Research on the monitoring early warning system for the foundation pit construction passing through the original subway elevated pile foundation on the basis of information exchange

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Abstract. The research background is the foundation pit excavation of the new metro station which passes through the existing metro elevated pile foundation. By using the finite element analysis method, the numerical simulation of the excavation of the foundation pit is carried out. The supporting structure in the excavation of the foundation pit and the safety of the original subway Viaduct Pile close to the foundation pit are studied. Through the research, the calculation results of the force and displacement deformation of the supporting structure and the original Metro Viaduct Pile in the process of foundation pit excavation are obtained. After comparing the above calculation results with the monitoring values, the reasonable optimization scheme for the support structure is obtained. In addition, through the method of building database, the information of structure attribute between the finite element model and BIM model is exchanged. On this basis, the visual programming method dynamo is introduced, the command flow and some custom nodes are compiled, and the mutual flow of monitoring information and early warning information between the finite element model and BIM model is completed. This realizes the safety control method of subway construction based on BIM Technology, which integrates engineering information, monitoring and early warning.

1. Introduction

As a convenient and fast way of public transportation, subway plays an increasingly important role in the city. However, with the continuous construction of metro lines, it is inevitable that new metro lines will cross the existing lines.[1][2] Therefore, the support structure and construction monitoring of the foundation pit have a great impact on the safety of the project.[3][4] Many scholars and engineers have carried out research on this. In the research, they usually use the method of finite element simulation to analyze the data and compare it with the monitoring data.[5] But this method can not directly integrate and compare the two kinds of data.

With the wide application of BIM Technology [6], it plays a great role in infrastructure construction [7][8]. The development of BIM Technology provides a theoretical basis and implementation method...
for solving the integration of theoretical value and monitoring value data and making an intuitive comparison.

2. Engineering survey
The foundation pit of the station passes through the existing in transit line section, and the bridge piles of section A11 and A12 in the line are located on both sides of the main structure of the station. The distance between the bridge pile and the bored pile edge away from the excavation foundation pit retaining structure is 3.86 and 6.16 m respectively, as shown in Figure 1.

![Figure 1. Plan of foundation pit excavation](image)

In the process of foundation pit excavation, it is necessary to strictly control the settlement deformation and possible displacement of bridge piles between A11 and A12, so as to ensure that the existing lines meet the operation design requirements. Because the existing line cannot be stopped, the excavation of the foundation pit has certain construction difficulty, and the monitoring of the foundation pit itself and the bridge pile is the key problem of the project in the excavation process.

3. Finite element analysis and calculation

3.1. Establish finite element model
This paper mainly uses PLAXIS to build the model. The process of foundation pit excavation is simulated by reasonable setting of all structural parts and excavation conditions. Through the finite element analysis and calculation, the stress and deformation of soil and two bridge piles in the excavation process are obtained. After confirming the parameters and dimension data, establish the finite element model as shown in Figure 2.

![Figure 2. Finite element analysis model](image)

3.2. Calculate
According to the construction organization design and actual situation, try to be close to the actual construction situation, and set the excavation condition in the finite element model. Through the analysis, the specific 9 working conditions are determined.

Before setting the working condition, the mesh of the finite element model has been divided, and the dividing standard is fine. During the calculation, one point shall be selected respectively on a11 and A12 bridge piles and concrete support beams, and four points shall be selected as the calculation points on the ground surface of the excavation site of the foundation pit. Through the finite element calculation, the cloud chart of the foundation pit excavation finite element model shown in Figure 3 is obtained.
4. Conclusion

4.1. Comparative analysis of surface subsidence

Drawing the monitoring values of four calculation points (DBC58-02, DBC62-02, DBC68-02, DBC69-02) selected from the surface. Obtain the curve of four monitoring values of surface settlement as shown in Figure 4.

![Figure 4. Curve of surface settlement monitoring value](image)

According to the simulation calculation, the cumulative control index of surface subsidence is ±30mm, and the change rate control index is ±3mm/day. Through the comparative analysis of monitoring value and early warning value, it can be seen that the excavation construction at this stage meets the requirements and is much less than the specified index.

4.2. Comparative analysis of bridge pile settlement

The monitoring data of jgc01-01 and jgc02-01 are obtained by the settlement automatic monitoring device arranged on the bridge pile and plotted as a curve, as shown in Figure 5 below.

![Figure 5. Curve of monitoring value of bridge pile settlement](image)
In the excavation construction, the two monitoring points basically show opposite settlement performance since the 10th day. However, the daily change rate is 0.03mm/day and 0.02mm/day, respectively, which do not exceed the warning value of daily change rate. Since the 23rd day, the settlement trend of the two piers is the same, the maximum cumulative value is 0.58mm, and the settlement warning value is not more than 3mm. The monitoring data of the two bridge piles are stable, and the structure of the bridge piles and the track area is safe.

5. Optimization analysis of support structure

Through the comparative analysis of the monitoring value and early warning value in the early stage of foundation pit excavation, it is found that the deformation monitoring value at this stage is far less than the early warning value. The main reason is that the supporting structure is too safe. In order to speed up the construction progress and obtain greater economic benefits, based on the results of the previous comparison, a more reasonable supporting scheme is optimized.

5.1. Optimization of support structure

The excavation from 22.17m to the bottom is stable due to good geological conditions. It is too safe to set five layers of support in the initial support scheme. After combining the soil layer information and monitoring data, the optimized support structure as shown in Figure 6 is adopted.

![Figure 6. Optimized support system](image)

The support mechanism avoids the phenomenon that four layers of soil in the same excavation stage in the initial support system. In addition, the third and fourth layer support spacing is expanded, and the second and third layer support spacing is reduced, which effectively guarantees the stability and safety of the second excavation construction.

