Deep Foundation Pit Deformation Prediction in Complicated Geological Conditions

Wei-yu Wang, Xing-Gao, Ji-hui Ding, Tuo-Zhao

***Abstract*— In the process of excavation to backfill of deep foundation pit, the foundation pit is predicted.The deformation of foundation pit is controlled. The safe excavation of foundation pit is guided. The smooth construction is ensured. Based on the grey prediction model, the concept of optimal dimension is proposed. Based on a deep foundation pit project in tangshan, the optimal dimension of foundation pit prediction in different stages is explored and its precision is studied.**

***Index Terms*— deep foundation pit; grey model; prediction; horizontal deformation of slope top; The vertical displacemnt of the slope**

I. INTRODUCTION

Since 1980s, China's engineering construction has developed rapidly. With the construction of large municipal facilities and the development of a large number of underground space, a large number of deep foundation pit projects emerge. However, due to the imperfect foundation pit design theory, the unpredictability of construction, the great variability of stratum and the complexity of surrounding environment. Accidents such as collapse of foundation pit, cracking of building and burst of pipeline caused by construction of deep foundation pit occur frequently. The foundation pit accident caused great economic loss and serious social consequences. So it is very important to predict the foundation pit deformation. Having a comprehensive understanding of the safety of the foundation pit project and its impact on the surrounding environment to ensure the smooth operation of the project. In case of any abnormal situation, timely feedback and take necessary engineering emergency measures. It will better ensure the foundation pit itself support structure and surrounding buildings security. It is of great significance to the safety of people's lives and property. At the same time, many scholars in China have studied the grey theory. Yong-qing Fu[1], pointed out that the predicted value of the model was generally too large, which to a certain extent indicated that the model was conservative in the prediction of displacement, which was also beneficial from the perspective of guarantee engineering. Dong-Hu [2],pointed out that the grey model has high precision but is only suitable for short-term prediction. Liang-ju Cai[3], analyzed the application of grey system theory in the observation of foundation pit deformation, and used the observation results to predict the deformation and displacement of foundation pit. Yu-hao Zheng[4], researched indicates that the short-term gray prediction results are relatively accurate and have certain effects on guiding foundation pit excavation and support. Wei-ping Wang[5], took the measured data of a deep foundation pit as the original sequence and made a prediction study of the foundation pit. During the prediction process, the model was optimized to make the prediction result closer to the measured value. Based on the grey theory, Sheng-feng Zhao[6], established a time series model with unequal step distance, and used this model for prediction, which verified the applicability of this model in settlement prediction. Many scholars have verified the applicability of grey theory to foundation pit. In this paper, based on the grey model, the foundation pit deformation is predicted, the influence of dimension on prediction precision is explored, and the optimal dimension is proposed.

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II. GREY MODEL THEORY

A system has the fuzziness of hierarchical and structural relations, the randomness of dynamic changes, the incompleteness or uncertainty of index data, then these characteristics are called gray. A system with grey properties is called a grey system. The prediction model established for the grey system is called grey model, which is called GM model for short. It reveals the process of continuous development and change of things within the system. The grey model is to build a grey differential prediction model by means of a small amount of incomplete information. Because the design theory of foundation pit is not perfect, the unpredictability of construction, the variability of the bottom layer is large, and the surrounding environment is complicated, grey theory is very suitable for the prediction of foundation pit.

Grey modeling is based on the analysis of the sequence, an approximate differential equation. The model is a minority, according to the model of the commonly used model is GM (1, 1) model, allowing the data as little as four. Grey model is neither a normal function model nor a pure differential equation model, but a model with partial differential and partial difference. The model has many uncertainties in relation, nature and connotation. The basic idea of modeling is to analyze general differential equations from the perspective of sequence. Define the conditions of its composition and construct a sequence similar to those conditions. Then the approximate differential equation model is established by some means. The modeling process consists of the following steps. First, data validation and data transformation are carried out, and then the appropriate model is selected according to actual needs. The parameters of the model are calculated. Test the accuracy of the model.

III. ENGINEERING EXAMPLES

The proposed foundation pit is located at the northwest corner of yuhua road and xueyuan road. Foundation pit length

198.3m, width 87.5m, safety grade of foundation pit is grade 1. The base elevation is -10m and the excavation depth is about 11m. 20 meters to the east of the foundation pit is xueyuan road, 5 meters to the south is the hospital road, and 10 meters to the west is the hardening road. The south side is supported by pile row and bolt, while the other parts are supported by bolt. The monitoring unit began to monitor the foundation pit on May 28, 2015, and completed the foundation pit backfill on January 15, 2016. The monitoring work was completed.

