The Application of the Gray Model in Building Subsidence Monitoring

Kexia Li

School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu 610500, China

18782972550@163.com

Abstract

With the development of society and the advancement of our country's modernization, the rise of high-rise building has put forward higher requirements to the settlement observation. Combined with several kinds of hot deformation monitoring data processing method in recent years, the paper explains the basic theory and content of gray model, applying gray theory to a construction settlement observation project in Chengdu. The practice proves that the settlement value and the measured value are close to the theoretical model. Grey theory model in building settlement prediction has strong logic, and the calculation formulas are simple, the characteristics of data processing is easy to handle, it has a good prospect of application and extension in building settlement monitoring.

Keywords

Deformation monitoring; Gray theory; Settlement observation.

1. Introduction

Along with the advancement of social development and modernization in our country, the pace of infrastructure construction and urbanization process accelerated, high-rise buildings rise rapidly. At the beginning of the construction of the building and use, in order to ensure the safety of construction and operation, we need to set the observation point on the building, and these observation points are cyclical repeat observation, then observation point position variation are obtained. In general, the structure of the deformation monitoring mainly includes two aspects: on the one hand, through the building deformation observation, we can master the deformation reason and law, reasonably predict the size of the deformation, to provide reliable data for the following construction survey design and the corresponding settlement parameter [1]. On the other hand, through observation, we can examine the rationality of the theory of observation method, to make further improvement [2]. Therefore, the necessity of high-rise building settlement deformation monitoring is more and more obvious, at the same time, the correct analysis and interpretation of various factors caused the building deformation, and establishing scientific and reasonable mathematical model to approach, simulate, and reveal the dynamic processes and characteristics of building subsidence is also has important practical significance.

At present, subsidence monitoring data processing method has been studied and discussed by many scholars. Among them, the more common and popular in recent years has the following several ways: multiple regression analysis method, the gray system model, Kalman filtering model, artificial neural network model, spectrum analysis. In addition, some scholars proposed hybrid model, such as gray linear regression model [3], gray dynamic model based on Kalman filter [4], gray system- neural network combination model [5]. These models have advantages and disadvantages in different aspects. In the paper, we compare and analysis the advantages and disadvantages of these models, and apply the

gray model in predicting the settlement of a building project. Results show that gray theory model in building subsidence monitoring has good application prospect, and it's worth further research.

2. The Establishment of Gray Model

2.1 Settlement Prediction Gray Model

In China in the 1980s, Professor J. L. Deng in Huazhong University of Science and Technology first put forward the gray system theory, also called GM (Gray Model). GM is a kind of poor information modeling, it makes all the random process as gray process, which is within a certain range change and time dependent. There will be no rule of the original data sequence, by adding or b-b processing, become new strong regularity series, then use a differential equation to describe the new series, solve the differential equation to get the relationship between independent variable and dependent variable. Therefore, it has the properties such as differential, difference, index compatible, model parameters can be adjusted, the structure with time change. It breaks though the limits of the general modeling that requires more data, and it's difficult to get the "differential" [6]. Now a variety of gray models are used to predict data. According to the number of predictor, gray model is subdivided into first-order multivariate prediction model GM (1, N) and first-order one yuan forecast model GM (1, 1), the dynamic gray model [7] and the improved gray model [8]. GM (1, 1) has been widely applied in practice. This article focuses on the establishment and application of the traditional GM (1, 1) .

Gray theory prediction model is established in this process as follows:

First of all, assuming that discrete sequence $\mathrm{x}^{(0)}$, as shown in formula (1).

$$\mathrm{x}^{(0)} = \{x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n)\} \tag{1}$$

Among them, n is the sequence length, use $\mathrm{x}^{(0)}$ to generates a sequence though first-order additive, We can acquire $\mathrm{x}^{(1)}$, as shown in formula (2).

$$\mathrm{x}^{(1)} = \{x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n)\} \tag{2}$$

Then establish first order differential equation based on the generated sequence, as shown in formula (3).

$$\frac{\mathrm{dx}^{(1)}}{dt} + \otimes a x^{(1)} = \otimes u \tag{3}$$

$\otimes a$ and $\otimes u$ are gray parameters, its whiting values(a possible value of gray intervals) is $\hat{\mathrm{a}}$, as shown in formula (4).

$$\hat{\mathrm{a}} = \left| a \quad u \right|^{T} = (B^{T}B)^{-1}B^{T}y_{y} \tag{4}$$

