Study of Displacement Prediction of Landslide Based on time Series Analysis

Fuyou Liu

No.2 Institute of Geological &Mineral
Resource Survey of Henan
Zhengzhou，China
895368014@qq.com

Fengbo Liu *

China University of Geosciences(Wuhan)
Mechanical and Electrical Engineering
Wuhan，China
237668254@qq.com
* Corresponding Author

Yong Liu

China University of Geosciences(Wuhan)
Mechanical and Electrical Engineering
Wuhan，China
99086669@qq.com

Yani Guo

China University of Geosciences(Wuhan)
Mechanical and Electrical Engineering
Wuhan，China
498914552@qq.com

Abstract—Based on the owned displacement monitoring data and displacement evolution of landslide, the total displacement can be divided into trend term displacement, which is controlled by its own geological conditions and periodic term displacement affected by external factors. Then the displacement prediction model of landslide can be established by time series analysis. Double moving average method is used to separate the trend term displacement and periodic term displacement of landslide. On this basis, roll GM (1，1) grey model is used to forecast the rend term displacement ; and autoregressive AR (p) model is used to forecast the periodic term displacement. Total displacement is obtained by adding the calculated predictive displacement value of each sub-stack. Taking baishuihe landslide in the Three Gorges reservoir area for example ，it is shown that the result could better reflect the development trend of landslide ，based on the comparative analysis of the measured and predicted displacement-time curves. The results demonstrate that the established landslide displacement prediction model is feasible and effective in the landslide displacement prediction.

Keywords-Landslide; Displacement prediction; Roll GM(1，1) Grey Model; Autoregressive AR(p) Model

I. INTRODUCTION

Landslide displacement prediction method of analysis, the curves drawn from each monitoring point, dynamic trends landslide qualitative analysis, using mathematical models related displacement - time statistical analysis and forecasting, to analyze the possible factors influencing landslide displacement of action occurred, the establishment of landslide displacement curves and to predict development trends of landslide displacements [1-4].

Now researchers commonly use the landslide displacement prediction model, usually based on the landslide displacement monitoring data analysis, and use relevant mathematical model to fit. Beside the conventional Prediction model, such as statistical forecasting model, discriminant models, including the information theoretical models developed later, gray theory prediction model, neural network model, catastrophe theory model, information theory model and collaborative forecasting models nonlinear theoretical model[5-9] . However, in addition to their own factors, there are many other external factors affecting the deformation of the landslide. This paper introduces the non-stationary time series forecasting model to solve this problem, based on its observations of landslide displacement dynamic forecasting model, and achieves good results.

Based on the principle of time series analysis, the total displacement of landslide displacements is divided into periodic term and trend term displacement, and separately for each displacement make model to predict. Cumulative displacement curve of baishuihe landslide in Three Gorges Reservoir monitoring points as an example, researchers use the standard GM (1,1) gray model and roll GM (1,1) gray model for trend items were fitting displacement time series, and take the good trend forecast as a result of displacement term prediction. For the forecast period items landslide displacement components, the paper chooses autoregressive AR (p) model. Predictive value is the total displacement of the two displacement components superimposed sum. The results showed that after the landslide of the total displacement decomposition analysis for each component separately calculated, which can effectively improve the accuracy of prediction, and in the landslide displacement prediction it is proven.

II. TIME SERIES ANALYSIS

A. Time series of concrete separately

The landslide displacement is usually a time sequence of change over time. On the analysis of the displacement

monitoring data of landslide in perspective, this paper chooses the time series decomposition method to establish the landslide displacement prediction model.