There are two main types of adverse geological action in this site, karst collapse and goaf. Tangshan downtown karst development zone rock mass is mainly jixian system and the ordovician carbonate rocks, caves dissolve gap development, good connectivity, pipe flow pattern, line karst rate for 20-22% commonly, have enough space for storage and diversion. The underground of tangshan city used to be excavated as a coal mine with a long history and irregular excavation distribution. The underground roadway is complicated and cannot be accurately detected with existing technologies.

Based on a large number of monitoring data of a deep foundation pit in tangshan, the deformation of foundation pit is predicted by using grey model. Because point s14 is located in the middle part of the long edge, affected by the space effect, this point can effectively reflect the deformation of the most vulnerable part of the whole supporting structure. The prediction of horizontal displacement below is illustrated by taking s14 point as an example.

The excavation of the foundation pit was conducted on May 28, 2015 solstice, July 12, 2015. Solstice on July 12, 2015, jan 15, 2016 is the period from excavation to backfilling. The horizontal displacement curve of foundation pit with time is divided into two parts, as shown in Fig. 4. The horizontal displacement of slope top is large and the deformation rate is fast during excavation. The horizontal displacement of foundation pit changes slowly with time from excavation to backfill. In view of the two stages, the foundation pit is in two different working states, this paper will explore the foundation pit excavation stage and the foundation pit excavation completion to the backfill stage respectively.

A. Study on optimal dimension of horizontal displacement on slope top of foundation pit

The accuracy of the monitoring data is too low and does not meet the standard requirements, which is not conducive to the prediction of the grey model. The horizontal displacement of slope top is predicted by the method of first fitting and then forecasting, so that the grey model can be predicted normally. As shown in Fig. 1.

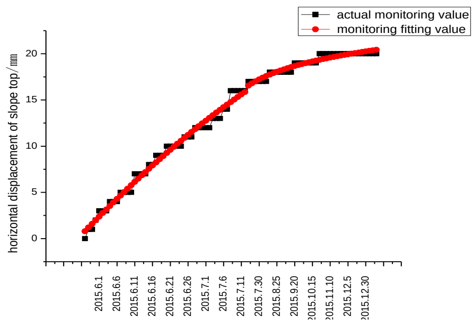

Figure 1. curve fitting of slope top horizontal displacement monitoring value

For the horizontal displacement of observation point S14 of foundation pit, a grey model of equal step time interval is established. After the establishment of models with different dimensions, the model can be tested. If the model meets the requirements, it can be substituted into the model for calculation. The accuracy of the prediction results is compared to determine the optimal prediction dimension.

In the excavation stage, the horizontal displacement at the observation point S14 of foundation pit was investigated in different dimensions. The characteristic of grey theory is that for the data prediction of "less sample and less information", the prediction dimension should not be too much. In the prediction model, the original data should not be less than four dimensions. The data exploration of 4-8 dimensions is enumerated and explained. The step interval of the model established in this stage is 5 days. The grey model can be used to predict the prediction of each dimension.

Table 1 8 dimensional data predicted value

the time of monitor	Monitoring value	Monitoring fitting value	Predictive value	Absolute error	relative error	average relative error	conclusion
2015.5.31	2	1.9838					
2015.6.5	4	3.908	5.0914	-1.1834	-0.3028		
2015.6.10	5	5.7642	6.0759	-0.3117	-0.0541		$C = S_1 / S_2 = 0.1627 < 0.35$
2015.6.15	8	7.5495	7.2507	0.2988	0.0395	0.0349	$p = 1$
2015.6.20	10	9.2612	8.6527	0.60853	0.0657		The best model
2015.6.25	11	10.8966	10.3258	0.5708	0.0523		
2015.6.30	12	12.4531	12.3224	0.1307	0.0105		
2015.7.05	13	13.9283	14.7051	-0.7767	-0.0555		

The calculation process of 4~7 dimensions is the same as that of 8 dimensions.As shown in table 2, on July 10, 2015 of the predicted results, 5 dimensional model's prediction results the highest degree of relative error is only reached 0.001, and 4 dimensional model's prediction results compared with the monitoring data of the relative error is 0.0157, is 5 dimensional model's prediction results error of 15 times. The relative error of the 6 dimensional and 7 dimensional prediction results reached -0.0233 and -0.0536, indicating that the 5 dimensional model's prediction results were closer to the actual observation values.

