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Application of Renewal Gray GM (1,1) Model to Prediction of Landslide Deformation

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Abstract

The gray renewal GM (1,1) landslide prediction model was established by improving the gray model. Based on the established model, the author has made prediction of landslide deformation to the Xiangjiapo landslide and the Lianziya dangerous rock body. The results show that the gray renewal GM (1,1) model can supplement the new information in time and remove the old information which reduces the meaning of the information because of time lapse. Therefore, the model is closer to reality.

Keywords

Landslide, Renewal Gray GM (1,1) Model, Gray System Theory

1. Introduction

Landslide prediction research has started from the 1960s, and has now become a hot topic in landslide research. Due to the complexity of the landslide problem, landslide time prediction is still a worldwide problem. In these recent years, domestic and foreign experts and scholars in the landslide forecast theoretical research and practical work in the geotechnical engineering field have done a lot of work, and achieved remarkable results [1] [2] [3] [4] [5], for disaster prevention and mitigation played a role. But many studies are still in the exploratory research phase.

There are many ways to forecast landslides, although the methods have their own unique, but there are corresponding shortcomings and deficiencies. The gray system analysis method has a good applicability for the incomplete or incomplete information. The GM (1,1) model has been widely used in landslide prediction [6] [7] [8]. In this paper, renewal gray GM (1,1) model is used to forecast the landslide, and the prediction accuracy is obviously improved. Renewal gray GM (1,1) model is superior to the GM (1,1) prediction model by the model accuracy test.

2. Gray System Theory

2.1. The Basic Idea of Gray System Prediction

Gray system theory is a famous scholar founded by professor Deng J. L. in 1982. It is based on the small sample of "some information is known and some information is unknown", and the "poor information" uncertainty system is the main research object. "Part" known information generation, development, extraction of valuable information, to achieve the correct understanding of the system and the exact description of the law, and scientific forecasting. Gray system is through the finishing of the original data to seek its changing laws, while the future state of the system to make scientific predictions. The gray prediction model, also known as the GM model, can be used to observe, analyze and long-term predictions of the studied system.

2.2. Conventional Gray GM (1,1) Model Principle [9] [10]

Assuming that the original number as $X^{(0)}$

$$X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right) \tag{1}$$

According to the gray system theory on the original sequence of first-order accumulation (1-AGO) generated, the resulting column is:

$$X^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\right) \tag{2}$$

$x^{(1)}(k)$ can be calculated using the following formula:

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1, 2, \cdots, n \tag{3}$$

The differential equation of the albino form of the system prediction model GM (1,1) is expressed as:

$$\frac{\mathrm{d}x^{(1)}}{\mathrm{d}t} + ax^{(1)} = b \tag{4}$$

Assuming that $\hat{a} = |a,b|^{\mathrm{T}}$, then identification a can be calculated by the following formula

$$\hat{a} = |a,b|^{\mathrm{T}} = \left(B^{\mathrm{T}}B\right)^{-1} B^{\mathrm{T}}Y \tag{5}$$

where $Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}$ (6)

$$B = \begin{bmatrix} -\frac{1}{2}\left[x^{(1)}(1) + x^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[x^{(1)}(2) + x^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\left[x^{(1)}(n-1) + x^{(1)}(n)\right] & 1 \end{bmatrix} \tag{7}$$

Then the time response sequence can be expressed as

$$\hat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-ak}+\frac{b}{a},\ k=1,2,\cdots,n \tag{8}$$

The simulation value is expressed as

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k),\ k=1,2,\cdots,n \tag{9}$$

2.3. Gray Metabolism GM (1,1) Model Principle

In the conventional GM (1,1) model modeling, the past data from the real time $t=n$ is used. However, the development of any gray system, with the passage of time, will continue to have some random disturbance factors into the system, so that the development of the system affected. Therefore, with the conventional GM (1,1) model, the higher accuracy is only a few recent data, farther away from reality, the weaker the prediction. In order to reflect the impact of the future random disturbance on the gray system and improve the prediction accuracy, the GM (1,1) model is grayed out.

In the original data $X^{(0)}=\left(x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(n)\right)$, the latest information $x^{(0)}(n+1)$ is placed and the oldest information $x^{(0)}(1)$, $X^{(0)}=\left(x^{(0)}(2),x^{(0)}(3),x^{(0)}(n+1)\right)$ is removed. The model established according to the above steps is the gray metabolic GM (1,1) model, and a series of prediction data is obtained at the same time.