Among them, the value of B and y_N are shown in formula (5) and formula (6).

$$B = \begin{vmatrix} -\frac{1}{2}(\mathrm{x}^{(1)}(2) + x^{(1)}(1)) & 1 \\ -\frac{1}{2}(x^{(1)}(3) + x^{(1)}(2)) & 1 \\ \cdots & 1 \\ -\frac{1}{2}(x^{(1)}(n) + x^{(1)}(n-1)) & 1 \end{vmatrix} \tag{5}$$

$$y_N = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix} \tag{6}$$

The value of $\hat{a}$ can be obtained by the above calculation and plug in formula (3), then we could solve the differential equation as formula (7).

$$\hat{x}^{(1)}(k+1) = (x^{(0)}(1) - \frac{u}{a})e^{-ak} + \frac{u}{a} \tag{7}$$

Make $\hat{x}^{(1)}(k+1)$ inverse accumulating generation operator (IAGO) to get the restore data as shown in formula (8).

$$\hat{x}^{(0)}(k+1) = (1-e^{a})(x^{(0)}(1) - \frac{u}{a})e^{-ak} \tag{8}$$

2.2 Error Test

Despite the gray model can describe the development trend of high-rise building settlement, but the prediction accuracy need certain means of inspection and evaluation standards for validation, we often use the method of correlation degree and posterior deviation test [9]. The paper adopts the latter to predict test results. Assuming that original data sequence $\{x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n)\}$, predicted data sequence $\{\hat{x}^{(0)}(1), \hat{x}^{(0)}(2),..., \hat{x}^{(0)}(n)\}$, residual error $\varepsilon(i) = x^{(0)}(i) - \hat{x}^{(0)}(i)$. In this paper, the relative error and posterior error ratio C to judge the model accuracy. As shown in formula (9).

$$C = S_2 / S_1 \tag{9}$$

S1 is the mean square error of original data, S2 is residual mean square error.

3. The Example Analysis

In this paper, the data is based on the measured data of subsidence monitoring of a construction project, which satisfy the fourth level measurement technology index, observation precision meet the precision index requirements of the specification. By using GM (1, 1) model to analyze the measured data, part of the observation data are shown in Table 1. We are making a difference in data processing, these data are interval data.

Table 1 Settlement Observation Data

The Observation Time	The Number of settlement /mm
2016-01-07	10.92
2016-03-07	11.67
2016-05-07	11.35
2016-07-07	11.44
2016-09-07	11.82

We build the GM (1, 1) model by MATLAB simulation projections for the original data sequence, then compare with the observed data, to test and verify the reliability of the model. This project selected the first four period data of original observed data sequences to built the model, posterior error ratio C = 0.50853, model accuracy is qualified. So we use the model to forecast data, the results as shown in Table 2.

Table 2 The Results of Gray Model Prediction

The Observation Time	The Number of settlement /mm	AGO Generated Data	Predictive Value	Residual /mm
2016-01-07	10.92	10.92	10.90	0.02
2016-03-07	11.35	22.27	11.20	0.15
2016-05-07	11.44	33.71	11.40	0.04
2016-07-07	11.67	45.38	11.58	0.09
2016-09-07	11.82	57.20	11.61	0.21

As can be seen from Table 2, using the first four period data with random noise, we established the GM (1, 1) model to predict data, the model accuracy and forecast effect is good.

4. Conclusion

Buildings uneven settlement will affect the normal use, also may endanger the safety of the buildings, so regular settlement monitoring of high-rise building and accurate predictions for settlement deformation in the future are extremely important in engineering. Gray forecasting method needs less original data, the regularity between the data is relaxed, which is in keeping with the deformation characteristics of the high-rise building. According to the gray theory to predict building subsidence calculation process is based on strict mathematical basis, the precision of prediction results can satisfy the engineering needs. The theory of gray modeling makes full use of the characteristics of small amount of data. Therefore using gray model to predict building subsidence trend is relatively simple. GM (1, 1) model has the advantages that it is required less sample, high precision and can test, has simple principle, and convenient operation, therefore GM (1,1) model has been widely used. However, how to improve the prediction accuracy of gray theory model, and the improvement is necessary to research. In order to get higher accuracy of building subsidence forecast must be comprehensive consideration of various causes of sedimentation and technical methods. So the gray model in the application of deformation monitoring data processing is still an important research topic, it is essential to in-depth study.

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