Generally, A time series $\{y_t\}$ can be directly or after function transform into additive model forms, such as:

$$y_t = T_t + S_t + C_t + I_t \qquad (1)$$

Where：T_t is the trend item, reflecting the major long-term trends of time-series; S_t is the Seasonal item, refers to the observation data of a seasonal cycle along with the change of seasons , reflects the time sequence of the change of seasons; C_t is the Cycle periodic item, non-seasonal cyclical fluctuation , reflects the time sequence cycle changes; I_t is the stochastic term, means the influence of all kinds of random factors on the sequence, reflects the random variation of time series. This article will make the Seasonal item and Cycle periodic item into the cycle item, temporarily not to consider the random factors on the influence of slope displacement.

B. Model building

The change of Landslide displacement is always controlled by its own geological conditions and external factors. Landslide displacement series is an unsteady time series and it will Monotonically increase over the time, besides, it has a certain regularity. Primarily, trend term displacement which is controlled by its own geological conditions and periodic term displacement affected by external factors. So, Time series additive model can be generalized into the following form[10]:

$$X(t) = \alpha(t) + \beta(t) \qquad (2)$$

Where: $X(t)$ is the displacement time series, $\alpha(t)$ is the trend term function, and $\beta(t)$ is the periodic term function.

Double moving average method is used to separate the trend term displacement. It can effectively eliminate the influence of factors to the periodic term and extract the trend term; Trend term displacement uses the grey model for time series of fitting.

Addition model based on time sequence, Total landslide displacement is the sum trend term displacement and the periodic term displacement. Considering the time series of periodic term displacement change will be affected by many complicated factors, and choose the autoregressive AR (p) model to analyze the periodic item displacements.

III. THE PREDICTION OF BAISHUIHE LANDSLIDE DISPLACEMENT

A. The geology of baishuihe landslide

Baishuihe landslide in the south of the Yangtze, about 56km away from the Three Gorges Dam(Fig. 1). And landslide in the Yangtze River valley wide area, the south is high , north is low , which step to the Yangtze distribution. Landslide classified as monoclinic bedding slope, Lithology of the Jurassic in thick-bedded sandstone, mudstone with thin shape. Rock occurrence is 15 degrees, inclination is 36 degrees. Its north-south length is 600m, east-west width is 700m, the leading edge height is 70m, the trailing edge

elevation is 410m, the average thickness of the sliding body is about 30m, and the volume is about 12.6 million m3. Rock fault structure is not developed, while joint fissures, mainly developed towards the EW and NS - trending steeply dipping fractures.

According to the landslide topography, geological conditions and monitoring the environment. Laiding the 11 GPS deformation monitoring points, three inclinometer drill holes and two groundwater level monitoring holes. Forming four main sliding direction substantially parallel to the Monitoring Profiles line to monitor landslide surface, displacement and changes in groundwater levels deep. ZG93 monitoring points located at a position where is in the Central and downwards of baishuihe landslide.
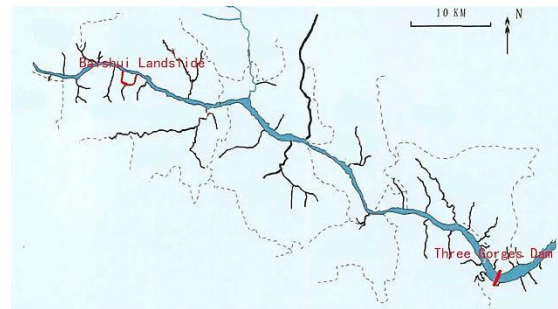

Figure 1. Baishuihe landslide Geography schematic

B. Baishuihe landslide monitoring data analysis

ZG93 monitoring points of Baishuihe landslide whose accumulated displacement and the monthly rainfall curve shown in Fig. 2, Spring Rainfall generally occurs in mid-March to mid-May; Autumn rains occurred in mid-July to mid-September; Prolonged rainfall, continuous rainfall and heavy rains can cause short-term increase in the amount of displacement of the landslide.

