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Study on corrosion rate of buried gas steel pipeline in Nanjing based on the GM(1,N) optimization model

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Abstract. In view of the complex and fuzzy corrosion mechanism of buried gas steel pipelines, the grey correlation analysis method is used to find out the main factors affecting the corrosion rate and sort them by association degree. And then the corrosion rate model of buried natural gas steel pipeline is established based on GM (1, N) model and OGM (1, N) (an optimization method for the GM (1, N)) model. Results show the main factors affecting the corrosion rate of buried steel pipelines in Nanjing are service life, pipeline protection measures, soil resistivity and stray current. Compared with the GM (1, N) model, the accuracy of OGM (1, N) model is greatly improved. OGM (1, N) model can effectively simulate pipeline corrosion rate considering multiple factors, which has a certain reference value for the study on residual life of buried gas steel pipelines.

1. Introduction

According to the statistics of Sichuan gas pipeline accidents from 1969 to 2003, the proportion of pipeline accidents caused by corrosion accounts for 39.5%, which is much larger than other accident causes such as material defects and external force damage [1]. Therefore, it is important to build a reliable prediction model for corrosion rate of buried pipelines for formulating reasonable pipeline maintenance, replacement cycle and safe and effective management measures.

Grey system theory is widely used in pipeline corrosion prediction because of its strong advantage in modeling and analysis of small sample data. Chen Dianbin used GM (1,1) model based on VB and MATLAB software to study on predicting the residual life of steel pipelines and analysed the structural reliability [2]; Wang Qingfeng used unbiased grey (GM (1,1) and Markov chain combination prediction model to predict the residual corrosion life of pipelines [3]; Zheng Ruyan predicted the corrosion rate of carbon steel in seawater environment based on GM (1,N) model [4]. In summary, most domestic scholars used GM (1,1) or its optimization model based on time series to predict the corrosion rate, without considering the relevant factors. The GM(1,N) model can simulate the multi-variable model, but its accuracy needs to be improved.

In this paper, the influence factors of corrosion are ranked by grey relational degree method. On this basis, the OGM (1, N) model proposed by Bo Zeng is used to predict the corrosion rate of pipelines [5], and the simulated results of OGM (1, N) model with the simulated results of the GM (1, N) model make the comparison.

2. Calculate the degree of grey incidence

Grey correlation analysis method is an important method to measure the correlation degree among factors on the basis of similarity or difference of the development trend among factors, namely "grey relational degree" [6].

The following table 1 shows the corrosion date of different buried gas steel pipelines measured in Nanjing.

Table 1. Pipeline-parameter date

Steel pipe number	Relative wall thinning/%	Service life /a	Stray Current Forward Potential/mv	Soil resistivity/ Ω	Protective measures level	Pipe pressure /KPa
1	22	31	840	14.23	2	2.31
2	13	17	3530	16.67	2	2.31
3	9	17	1740	19.23	2	242.89
4	8.25	11	520	6.8	1	250
5	5.5	10	70	8.66	1	70
6	3.25	8	20	13.89	1	20

2.1. Doing non-dimensional treatment.

let Y_i be the mean sequence ,(when i = 1, Y_i is the independent variables; when i= 2,... N, Y_i is the dependent variables) , $X_i(k)$ be the original sequence. (when i = 1, $X_i(k)$ is the independent variables; when i=2,...,N, X_i(k) is the dependent variables.)

$$Y_i = \frac{X_i(k)}{\frac{1}{m}\sum_{k=1}^{m} X_i(k)} \tag{1}$$

Where i is the factor position, N is the number of sub-factors, k is the serial number of variables and m is the number of sequences contained in each factor.

2.2. Calculating Grey Relational Coefficient

Let $\delta_i(k)$ be the grey relational coefficient defined by grey theory. $\delta_i(k)$ is given by

$$\delta_i(k) = \frac{\min_i \ \min_k|Y_0(k)-Y_i(k)\ | + \alpha \max_i \ \max_k|Y_0(k)-Y_i(k)\ |}{|Y_0(k)-Y_i(k)\ | + \max_i \ \max_k|Y_0(k)-Y_i(k)\ |} \tag{2}$$

Where α is the resolution coefficient, which ranges from 0 to 1, and most are assigned as 0.5; $Y_0(k)$ is the mean series of independent variables; $Y_i(k)$ is the mean series of independent variables $(i \neq 0)$.