table 2 Comparison of prediction precision of different dimensions

dimension	Monitoring value on 2015.7.10	Predictive value on 2015.7.10	Absolute error	relative error
8	16	17.5485	-1.5485	-0.0967
7	16	16.8572	-0.8572	-0.0535
6	16	16.3731	-0.3731	-0.0233
5	16	16.0166	-0.0166	-0.0010
4	16	15.7491	0.2509	0.0156

Stress mechanism is different, lead to the stage of excavation of foundation pit horizontal displacement changing with time curve and the excavation to backfill stage stage of foundation pit horizontal displacement curve changes over time there is an obvious change trend. Excavation complete to backfill the curve of phase rate of change are much smaller than the excavation phase rate of change of curve. In order to more accurate in the process of the foundation pit excavation to backfill the forecasting, decided to complete to backfill on excavation stage to study alone. Also, in view of the foundation pit horizontal displacement of slope top S14 point can be attained, the different dimension of inquiry. The prediction model of 4-8 dimensions was explored, and the step interval of the model established at this stage was 10 days. The prediction models with the tested dimensions all meet the requirements, and the grey model can be used to predict the foundation pit excavation from completion to backfilling stage.

table 3 Comparison of prediction precision of different dimensions

dimension	Monitoring value on 2015.12.20	Predictive value on 2015.12.20	Absolute error	relative error
8	20	20.1851	-0.1851	-0.0092
7	20	20.1699	-0.1699	-0.0085
6	20	20.1578	-0.1578	-0.0078
5	20	20.1481	-0.1481	-0.0074
4	20	20.1406	-0.1406	-0.0070

The average relative error method was used to test the accuracy of the grey model. Table 4-3, in the prediction results of December 20, 2015, the dimensions of the relative error of the predicted values and the observed value has no obvious difference, are between 0.007 ~ 0.1, with the decrease of the dimension, prediction accuracy slightly increased.

A. B Study on optimal dimension of vertical displacement of slope top of foundation pit

The 5-8 dimensional model was explored in the excavation phase of foundation pit, and the step interval of the model was 5 days.

table 4 Comparison of prediction precision of different dimensions

dimension	Monitoring value on 2015.7.10	Predictive value on 2015.7.10	Absolute error	relative error
8	2.44	2.7186	-0.2786	0.1142
7	2.44	2.6294	-0.1894	0.0776
6	2.44	2.5862	-0.1462	0.0599
5	2.44	2.6191	-0.1791	0.0734

As shown in table 4, among the prediction results on July 10, 2015, the 6 dimensional prediction results had the highest accuracy, and the relative error only reached 0.0599. The relative error of 5 and 7 dimensional prediction results reached 0.0732 and 0.0776. The relative error of 8 dimension prediction result even reached 0.1142, which exceeded the requirement of prediction precision. It is not recommended to adopt it. The prediction results of the 6 dimensional model are closer to the actual monitoring values.

From excavation to backfill stage, the 4-8 dimensional model was explored, and the step interval of the model established in this stage was 10 days.

table 5 Comparison of prediction precision of different dimensions

dimension	Monitoring value on 2015.12.20	Predictive value on 2015.12.20	Absolute error	relative error
8	3.73	3.7555	-0.0255	0.0068
7	3.73	3.7522	-0.0222	0.0060
6	3.73	3.7378	-0.0078	0.0021
5	3.73	3.7311	-0.0011	0.0003
4	3.73	3.7172	0.0128	0.0034

As shown in table 5, the predictions of a December 20, 2015, the prediction accuracy of different dimension of relative error are less than 0.01, belong to the best level of grey model. 5 dimensional model prediction relative error of the least, the relative error is only 0.003. The relative error of the 4 and 6 dimensional predictions reached 0.0034 and 0.0021. The accuracy of 5 dimensions is nearly 10 times that of 4 and 6. The relative error is greater for 7-8 dimensions. It can be seen that the prediction result of the 5 dimensional model is the closest to the monitoring value.

C Study on optimal dimension prediction precision

All monitoring points in the foundation pit are predicted with the optimal dimension mentioned above, and the prediction precision of the optimal dimension is explored, and its prediction precision k value distribution is shown in figure 2~5.

