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Geostatistical Analysis for Corrosion in Oil Steel Tank

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Abstract
This paper aims to study the variation of tank thickness using geostatistical methods. The tank was divided into three separated zones. Experimental variograms were constructed to characterize the spatial variability of the measured thickness of the tank. Spherical and exponential variogram models were fitted to the experimental variograms. The selected models were used to construct a corrosion map using the ordinary kriging for the three different zones.

1. Introduction

Corrosion is one of the most common causes of structural degradation in vessels. It can occur as uniform corrosion or as localized (pitting) corrosion. Both types of corrosion decrease the load bearing capacity of the structure, making it prone to failures [1]. Moreover, failures of vessels have been the cause of significant environmental damages. This fact has been recognized by the engineering profession and during the last decade [2]. Inspection, repair and renewal of corroded plates are crucial elements of structural strength maintenance strategies, in order to prevent structural failure [1]. According to the U.S. Department of Transportation Office of Pipeline Safety, internal corrosion caused approximately 15% of all reportable incidents affecting gas transmission pipelines over the past several years, leading to an average cost of $3 million annually in property damage, as well as several fatalities. The need to manage and mitigate corrosion damage has rapidly increased as materials are placed in more extreme environments and pushed beyond their original design life [3].

Storage tank is important equipment for oil and gas industries. Most tanks are made of steel, a material which is susceptible to corrosion. One main reason for storage tank failure is corrosion [4,5]. Corrosion can appear under different circumstances, affecting the tank in different ways [6]. Apart from the fact that leaking storage tanks pollute the environment and threaten public health, a failure in a storage tank can lead to enormous direct and indirect costs for the industrial sector. In order to predict and prevent such a catastrophe, non-destructive testing (NDT) is widely adopted and the development of new systems is ongoing given the importance of the subject. Unfortunately, the structures that need inspection are often large and only partially accessible or the inspection to all structure can be costly [7]. Significant efforts have been directed toward the formulation of engineering models for the prediction of corrosion degradation, both in deterministic and probabilistic terms [2]. Geostatistics technique can be used to predict corrosion degradation where no data have been collected.

An attempt [7] has been done to investigate the variation of oil tank thickness as one zone by geostatistical analysis. While this paper is intended to study the variation of oil tank thickness by dividing the tank into three separated zones to investigate the similarity and variation through the different zones.

2. Methodology

2.1. Variography

The characterization of tank thickness has been carried out through variogram. Let z(x) represent the value of tank thickness at location *x* and let *z (x+ h)* represent the value of tank thickness at some h distance and direction (or lag) away. The semi-variance is a function describing half of the expected squared differences between *z(x)* and *z(x+h)*. The variogram function summarizes the spatial continuity for all possible pairings of data for all lag distances (h) as [8-15]:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}[z(x_i)-z(x_i+h)]^2 \qquad (1)$$

Where $\gamma(h)$ is defined as half the average quadratic difference between two observations of a variable separated by a distance vector *h*. *N is* the observation points.

Mathematical models are fitted to experimental variograms to describe their behavior. The empirical distributions are described by three parameters (Figure 1) as:

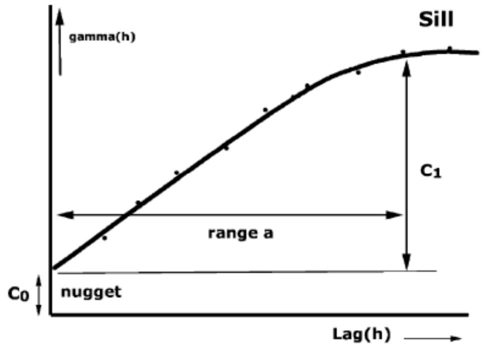


Figure 1. *Experimental variogram (black dots) and theoretical variograms (curve)*

1- The nugget variance C_0. This is the y-intercept, usually non-zero, and can be attributed to measurement errors and unresolved spatial variation.

2- The range *a*. This is the lag at which statistical correlation between data is zero and variability can be considered purely random. It represents the scale of variation of the data.

3- The sill *C*. This is the corresponding variance found for pairs separated by lags greater than the range. It can be decomposed into two factors c_0 and c_1. The former is the nugget, the latter can be considered as structured variation.