2.4. Accuracy Test

The accuracy of the gray prediction model is usually checked by the posterior difference method. The model accuracy is evaluated by the mean square error ratio and the small error probability. The smaller the mean square error ratio and the smaller the probability of small errors, the higher the accuracy of the prediction model. The basic method is as follows: assuming $X^{(0)}$ for the original sequence, $\hat{x}^{(0)}$ for the GM (1,1) model simulation sequence, $\varepsilon^{(0)}$ for the residual series, then

$$\bar{x}=\frac{1}{n}\sum_{k=1}^{n}x^{(0)}(k), \tag{10}$$

$$S_1^2=\frac{1}{n}\sum_{k=1}^{n}\left(x^{(0)}(k)-\bar{x}\right)^2 \tag{11}$$

Respectively, the mean of $X^{(0)}$, variance;

$$\varepsilon^{(0)}(k)=x^{(0)}(k)-\hat{x}^{(0)}(k) \tag{12}$$

$$\bar{\varepsilon}=\frac{1}{n}\sum_{k=1}^{n}\left(\varepsilon^{(0)}(k)-\bar{\varepsilon}\right)^2 \tag{13}$$

$$S_2^2=\frac{1}{n}\sum_{k=1}^{n}\left(\varepsilon^{(0)}(k)-\bar{\varepsilon}\right)^2 \tag{14}$$

$$C=\frac{S_2}{S_1} \tag{15}$$

where $\bar{\varepsilon}$ is the mean of residual $\varepsilon^{(0)}(k)$, S_2^2 is the residual variance, and C is the mean square deviation. The mean square error ratio C and the small error probability p are calculated from $C = \frac{S_2}{S_1}$ and $p = P\left(\left|\varepsilon(k) - \bar{\varepsilon}\right| < 0.6745 S_1\right)$. The accuracy of the model is shown in Table 1.

3. Model Application Example

3.1. Xiangjiapo Landslide

In order to test the actual prediction effect of the gray metabolic prediction model, Xiangjiapo landslide data were used to predict. The landslide is located in K13+500 - K13+960 of Chongqing-Guizhou expressway. The landslides in the landslide are the quaternary of the quaternary system and the Jurassic lower Pearl Group (J_{1Z}), the spontaneous flow ($J_{1\text{-}2Z}$) and the Triassic upper Xujiahe formation (T_{3XJ}). The landslide occurred mainly in the quaternary landslide accumulation layer (Q_4^{del}) and the quaternary system (Q_4^{col+dl}). The landslide is mainly composed of silty clay clumps and strong weathering sand and mudstone. It belongs to mixed rock and rock landslide. The rock mass structure is loose, the water content is high, unstable and easy to deform.

The highway landslide monitoring information see the literature [11], displacement measured in Table 2. According to the data, it can be seen that the time series of landslide deformation has obvious increasing trend and obvious nonlinearity. Therefore, the renewal GM (1,1) model can be used to predict the displacement of JB5. The prediction results are shown in Table 3. The accuracy of the model is shown in Table 4.

Model 1 is the predicted value using t = 1, 2, 3, 4, 5, and 6 weeks. Model 2 is the predicted value using t = 2, 3, 4, 5, 6 and 7 weeks. Model 3 is the predicted value using t = 3, 4, 5, 6, 7, and 8 weeks. As can be seen from Table 3, t = 9 weeks of the relative error from 32.89977% gradually reduced to 6.126906%. It can be seen from Table 4 that the accuracy of model 1 is two, and the accuracy

Table 1. The reference table of precision check grade.

Model accuracy level	Small probability of error p	Mean square deviation ratio C
Level 1 (good)	≥ 0.95	≤ 0.35
Level 2 (qualified)	$0.80 \ll p < 0.95$	$0.35 < C \leq 0.50$
Level 3 (barely)	$0.70 \ll p < 0.80$	$0.50 < C \leq 0.65$
Level 4 (unqualified)	< 0.70	> 0.65

Table 2. Actual displacements of No. JB5 monitoring point in Xiangjiapo.

Monitoring date	1	2	3	4	5	6	7	8	9
Measuring point displacement value/mm	32.300	48.600	69.600	96.370	128.700	168.200	207.870	256.400	306.800

Table 3. The forecast data and relative error of information renewal GM (1,1).