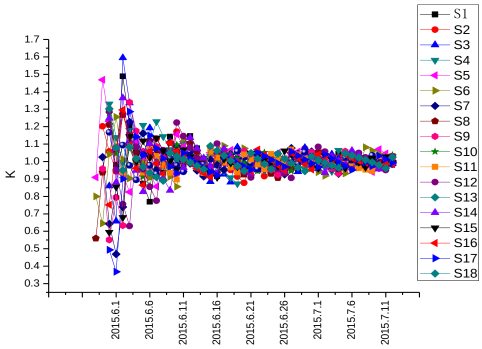

Figure 2. prediction accuracy of horizontal displacement during excavation

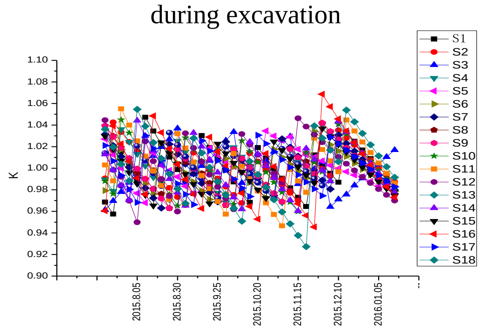

Figure 3. prediction accuracy of horizontal displacement between

excavation completion and backfill stage

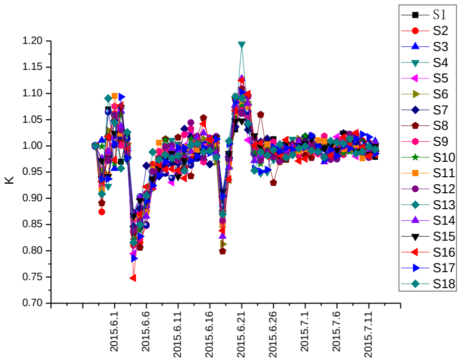

Figure 4. prediction accuracy of vertical displacement during excavation

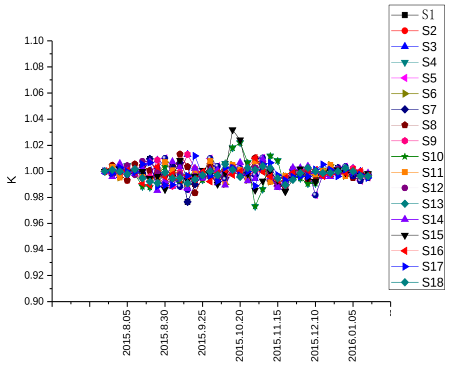

Figure 5. prediction accuracy of vertical displacement between excavation completion and backfill stage.

As shown in Fig. 2 ~ Fig. 4, the value of the correction coefficient k fluctuates up and down at the vertical coordinate of 1. 2015 on May 31 to June 5, 2015, during the k value is volatile, is the result of foundation pit supporting is not timely. This time the top horizontal displacement deformation rate increases, lead to the fitting degree of fitting of measured values is low, so that the prediction error. The fluctuation range of k is between 0.5 and 1.5, and then the k value tends to converge, and the ratio between the final predicted value and the monitored value is between 0.9 and 1.1.Compared with the excavation phase, the k fluctuation range from the completion of excavation to the backfill phase is small and stable. The fluctuation range of k is between 0.95 and 1.05.

As shown in Fig. 4 ~ Fig. 5, June 18, 2015, the vertical displacement anomalies mutations, suddenly decrease. Due to the abnormal mutations, predicted results deviate from the original trend prediction curve, from June 17 to 23 appear larger fluctuation. And then returns to normal, the range of the ratio of the measured data and predicted values k in between 0.95 ~ 1.05. Completed in excavation and backfilling stage its range is very little. According to the study of k value in the figure 4, the fluctuation range of k is between 0.985 and 1.015.

IV. CONCLUSION

As a grey system, the foundation pit deformation is predicted by using grey model. In the process of foundation pit excavation and foundation pit excavation and backfill, the optimal dimension of the prediction model is explored and its precision is analyzed, and the following conclusions are drawn:

1.In the top horizontal displacement prediction, in the foundation pit excavation stage 5 dimensional prediction model is the optimal prediction model, in the foundation pit excavation and backfilling stage, no effect on the dimension precision of prediction results.

2.In the vertical displacement prediction of slope top, in the foundation pit excavation stage ， 6 dimensional prediction model is the optimal prediction model. In the foundation pit excavation and backfilling stage,5 dimensional prediction model is the optimal prediction model.

3.In the prediction of slope top horizontal displacement, under the optimal dimension, the range of prediction precision k at excavation stage is 0.9~1.1, and the range of prediction precision k from excavation completion to backfill stage is 0.95~1.05.

4.In the prediction of slope top vertical displacement,under the optimal dimension, the range of prediction precision k at excavation stage is 0.95~1.05, and the range of prediction precision k from excavation completion to backfill stage is 0.985~1.015.

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