2.2. Kriging

Kriging is a powerful spatial interpolation technique, especially for irregularly spaced data points, and is widely used throughout the earth and environmental sciences. The estimation at an unsampled location is given as the weighted sum of the circumstance observed points. The weighting factors depend on a model of spatial correlation. Calculation of the weighting factors is done by minimizing the error variance of a given or assumed model of the auto-covariance for the data with regard to the spatial distribution of the observed data points [8-15]. Several indices are suitable to evaluate the interpolation. These indices are all a measure of the estimation error that is the difference between the estimated and the observed value*s* [8-15].

3. Experimental Work

The present study was carried out on crude oil storage tank T-3510A which stores oil before exporting through 12” oil export line to El-hamra terminal, Western desert, Egypt. Settling operation is done through the tank to separate all residual water. T 3510 A consists of nineteen plates; every plate has nine meters long and 2.4 meters width which were arranged through the tank shell in three courses. T-3510A with a chemical composition of C 0.21 %, Mn 1.5 %, S 0.045% and Fe balance. The ultrasonic measurements were carried out at fixed intervals of 1.2 m ×4.5 m (Figure 2). Histogram were made with (Smith statistical backage, Version 2.8, Copyright ©1995-2005 Garey Smith). Spatial distribution map was made with (Gridat Geostatistical software, Version 2.0.1, Copyright ©2010 ampiroid).

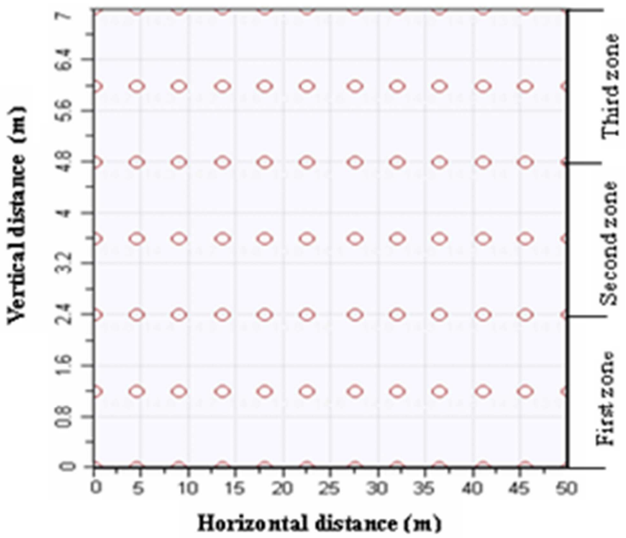


Figure 2. *The ultrasonic reading spot distribution for T-3510A*

4. Results and Discussions

4.1. Conventional Statistical Analysis

In order to obtain elementary knowledge about the thickness of the three zones of steel tank, conventional statistical analysis was performed (Table I). The mean value of the data sets was 14.3 mm. for the first zone and 14.4 for the second and third zone, which was very close to the median value that was respectively 14.6, 14.4 and 14.5. The coefficient of skewness is relatively low (-0.123) for the second zone data set and not very high (-0.75 and -0.62) for the first and third zone data set respectively, indicating that in the second zone the histogram is approximately symmetric and in the first and third zones that distribution is only slightly asymmetric. The very low values of the coefficient of variation reflect the fact that the histograms do not have a tail of high values.

Figure 3 shows the plots of the normal distribution adjusted to the histograms of the thickness of the three zones of steel tank. It is shown from Figure 3 that the distributions are homogenous, i.e. without statistically significant gaps. Figure 3 shows also the plots of the normal distribution adjusted to the histogram. It can be seen that the histograms are reasonably close to the normal distribution. Therefore the ordinary kriging method works well for the three zones of tank.

