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Predicting maximum depth of corrosion using extreme value analysis and Bayesian inference

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ABSTRACT

In the present study, overall thickness profile data for the backside corrosion of the bottom floors of the same oil storage tank were collected in 2006 and 2011. A custom-developed program was used to create virtual discrete thickness data from the overall thickness profile data. Using the created discrete thickness data, the scale parameter of Gumbel plots was examined by comparison with the data from 2006 and 2011. Using the experimental findings, a method combining extreme value analysis and Bayesian inference was proposed. With the proposed method, the actual maximum depths of corrosion were accurately predicted using the detected maximum depth of corrosion.

1. Introduction

Many aboveground oil storage tanks have been installed in Japan over the past 40 years. Inspection of these aging facilities is very important. In particular, backside corrosion in the bottom floors of storage tanks is a significant problem, as shown in Fig. 1. According to the Japanese Fire Service Act (JFSA), the conventional inspection technique for backside corrosion in the bottom floors is discrete ultrasonic thickness measurements. Based on the JFSA guidelines, the thicknesses of bottom floors of oil storage tanks are usually measured every 8 years as part of overall inspections of the tanks. The corrosion rate, which is evaluated based on the ratio of the detected minimum thickness to the usage time, is used to ensure that appropriate maintenance is performed to prevent leakage accidents. However, discrete thickness measurements cannot determine the maximum depth of the corrosion when the bottom floors of oil storage tanks exhibit localized corrosion. Under such conditions, the contents of an oil storage tank may leak and consequently cause a major accident.

Many studies have adopted a statistical approach to predict the maximum depth of the corrosion. Aziz [1] applied extreme value analysis to predict the maximum pit depth for aluminum. Joshi [2] also used extreme value analysis to characterize the corrosion data obtained from ultrasonic testing of the floor plates of aboveground crude oil storage tanks. Vajo et al. [3] applied extreme value analysis to analyze the crevice corrosion of aluminum under an elastomeric seal. Shibata [4] determined the optimum return period and sample size from accumulated data and used the minimum-variance linear unbiased estimator to predict the maximum corrosion from a Gumbel plot. Robert [5,6] used a Frechet plot to predict the maximum corrosion.

As for a stochastic model to predict the maximum corrosion, Rivas et al. [7] proposed block maxima and peak-over-threshold approaches and indicated that the peak-over-threshold approach can predict large pit depths. Markov chains have been successfully applied to reproduce the time evolutions of extreme pitting and corrosion depth in low carbon steel [8]. According to Valor et al. [6,8,9], pit initiation can be described by a non-homogeneous Poisson process, and pit growth can be modeled by a non-homogeneous Markov process. Zhou and Zhai [10] modeled the distribution of pit initiation by a non-homogeneous Poisson process and the distribution of pit growth by a stationary gamma

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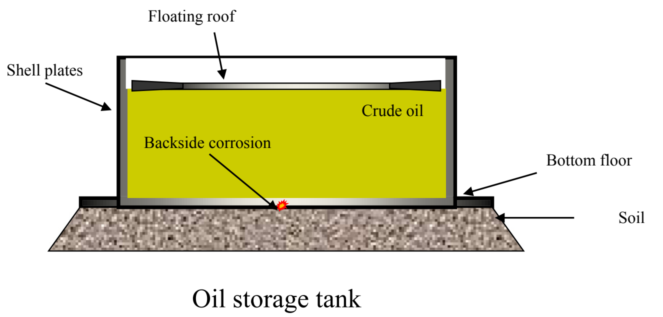

Fig. 1. Backside corrosion on the bottom floors of oil storage tanks; the focus of the present study.

process. Stochastic models for pitting corrosion are usually complex.

In our previous studies, to analyze the corrosion phenomena, authors assumed the propagation of backside metal loss of the bottom floors to be a stochastic process and applied the directed percolation model to the phenomena [11]. Authors also proposed a new method that uses fractal theory to evaluate corrosion risk of the bottom floors [11,12]. In the present study, we attempted to develop a simple method to predict the maximum depth of corrosion.

Bayesian inference is generally used to predict the value of a parameter. For prediction of the corrosion distribution, the Bayesian inference method can update the probability with use of additional data. Farias and Netto [13] applied the method to predict the corrosion distribution combined with a nonlinear corrosion evolution model. Khalifa et al. [14] applied the method to calculate the minimum size of a sample to estimate general corrosion.