And the monitoring data at the monitoring points of January 2006 to December 2008 were analyzed.
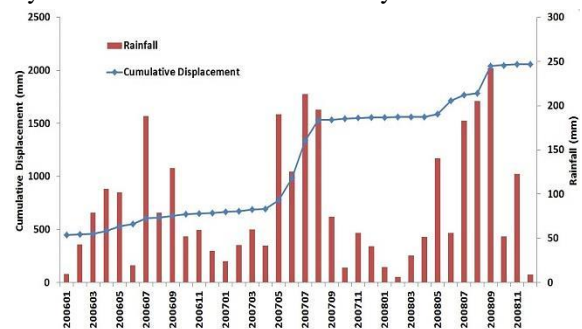

Figure 2. Rain and landslide displacement detection data

C. Trend term separation and prediction

Changes of landslide slope mainly affected by the displacement geological structure itself as well as external factors control the properties. Therefore, in the baishuihe landslide displacement analysis, this can be considered that the total displacement is added by the trend term displacement and periodic term displacement.

In this paper, take the the cumulative displacement of baishuihe landslide monitoring period from January 2006 to December 2008 as a time series of the original sample, and displacement from January 2006 to December 2007 as the initial calculation of samples, and to January 2008 to December 2008 as the predicted displacement test samples.

1) Landslide Displacement separation and prediction

Long-term trend changes in the law that is on behalf of a major landslide displacement evolving, double moving average method is used to separate the trend term displacement, calculated as follows: Observation of time series set a value of $y_t (t = 1,2, \cdots, N)$,One or double moving average were recorded $M_t(1), M_t(2)$, so:

$$M_t(1) = (y_t + y_{t-1} + \cdots + y_{t-n+1})/n \qquad (3)$$
$$M_t(2) = [M_t(1) + M_{t-1}(1) + \cdots$$
$$+ M_{t-n+1}(1)]/n \qquad (4)$$

Taking into account the cyclical displacement of periodic term, where take n = 6, in an average of 0.5 cycles, double means just for one cycle. The resulting double trend term moving average is extracting the value of the total displacement.

Trend term displacement is a time series affected by a variety of factors, with great uncertainty; in essence, it is a dynamic gray system. Therefore, using standard GM (1,1) gray model and roll GM (1,1) gray model to forecast trends term displacement, the displacement time series analysis is as follows:

$$X^{(0)} = \left[x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right] \qquad (5)$$

Once accumulated generating of $X^{(0)}$, and it is generated sequence:

$$X^{(1)} = \left[x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\right] \qquad (6)$$

Among them,

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

$X^{(1)}$ structures background sequence:

$$Z^{(1)} = \left[z^{(1)}(2), z^{(1)}(3), \cdots, z^{(1)}(n)\right] \qquad (7)$$

and,

$$z^{(1)}(k) = \alpha \, x^{(1)}(k-1) + (1-\alpha) \, x^{(1)}(k), k$$
$$= 2,3, \cdots, n。$$

Take $\alpha = 0.5$ build equation:

$$\frac{dx}{dt} + \alpha \, x^{(1)} = b \qquad (8)$$

Where: a and b are parameters to be determined.

Equation (8)'s solution of differential equation is:

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right) \cdot e^{-ak} + \frac{b}{a} \qquad (9)$$

By the least squares method to estimate the parameters, the parameters which are a and b that can be calculated to the ZG93 trend term displacement series model. Taking a and b back in the expression (9), and $\hat{x}^{(1)}(k)$ calculated by the regressive process, you can get the predicted value of the original time series:

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \qquad (10)$$

Based on the above theory to solve the gray, you can get the standard GM (1,1) gray model to predict the trend of displacement items.

On the basis of the standard GM (1,1) gray model, to establish the roll GM (1,1) gray model;

Set $x^{(0)}(k+1)$ as the latest information, and imbed the $x^{(0)}(k+1)$ into $X^{(0)}$; the same time, remove the oldest information $x^{(0)}(1)$;

The newly established model is:

$$X'^{(0)} = \left[x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(k+1)\right] \qquad (11)$$

According to this method, roll GM (1,1) gray model is to build a new model in a time of the original message scrolling iteration, so the landslide displacement prediction.