Observed total time/week	Measured value/mm	Model 1	Relative error/%	Model 2	Relative error/%	Model 2	Relative error/%
1	32.300	32.30000	0				
2	48.600	51.70845	6.39598	48.6	0		
3	69.600	69.45098	0.21411	74.3689	6.85182	69.6	0
4	96.370	93.28144	3.20490	96.4319	0.06426	101.6628	5.49217
5	128.700	125.28876	2.65054	125.0405	2.84346	128.3116	0.30181
6	168.200	168.27863	0.04675	162.1363	3.60505	161.9458	3.71833
7	207.870	226.01947	8.73116	210.2374	1.13889	204.3965	1.67102
8	256.400	303.57270	18.39809	272.6087	6.32164	257.9747	0.61416
9	306.800	407.73650	32.89977	353.4837	15.21633	325.5973	6.12691

Table 4. Data table of precision check grade.

model	Relative error α	Mean square deviation ratio C	Small probability of error p
model 1	0.09068	0.38085	1
model 2	0.05149	0.19714	1
model 3	0.02987	0.10169	1

of model 3 is level 1, and the values of C and α are decreasing from model 1 to model 3, indicating that the accuracy of the model is gradually increasing. It can be seen that the gray renewal GM (1,1) model is used to predict, because the system constantly update the modeling data, remove the old data, so that the system's prediction accuracy has been improved, gradually close to the measured value.

3.2. Lianziya Hazardous Rock Masses

The rock masses is located in the south bank of the Xiling gorge in the Xintan Town, Zigui Town, Zigui County, Hubei Province. It is located at 26 km from the Sandouping dam. The site and the new beach landslide confrontation, its length 700 m, east-west width of 30 - 200 m, nearly 100 m high. According to the monitoring data of the Lianziya hazardous rock masses in the literature [12] from december 1978 to december 1985, the monitoring data were predicted. Gray renewal GM (1,1) model for GA monitoring point displacement change prediction results in **Table 5**.

Model 1 is the predicted value when the observed values are from 1978.12 to 1983.12, the model 2 is the predicted value at 1979.12 to 1984.12, and the model 3 is the predicted value at 1980.12 to 1985.12. As can be seen from **Table 6**, the values of the model accuracy test values C and α are decreasing from model 1 to model 3, indicating that the accuracy of the model is increasing. From the prediction results, it can be seen that the gray renewal GM (1,1) model not only

Table 5. The simulation-forecast results of renewal GM (1,1) model in Lian Ziya hazardous rock masses (G_A).

Time (year/month)	Displacement observations/mm	model 1	Relative error/%	model 2	Relative error/%	model 3	Relative error/%
1978.12	10.32	10.32	0				
1979.12	26.96	29.37167	8.94537	26.96	0		
1980.12	34.07	32.97365	3.21794	35.43405	4.00365	34.07	0
1981.12	38.65	37.01735	4.22420	38.25624	1.01879	39.87869	3.17901
1982.12	42.98	41.55695	3.31097	41.30320	3.90134	42.02683	2.21771
1983.12	44.93	46.65325	3.83542	44.59285	0.75038	44.29068	1.42292
1984.12	47.16	52.37454	11.05713	48.14451	2.08759	46.67648	1.02527
1985.12	48.38	58.79746	21.53258	51.97904	7.43911	49.19080	1.67590

Table 6. Data table of precision check grade.

model	Relative error α	Mean square deviation ratio C	Small probability of error p
model 1	0.08018	0.33823	0.857
model 2	0.03200	0.23306	1
model 3	0.01904	0.17360	1

has high prediction accuracy, but also has strong self-adjustment ability. It can adjust the model parameters with the new data, and reflect the evolution direction of the system in time prediction.

4. Conclusion

Based on the data of GA point deformation data of Xiangjiapo landslide and Lianziya hazardous rock masses, this paper uses the gray renewal GM (1,1) model method to predict the landslide. The results show that the gray metabolic GM (1,1) model can supplement the new information in time and remove the old information which reduces the meaning of the information because of time lapse. Therefore, it can reflect the current characteristics of the system. The model is closer to reality. The method has high accuracy, the prediction results can be used to guide the construction site, to achieve the dynamic management of landslide management, and application prospects are very broad.

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