We attempted to utilize the detected maximum depth of corrosion of discrete thickness measurements from the JFSA guidelines. In the present study, extreme value analysis is conducted using Bayesian inference and the maximum depth of the discrete thickness data from the JFSA guidelines. Overall thickness profile data were obtained for the same tank in 2006 and 2011. The behavior of the scale parameter with the overall thickness profile data from 2006 and 2011 was investigated. The effectiveness of the method to predict the maximum depth of corrosion was estimated using the data.

2. Thickness data for bottom floors of oil storage tank

2.1. Discrete thickness data from JFSA guidelines

The thicknesses of bottom floors of oil storage tanks are usually measured every 8 years. During overall inspection of the tanks, measurements of the discrete thickness data are generally carried out based on the guidelines set forth by the JFSA. According to the JFSA, the measurement interval must be 100 mm in annular plates that are less than 500 mm away from the shell plates, as shown in Fig. 2(a). Otherwise, the required measurement interval is 1000 mm, as shown in Fig. 2(b).

2.2. Overall thickness profile data

In the present study, an overall thickness profile measurement device is used to detect the actual maximum depth of corrosion. The device for measuring overall thickness comprises ultrasonic reflection probes, coating thickness gauges, and a rotary encoder to measure the distance. The device has 12 sensors with an effective width of 25 mm. The sensors are in a houndstooth arrangement, which allows the thickness of the entire bottom plate to be measured. The probe (including the 12 sensors) is 300 mm wide. The pulse reflection method is used to measure the thickness of the bottom floors of the tank. The actual thickness is obtained by subtracting the measured thickness of the coating at every position on the bottom floors. At a scan speed of 500 m/s and sampling frequency of 1000 Hz, the sampling distance is 0.5 mm. The minimum thickness data for 10 measurement points for each sensor are stored on a computer. These measurement data are called the overall thickness profile data. As an example, the data set for the measured thickness of the bottom floors of a large tank (diameter: 90 m) contains over 200 million data points. The accuracy of the depth of corrosion detection is 0.1 mm using the reference test piece in advance. For actual measurements, the overall thickness profile data were obtained after cleaning the bottom floors.

We define the corrosion as:

$$CR\left(x_i, y_j\right) = DT - MT\left(x_i,\ y_j\right), \tag{1}$$

where $CR(x_i,\ y_j)$ is the corrosion at each measurement position $(x_i,\ y_j)$, DT is the designed thickness, and $MT(x_i,\ y_j)$ is the measured thickness at each measurement position $(x_i,\ y_j)$.

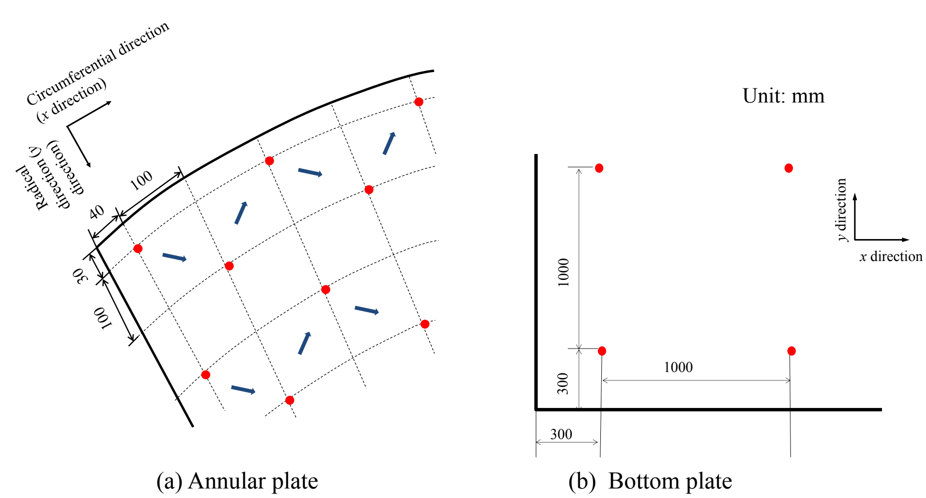

Fig. 2. The discrete thickness data of bottom floors of oil storage tanks based on the JFSA guidelines. Red dots indicate measurement points. (a) Annular plate. (b) Bottom plate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)