Based on the above gray theory to solve the question, researchers can get standard GM (1,1) gray model and roll GM (1,1) gray model respectively to predict the trend term displacement value, making the predictive value compares the extract value previously mentioned, as shown in Fig. 3.
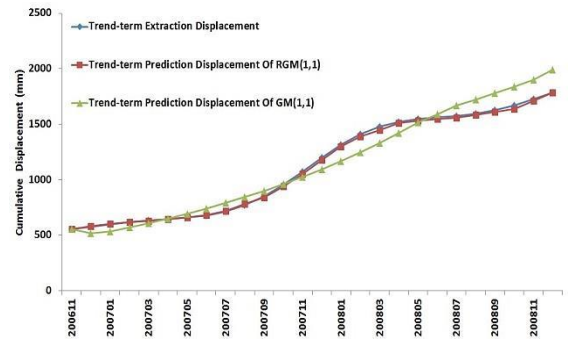

Figure 3. Extract displacement and predictive displacement of trend term displacement

Form the Fig. 3, researchers know that roll GM (1,1) gray model prediction is more accurate than the standard GM (1,1) gray model ,mainly because the rolling GM (1,1) gray model will be as landslide displacement data continued renewal and will be able to secure gradual manner prediction model gradually into the future from the past, always the best indicator of future trends in the real system characteristic data sequence forecasting system, which can obtain a more satisfactory prediction.

But the roll GM (1,1) gray model to predict the trend term displacement curves and Trend Extraction value curve in a small area showing in some errors. The reason is due to the influence of rainfall factors. Long and high intensity rainfall causes the water table elevation, which leads to considerable variation landslide displacement.

2) Separation and prediction of periodic term

a) Separation of Periodic term displacement series

Addition model based on time sequence, excluded the trend item in the original displacement series, researchers can get the periodic term displacement. The result of landslide periodic term displacement series to calculate the sample is shown in Fig. 4.
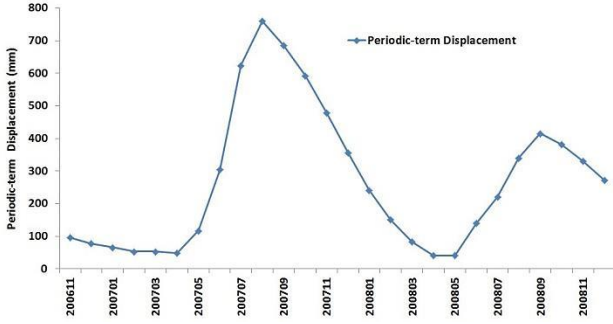
Figure 4. Periodic term displacement

b) Duild the mode and forecast

After removing the original displacement sequence term trend remaining part can be used as a stationary stochastic process to deal with. Of such random series called a time series, with $\{x_t\}$ $(t = 1,2,\cdots,N)$ to represent, where t indicates a time. Establish autoregressive AR (p) model, namely p autoregressive prediction model:

$$x_t = \beta_1 x_{t-1} + \beta_2 x_{t-2} + \cdots + \beta_p x_{t-p} + \alpha_t$$

$$= \sum_{i=1}^{p} \beta_i x_{t-i} + \alpha_t \qquad (13)$$

In the formula, $\beta_1, \beta_2, \cdots, \beta_p$ is p autoregressive model parameters; α_t is white noise series that random errors have mean 0 and variance is σ_{a2}. Autoregressive AR (p) model order and autoregressive parameters estimated use FPE order as selection criteria, the minimum criteria to determine the final prediction error is defined as:

$$FPE(p) = \left(\frac{1 + p/N}{1 - p/N}\right)\left(\hat{r}_0 - \sum_{i=1}^{p} \hat{\beta}_i \hat{r}_i\right) \qquad (14)$$