5.2. Comparative analysis results after optimization

Through the finite element simulation calculation of the optimized support structure, the settlement curve of the bridge pile under various working conditions is obtained, as shown in Figure 7.

![Figure 7. Settlement value curve of bridge pile after optimization](image)

By comparing the optimized early warning value with the monitoring value, it can be found that the optimized calculation results are more close to the monitoring data and meet the requirements of construction safety.
6. Information exchange modeling of finite element model and BIM model

6.1. Restrictions on information exchange
The non-interoperability of information is mainly due to the different information formats of FEM and BIM. In order to find a way of information transmission that can be used by both, many scholars have carried out research on it.[9] [10] However, there are still some problems. First, it is impossible to integrate all kinds of information in the BIM model for the realization of simple information interchange; second, part of the way to realize real information interchange is to find a third-party model for information integration, which greatly increases the workload.[11]

6.2. Call database for information exchange
Both the finite element model and BIM model can be built by using the information in the database. Therefore, dynamo can be used to call the database established by the command flow of the expert system in PLAXIS. In this way, the structural attribute information can be exchanged between the finite element model and BIM model.

In this paper, the finite element model and BIM model of the support structure of the foundation pit excavation are established by the way of information exchange based on the database mentioned above. The implementation process and effect are shown in Figure 8 below.

![Figure 8. Implementation process and effect of information exchange modeling](image)

Now, the exchange of structural attribute information between finite element model and BIM model is completed by means of database information exchange. Next, the exchange of other information in engineering information will be realized.

7. Monitoring early warning system
Through dynamo writing command flow, the relationship between monitoring value and early warning value of each point in each working condition is processed, which is embodied in BIM model of foundation pit excavation. By viewing BIM model, you can view the monitoring value, early warning value and the relationship between them under specific working conditions.

The data acquisition layer of the system mainly obtains the monitoring data through the automatic monitoring system, obtains the early warning value through the finite element simulation calculation, and compiles them into the database after the preliminary arrangement. The processing layer will call this data in the next step. The implementation effect is shown in Figure 9.
Figure 9 shows the comparative analysis of measuring point A and B under the same working condition and comparison analysis with A measuring point under different working conditions. The information of measuring point, working condition, monitoring value, early warning value, the difference between the two and whether it is early warning is reflected in BIM model. This also completes the exchange of other information in the engineering information in the two models.

8. Conclusion

(1) Through the finite element calculation and analysis, the early warning value is obtained, and compared with the monitoring value, it is found that the settlement and deformation meet the design requirements. Then through the reasonable optimization of the support system, arrange the construction organization sequence and key monitoring. The reasonable control of settlement value of bridge pile during excavation is realized.

(2) Using database as information carrier, the structural attribute information in engineering information is exchanged in finite element model and BIM model. Combined with command flow and other forms of automatic modeling, it saves a lot of time. Because the modeling is based on the same database, the modeling error is fundamentally solved.

(3) Using dynamo to write command flow and user-defined nodes, automatic data extraction and comparison are realized, and a monitoring early warning system is established. The system is conducive to the control of construction safety and monitoring during the construction process, and effectively saves time and energy.

(4) This paper explores a way to combine BIM Technology with finite element analysis and calculation. This paper uses the idea of programming calculation to solve the problems in practical engineering, and initially explores the information construction of engineering industry.

References

[1] Lai Hongpeng, Zhao Xin, Kang Zuo. Settlement control standard of existing metro line when new metro tunnel is underpass in Loess Area [J]. Journal of transportation engineering, 2018, 18(04): 63-71

[2] Huang Hongwei, Huang Xu, F. Helmut S. numerical simulation study on the influence of foundation pit excavation on the underlying operating shield tunnel [J]. Journal of civil engineering, 2012, 45(03): 182-189.

[3] Liu Feng, Peng Chaoguo. Design and measurement of foundation pit support of Nanjing shuangmen building complex [J]. Journal of geology, 2011, 35(03): 322-327

[4] Wang J, Wu Y, Liu X, et al. Areal subsidence under pumping well-curtain interaction in subway foundation pit dewatering: conceptual model and numerical simulations[J]. Environmental earth sciences, 2016, 75(3):198.1-198.13.

[5] Zhang Yucheng, Yang Guanghua, Yao Jie, et al. Numerical simulation analysis of the influence of foundation pit excavation and unloading on the existing subway tunnel below [J]. Journal of geotechnical engineering, 2010, 32(S1): 109-115

[6] Ghaffarianhoseini A, Tookey J, Ghaffarianhoseini A, et al. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges[J]. Renewable and Sustainable Energy Reviews, 2016.

[7] Eleftheriadis S, Mumovic D, Greening P. Life cycle energy efficiency in building structures: A
review of current developments and future outlooks based on BIM capabilities [J]. Renewable and Sustainable Energy Reviews, 2017, 67.

[8] María Eguaras-Martínez, Marina Vidaurre-Arbizu, César Martín-Gómez. Simulation and evaluation of Building Information Modeling in a real pilot site [J]. Applied Energy, 2014, 114.

[9] Yang Qingnian, Zheng Junjie, Ding Liyun, et al. Three dimensional numerical simulation of deep foundation pit excavation adjacent to viaduct [J]. Journal of Huazhong University of science and Technology (NATURAL SCIENCE EDITION), 2010, 38 (06): 120-123 + 128

[10] Qin Ling, Deng Xueyuan, Liu Xila. Industrial foundation classes based integration of architectural design and structural analysis [J]. Journal of Shanghai Jiaotong University (Science), 2011, 16 (01): 83-90

[11] Ding L Y, Zhong B T, Wu S, et al. Construction risk knowledge management in BIM using ontology and semantic web technology [J]. Safety Science, 2016, 87.