Table I. *Summary statistics of oil storage tank thickness measurements*

Statistical factors	**Thickness [mm]**		
	First zone	**Second zone**	**Third zone**
Minimum	13.9	13.9	13.9
Median	14.6	14.4	14.5
Maximum	14.9	14.9	14.8
Coefficient of skewness	-0.75	-0.123	-0.62
Coefficient of variation	0.019	0.019	0.017
Standard deviation	0.23	0.21	0.22

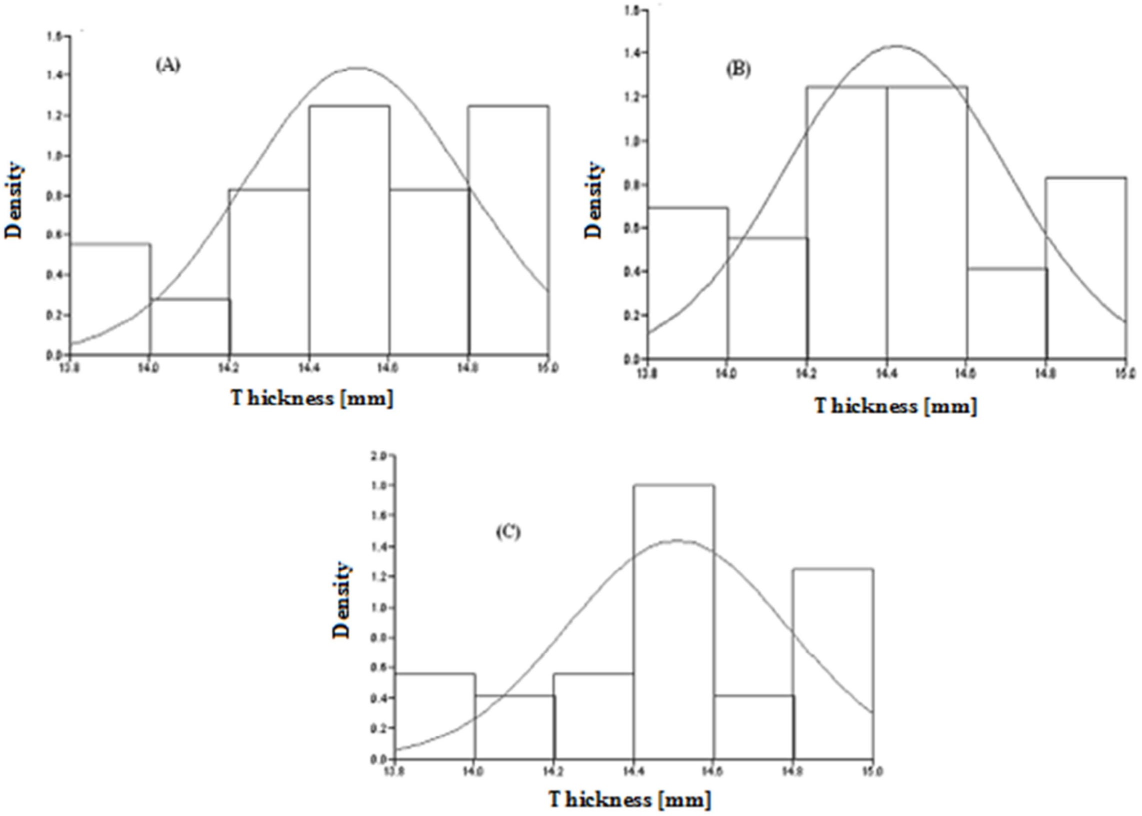


Figure 3. *Histograms of oil storage tank thickness for the three different zones. (A)-first zone, (B)- second zone and (C)- third zone*

4.2. Variography

Geostatistical study for spatial characterization of oil steel tank thickness has been carried out through geostatistical structural modeling (variography). Estimation of the variograms was undertaken for each zone of the tank to enable identification of spatial variability in thickness: high corrosion zones may indicate the presence of corrosive ions or water which allow increasing the electrochemical reaction and hence increasing the corrosion rate. Different types of variogram models used to fit the experimental variograms including exponential, Gaussian, spherical, tetraspherical, pentaspherical, Hole affect models. The exponential model (Figure 4A) was selected for the first zone whereas the spherical model (Figure 4 B and C) had the best fits and was chosen for the second and third zones. The exponential model is defined as [10]:

$$\gamma(h) = c_c + c_1 + \left\{1 - \exp\left(-\frac{3h}{a}\right)\right\} \tag{2}$$

On the other hand the spherical models are defined as [10]:

$$\gamma(h) = \begin{cases} c_0 + c\left(\dfrac{3h}{2a} - \dfrac{1}{2}\left(\dfrac{h}{3}\right)^3\right) & for \quad h \le 2.55 \\ c_0 + c & for \quad h > 2.55 \end{cases} \tag{3}$$

The parameters of the fitted models are represented in Table II. Inspection of data in Table II reveals that the variograms of the first zone has nugget effect of 0.04 and range of 14m which means the variation occurs over long distance and long continuity are present. On the other hand Table II indicates that the nugget effect for the second and third zones are 0.38 and 0.58 with range of 5.3 and 5.2 m respectively. This behavior indicates that the variation in the second and third zones occurs over short distance and they are similar.