Specific steps are as follows:

setting a suitable model order limit nk, generally N/3≤nk ≤N/2;

$\{x_t\}$ $(t = 1,2,\cdots,N)$ sample series seek autocovariance function $\{\hat{r}_0, \hat{r}_1, \cdots, \hat{r}_{nk}\}$, r_k is calculated as follows:

$$r_k = \frac{1}{n}\sum^{n-k}(x_t - \bar{x})(x_{t+k} - \bar{x}) \qquad (15)$$

When $1 \leq p \leq nk$, determined least squares parameter estimation $\hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_p$, And substituted it into the formula (14) to calculate FPE (p).

Take the smallest FPE (p) corresponding to p as the order of AR model. $\hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_p$ corresponding value is estimated from the regression parameters.

According to the above theory of time series, make the extracted periodic term displacement values to apply in the model, then to verify the reliability of the model. After autoregressive AR (p) model order, autoregressive parameters estimation, calculation and analysis, get periodic terms of displacement and predicted values extracted compared in the chart, shown in Fig. 5.

Form the Fig. 5, it can be seen that the regression AP (p) model for periodic terms displacement fitting result can better reflect the actual landslide displacement deformation.

However, in 2008 August-September period, there has been displacement between the predicted value and extract the value of some differences, due to continuous rains and the impact of heavy rains during this period, making the landslide displacement showed a minor error. Overall, autoregressive AP (p) model for periodic terms displacement fits better.
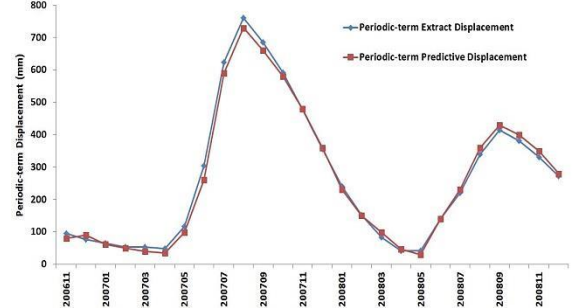

Figure 5. Extract displacement and predictive displacement of periodic term displacement

3) Total landslide displacement prediction

Based on time-series additive model $X(t) = \alpha(t) + \beta(t)$, trend term prediction displacement value add to the periodic term prediction value is the value of the total displacement prediction, as shown in Fig. 6.
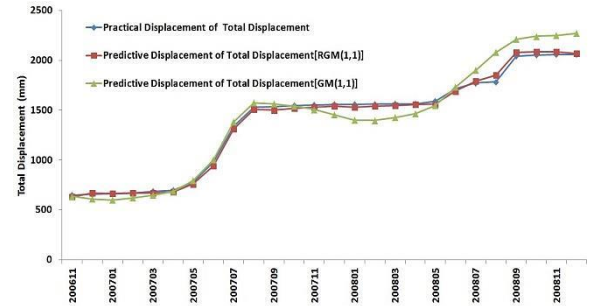

Figure 6. Extract displacement and predictive displacement of total term displacement

As can be seen from Fig. 6, the improved standard GM (1,1) gray model, namely roll GM (1,1) gray model to predict the total displacement obtained relative error is much smaller; and then compare the total displacement monitoring points predicted and actual values, roll GM (1,1) gray model to predict the corresponding displacement curve, its trends and the measured displacement curve more consistent. Roll GM (1,1) gray model by observing the corresponding curve can be seen: from May to August 2007, the cumulative rainfall reached 724mm, displacement curves steep. Displacement error larger point corresponding monitor time in August 2008, primarily because of heavy rainfall on slope displacement is obvious.