2.3. Calculating Grey Relevance Degree

let γ_i be a grey correlation degree, and the sequence γ_1、γ_2, ... , γ_N indicates the influence of various dependent factors on the results. The greater the γ_i is, the greater the influence is. The γ_i is as follow

$$\gamma_i = \frac{1}{m}\sum_{k=1}^{m} \delta_i(k); i \neq 0 \tag{3}$$

The results show that: γ= (0.8855 0.6174 0.7493 0.7988 0.5373), that is, sorted according to the degree of grey association the order is: service life > protection measures > soil resistivity > stray current > pipeline pressure. That means the main corrosion factors of buried gas steel pipelines are service life, pipeline protection measures, soil resistivity and stray current.

3. building GM (1, N) model

3.1. GM (1, N) Model

GM (1, N) model is a grey system prediction model which can simulate the linear relationship between multiple independent variables and a dependent variable. The modeling steps are as follows.

3*.1.1. Establishment of Initial Sequences.*

Let $x_1^{(0)}$ be the Relative wall thickness reduction, $x_2^{(0)}$ be the service life, $x_3^{(0)}$ be the protective measure, $x_4^{(0)}$ be the soil resistivity and $x_5^{(0)}$ be the stray current,

$$x_i^{(0)} = (x_i^{(0)}(1), x_i^{(0)}(2),\ldots, x_i^{(0)}(m))$$

3.1.2. Establish $x_j^{(0)}$ (j=2, ..., N) as the first order cumulative sequence. Let $x_j^{(1)}$ be the first order accumulating generating operator (1-AGO) of $x_j^{(0)}$,j= 2,3…, N,

$$x_j^{(1)}=(x_j^{(1)}(1), x_j^{(1)}(2),\ldots, x_j^{(1)}(m))$$

Where

$$x_j^{(1)}(k)=\sum_{l=1}^{k} x_j^{(0)}(l), \text{ k=1,2, …, m.} \tag{4}$$

3.1.3. Generate the $Z_1^{(1)}$.

Let $Z_1^{(1)}=(Z_1^{(1)}(1), Z_1^{(1)}(2),\ldots, Z_1^{(1)}(m))$,

where $Z_1^{(1)}(k)=(x_1^{(1)}(k) - x_1^{(1)}(k-1))/2$(k=2,3, …,m),

Then $x_1^{(0)}(k)+aZ_1^{(1)}(k)= \sum_{i=2}^{N} b_i\, x_i^{(1)}(k)$ is called GM (1, N) model.

a is the system development coefficient, $b_i\, x_i^{(1)}(k)$ is the driving term, and b_i is the driving coefficient.

3.1.4. Mean generation B and constant term vector Y for cumulative generated data.
Let $\breve{\alpha}=[\mathrm{a}, \mathrm{b}_1, \mathrm{b}_2, \ldots, \mathrm{b}_\mathrm{N}]^T$ be the system parameter packet,
where

$$\breve{\alpha}=(B^T B)^{-1} B^T Y \tag{5}$$

$$B=\begin{bmatrix} -Z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -Z_1^{(1)}(3) & x_2^{(1)}(3) & \ldots & x_N^{(1)}(3) \\ \cdots & \cdots & \ldots & \cdots \\ -Z_1^{(1)}(m) & x_2^{(1)}(m) & \ddots & x_N^{(1)}(m) \end{bmatrix}, \quad Y=\begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(m) \end{bmatrix}$$

3.1.5. Construe whitenization equation.

$$\frac{dx_1^{(1)}}{dt} + a x_1^{(1)} = \sum_{i=2}^{N} b_i\, x_i^{(1)} \tag{6}$$

3.1.6. Calculate the Grey Parameters. According to the above formulas, $\hat{x}^{(1)}(k+1)$ is given by

$$\hat{x}^{(1)}(k+1) = \left[x_1^{(1)}(1) - \frac{1}{a}\sum_{i=2}^{N} b_i\, x_i^{(1)}(k+1)\right] e^{-ak} + \frac{1}{a}\sum_{i=2}^{N} b_i\, x_i^{(1)}(k+1) \tag{7}$$

then the predicted value is given by

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \tag{8}$$

3.2. OGM (1, N) Model. Let $x_1^{(0)}$ be the relative wall thickness reduction, $x_i^{(0)}$ be the influence factor of corrosion, $x_j^{(1)}(k)$ be the 1-AGO of $x_j^{(0)}(j=1,2,\ldots,N)$, then OGM(1, N) is given by

$$x_1^{(0)}(k) + aZ_1^{(1)}(k) = \sum_{i=2}^{N} b_i\, x_i^{(1)}(k) + (1-k)h_1 + h_2 \tag{9}$$