Table II. *Parameters of the exponential and spherical variogram models*

Zone	Model type	Range (a) [m]	Sill ($C_0 + C$) [mm]	Nugget C_0 [mm]
First	Exponential	14	0.088	0.040
Second	Spherical	5.3	0.088	0.036
Third	Spherical	5.2	0.088	0.058

4.3. Cross Validation and Interpretation of Variograms Results

The respective models should undergo an iterative process of cross validation and parameter refinement until the model provides the best results. The resulting true and estimated values were compared using summary statistics like mean, standard deviation and so on. The cross validation results of the three models are shown in Table III. The cross validation results show that the chosen models and their parameters are adequate.

Table III. *The cross-validation results for exponential and spherical variogram*

Statistical factors	Thickness [mm.]		
	First zone	Second zone	Third zone
Minimum	14.01	14.02	13.9
Mean	14.53	14.43	14.41
Maximum	14.78	14.80	14.81
Coefficient of skewness	-0.75	-0.72	-0.62
Coefficient of variation	0.014	0.012	0.017
Standard deviation	0.21	0.20	0.20

4.4. Spatial Prediction

Ordinary kriging (OK), which allows the mean of the measurements to vary spatially, was used in this study. Spatial distribution maps in respect of kriging variances for the three different zones are computed based on the selected models of variograms and represented in Figure 5. It can be seen from Figure 5 that Ordinary kriging, always results in values that are 'best' in the sense that the expected squared prediction error is minimal. These maps would be of aid in inspection and maintenance strategies to detect damages and this improve the quality control of oil steel tank.

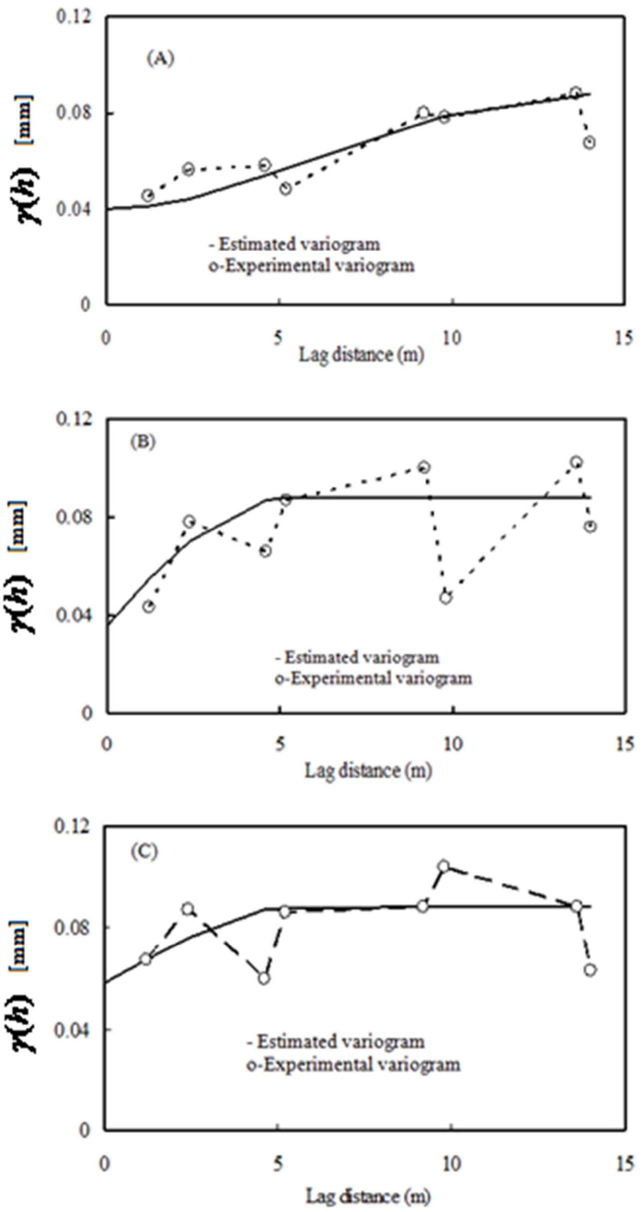
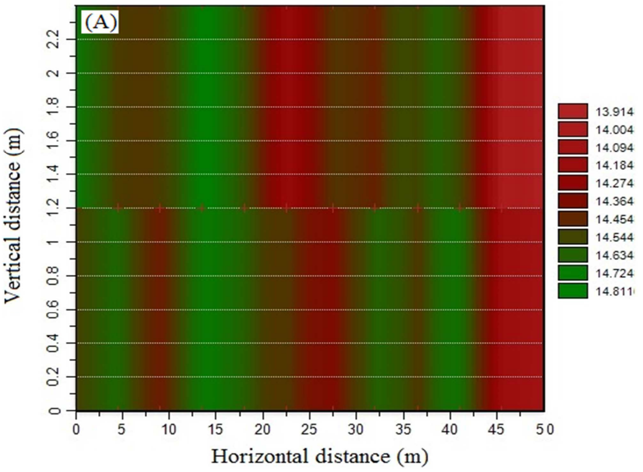