IV. CONCLUSIONS

Factors affecting the landslide displacement, there are many factors which can be divided into intrinsic and extrinsic

factors that affect both. Where the internal factors are mainly landslide topography, geological structure and rock 、 soil mechanics and nature of physical factors; Without taking into account the impact of external factors in the case, change the internal factors affecting landslide displacement is a steady growth curve. For the main external factors, including factors landslide rainfall, the water level change, human activities; where rainfall is the most important factor of external factors that influence the landslide displacements from Fig. 2, the rainfall is concentrated in mid-July each year until around mid-September, so it exhibits the characteristics of a periodic, seasonal variation. Therefore, based on time series methods and timing characteristics of landslide displacement, researchers use the second moving average method with Trend isolated displacement landslide displacement, and then by the additive model, separating the displacement of periodic term.

Trend term forecast for displacement, this paper establish standard GM (1,1) gray model and roll GM (1,1) gray model.to use the roll GM (1,1) gray model to predict trends have a small error between the real value and the predictive value, reflecting in Fig. 3, the real value of the curve and the curve fit of the predicted value is also very high. The roll GM (1,1) gray model to replace the original data sequence data with current data continuously, researchers can continue to react the landslide displacement information obtained pursuant to predict the predicted value and the real value very consistent. Rather than the standard GM (1,1) model to predict the value of the farther away from the initial value is greater the error. Complex nonlinear time series and the cycle is a term displacement is affected by multiple factors, using autoregressive AP (p) model to predict displacement cycle entry, external factors can effectively exclude the impact of the situation on the predicted value, so choose from regression AR (p) model can be better predicted.

The combined model for landslide displacement curve fits better, consistent with the actual displacement trends. But prediction curve and the measured curve occurs in a small area some errors because of the complex factors that affect the slope of the external environment could not have added to the actual calculation of landslide displacement of factors ,such as rainfall, the water level changes and human activities and so on. These factors accelerate the development process of landslide displacement or a direct result of landslide produces a certain influence. Therefore, improvements in the model need to be further improved.

ACKNOWLEDGEMENTS

REFERENCES

[1] YIN Kunlong. Landslide hazard prediction and evaluation[M]. Wuhan : China University of Geosciences Press, 2004 : 3-9.

[2] SHI Aiming, KANG Qinrong, XIE Yu. Review about the actuality and tendency of landslide disaster time prediction and evaluation[J]. Chinese Journal of Underground Space and Engineering, 2008, 4(6) : 1 183-1 188.

[3] LI Qiang, LI Duanyou. Study of dynamic predication technique for landslide displacement monitoring[J]. Journal of Yangtze River Scientific Research Institute, 2005, 22(6) : 16–19.

[4] XU Qiang, HUANG Runqiu, LI Xiuzhen. Research progress in forecast and prediction of landslides[J]. Advance in Earth Sciences, 2004, 19(3) : 478-483.

[5] DAI yue. Study on the Method of Regional Early Warning of Landslide in Three Gorges Area Based on Information Model[D]. Beijing : Tsinghua University, 2013.

[6] Guo baoli. Study on the Combination Forecast Model of Annual Rainfall based on the Grey-neural Network[D].Chongqing : Chongqing University, 2014.

[7] HUANG Runqiu, XU Qiang. Synergetic prediction model of slope instability[J]. Mountain Research, 1997, 15(1) : 7-12.

[8] Zhao yanlin, Wu qihong Wang weijun. Strength reduction method to study stability of goaf overlapping roof based on catastrophe theory[J]. Chinese Journal of Rock Mechanics and Engineering , 2010 , 07:1424-1434.

[9] Li xiaojun , Fang bin.Urbanization Quality Zoning Research of Economically Developed City Based On Catastrophe Theory –A Case of 13 Prefecture-Level Cities of Jiangsu Provice[J].EONOMIC GEOGRAPH, 2014, 03:65-71.

[10] DU Juan, YIN Kunlong, CHAI Bo. Study on the displacement prediction model of landslide based on the response analysis of inducing factors[J]. Chinese Journal of Rock Mechanics and Engineering, 2009, 28(9) : 1 783-1 789.