0.0007	0.00099	0.00088	0.00083	0.0003	0.0008	0.00088

and FDM approaches. *Journal of Rehabilitation in Civil Engineering*, 8 (4), 1 – 14.

References

1. Al-Amiery, A., Roslam, W.N., Isahak, W., & Al-Azzawi, W.K. (2024). Sustainable corrosion inhibitors: A key step towards environmentally responsible corrosion control. *Ain Shams Engineering Journal*, 15, 102672.
2. Dhairyashil, S. M. and Rasal, S. A. (2023). Depiction of damage mechanism and deteriorating pattern of concrete jetty structure in marine environment: A literature review. *Journal of Engineering Technologies and Innovative Research*, 10 (6), 150 – 155.
3. Farahani, A. & Taghaddos, H. (2020). Prediction of service life in concrete structures based on diffusion model in a marine environment using mesh free, FEM
4. Iyasele, E. O. (2018). Comparative analysis on the mechanical properties of a metal matrix composite reinforced with palm kernel/periwinkle shell ash. *Global Scientific Journal*, 6 (8), 1 – 24.
5. Kausar, A., Ahmad, I., & Zhao, T. (2023). Corrosion-resisting nanocarbon nanocomposites for aerospace application: an up-to-date account. *Applied Nano*, 4, 138–158.
6. Melchers, R. E. & Tan, M. Y. (2022). Literature review on prediction of lifespan and corrosion behaviour in the ocean. *A Report by the National Decommissional Research Initiative*, 1 – 21.
7. Sousa, M. L, Dimova, S., Athanasopoulou, A., Rianna, G., Mercogliano, P., Villani, V.,

- Nogal, M., Gervasio, H., Neves, L., Bastidas-Arteaga, E., Tsionis, G. (2020). Expected implications of climate change on the corrosion of structures. *JRC Technical Report*, 1 – 80.
8. Sylvester, O. O., Felix, U. A. & Okiemute, O. (2020). Assessment of the conditions of an existing marine concrete structure in the Niger Delta region of Nigeria. *Journal of Civil Engineering Research*, 10 (3), 63 – 71.
9. Tezdogan, T., & Demirel, Y.K. (2014). An overview of marine corrosion protection with a focus on cathodic protection and coatings. *Brodogradnja/Shipbuilding*, 65(2), 49-59.