Let $\breve{\alpha}=(B^T B)^{-1} B^T Y$, where

$$B=\begin{bmatrix} x_2^{(1)}(2) & x_3^{(1)}(2) & \ldots & x_N^{(1)}(2) & Z_1^{(1)}(2) & 1 & 1 \\ x_2^{(1)}(3) & x_3^{(1)}(3) & \ldots & x_N^{(1)}(3) & Z_1^{(1)}(3) & 2 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_2^{(1)}(m) & x_3^{(1)}(m) & \ldots & x_N^{(1)}(m) & Z_1^{(1)}(m) & m-1 & 1 \end{bmatrix}, Y=\begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(m) \end{bmatrix}$$

let $\mu_1 = \frac{1}{1+0.5a}$, $\mu_2 = \frac{1-0.5a}{1+0.5a}$, $\mu_3 = \frac{h_1}{1+0.5a}$, $\mu_4 = \frac{h_2-h_1}{1+0.5a}$, then

$$\hat{x}^{(1)}(k) = \sum_{t=1}^{k-1}\left[\mu_1 \sum_{i=2}^{N} \mu_2^{t-1} b_i x_i^{(1)}(k-t+1)\right] + \mu_2^{k-1}\hat{x}^{(1)}(1) + \sum_{j=0}^{k-2}\mu_2^{j}[(k-j)\mu_3 + \mu_4], \ \mathrm{k}=2,3,\ldots,\mathrm{m}. \tag{10}$$

The predicted value is given by

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \tag{11}$$

4. Result Analysis

Based on the data in Table 2, GM (1, N) model and OGM (1, N) model are established respectively after screening and sorting influencing factors according to the grey relational degree. The Simulation results and errors between two models and the measured date are shown in Table 2, the simulated curves of relative wall thickness reduction are shown in Figure 1.

Table 2. Simulated data and errors of relative wall thickness reduction

Sample number	Relative wall thickness reduction				
	Measured date/%	GM (1, N) Model		OGM (1, N) Model	
		Simulation date/%	Simulation error /%	Simulation date /%	Simulation error /%
1	22	22	0	22.00	0
2	13	9.32	28.32	13.0458	0.3526
3	9	10.13	12.59	9.0503	0.5587
4	8.25	8.46	2.57	8.3000	0.6058
5	5.5	6.28	14.16	5.5500	0.9091
6	3.25	3.89	19.60	3.3000	1.5385
Average Error		15.45		0.7929	

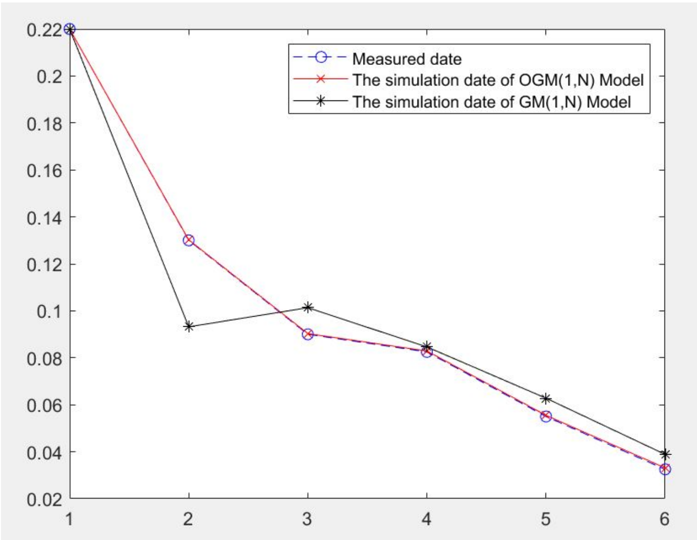

Figure 1. Simulated curves of relative wall thickness reduction

5. Conclusion

Through analysis, the main corrosion influencing factors of buried gas steel pipelines in Nanjing are service life, pipeline protection measures, soil resistivity and stray current. For pipelines with long service life and lack of effective protection measures, the management of inspection and maintenance should be strengthened.

Compared with the simulated errors of GM (1, N) model, the accuracy of the OGM (1, N) model has been greatly improved, which average error is only about 15.45%.OGM (1, N) model can effectively predict the corrosion rate of pipelines, meanwhile, it can provide reference for the study on predicting residual life of pipelines.

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