Figure 4. *Experimental and calculated variograms for oil steel tank thickness. (A)- the first zone, (B)- the second zone and (C)- the third zone*



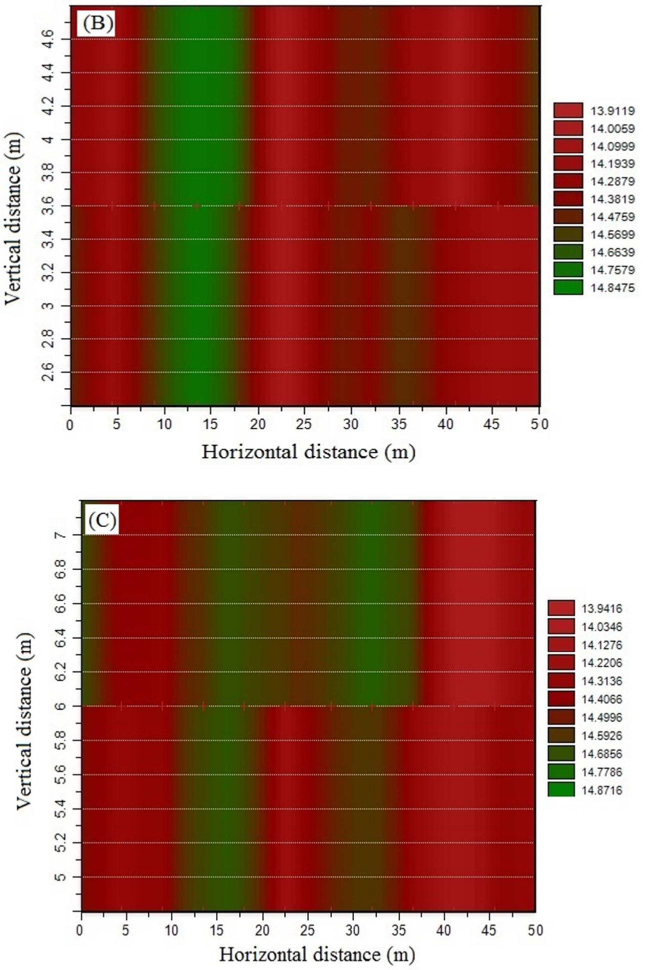


Figure 5. *Corrosion maps using ordinary kriging for the three different zones. (A)-the first zone, (B)-the second zone and (C)-the third zone*

5. Conclusions

1- The variogram function can be used in optimizing sampling design for estimating the kriging variance that may be acceptable for a given survey.

2- The modeling results indicated that the kriged tank thickness satisfactorily matched the observed tank thickness values.

3-Geostatistical analysis allows predicting the thickness for the required life along the tank. This information can facilitate the optimization of repair or maintenance strategies for oil steel tank structures.

4- Geostatistical analysis can be used successfully in constructing a corrosion map for oil steel tank structure.

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