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Application Research of BIM Technology in Computer Aided Design of Building Foundation

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With the rapid development of the domestic high-rise buildings, the scale and depth of deep excavation pit projects are also expanding. More and more deep foundation pit appear in built-up and densely populated areas, which imposes higher requirements on the excavation engineering design. BIM technology, as a new technology in the construction industry, has gradually been used in various fields. In this paper, taking the deep foundation pit project of Changsha Zhongqing Square for example, the BIM software REVIT was used to establish a 3D model of excavation pit supporting. The structural collision checking, simulation of construction process and deepening design of nodes were carried out to provide guidance to building construction. The problems and causes of applying BIM technology in the design of building foundation pits were analyzed and summarized. The expectations on the development of BIM technology in the field of building foundation pits were also made.

1. Introduction

With the large-scale construction of high-rise buildings in China, the development and utilization of urban underground space is also expanding. The projects of deep foundation pit with an excavation depth of more than 20m continuously appear. Most deep foundation pits are concentrated in the built-up and densely populated urban areas. Due to small construction site and complicate construction conditions, more and more attention has been paid to how to reasonably design the supporting of deep foundation pit, reduce the impacts of foundation pit during construction on the surrounding environment, and improve the construction quality of deep foundation pit.

The project of deep foundation pit is a major system engineering, which involves a wide range of specialties, complicated construction conditions, great impacts from geological conditions, underground structure and construction site. Therefore, it requires scientific planning and design, reasonable construction organization and a sound monitoring system. BIM technology is a digitization tool used for engineering design and construction management (Xia and Ma, 2014).Through integrating the parametric model with a variety of information related to the project, it can be used for project design and construction management. It is advantageous to use BIM technology in the construction process of deep foundation pit, especially program design in the design stage, visual representation, automatic collision checking, construction drawing design and cost control and many other aspects. It can facilitate the systematic verification of design, construction deepening guidance, control of construction progress and project amount (Kang et al., 2015). It can also greatly improve the centralization degree of high-rise building projects, and improve the quality and efficiency of the entire project, especially the design work.

2. Overview of BIM technology

The Building Information Modeling is abbreviated to BIM. Based on 3D digital technology, BIM can create and use the digital model to carry out design, construction and operation management in the whole process of the project. It can use 3D software tools to create complete digital models of building project, and can include detailed engineering information in the model. In addition, the models and information will be used in the full

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building life cycle which includes construction engineering design, construction management, operation management, etc (Adamu et al., 2015). The features of BIM mainly include as follows:

(1) Information integration

The core of BIM technology is to establish a 3D model database through the digital information. When the designer is conducting program design, the relevant design information can be directly extracted from the database. This kind of design method is different from the traditional 2D design mode. The designers can quickly and easily simulate the real information of buildings by digital information, including the geometry and spatial relationship of each member inside building, building information and features of each design element (such as beams, plates, columns, piping, equipment), as well as direct connection mode, load condition of each member, etc. In addition, the 3D deepening design can also be made for each complex building node of a project, which is also the biggest drawback of 2D drawings.

(2) Operation coordination

BIM technology can be used to build a new platform for synchronous operation for the parties involved in the construction process of a building. Through the platform, the owner, designer, construction unit, supervision unit and post-stage operational manager can timely communicate information, pay attention to all aspects in the construction process, and improve the project quality without affecting work efficiency(Mill et al., 2013). With the 3D model created by BIM technology, the collision checking can be conducted on the structure, pipelines and other systems. Based on meeting the different laying principles of each specialty, the conflicts or effects between the various systems will be automatically found out to improve the work efficiency of the entire design team and enhance the communication between specialties.

(3) Working relevance

One of the basic characteristics of BIM is to keep correlation of building information in the modeling process. Therefore, the changes in any content of the building can be timely reflected onto the plane, elevation, section of the 3D model by using the BIM technology (Nath et al., 2015). It facilitates the review and changes by engineering personnel, so the engineers don't need to deal with the drawings one by one. This feature enables the building information to be passed on to the technical personnel of relevant specialty in the shortest time, which saves manpower, reduces costs and improves efficiency.

At present, the introduction, application and development of BIM technology in China are concentrated in the field of building structure. The application of BIM technology in underground engineering is basically limited to the design and construction process of subway station, etc. The BIM technology is mainly used for the cooperation of specialties (Merschbrock et al., 2015), integrated collision checking of pipelines and simulation of construction process. Based on the advantages and domestic applications of BIM technology, the study about in-depth application of this technology in the preliminary investigation, program design, construction management and other aspects of deep foundation pit projects, and giving full play to the 3D visualization, collaborative work, detailed design and resource sharing and other advantages of this technology, is of great significance to project construction.

3. Application of BIM technology in foundation pit project

3.1 Preliminary comprehensive investigation

In the preliminary investigation and planning stage of foundation pit project, based on the existing geological investigation data, structural design program and information of surrounding environment, the design programs of foundation pit system are preliminarily compared, and then the environmental model related to the designed foundation pit is established (Motawa et al., 2013). The model includes geological and topographical conditions, surrounding special building structures, underground pipelines and building foundation and other information. Based on the above information, the preliminary selection, calculation and analysis of foundation bracing program can be made.

3.2 D visualization design of supporting program

The 3D design is made based on the supporting program after preliminary calculation and analysis. The 3D solid model of foundation supporting system is established based on the previous environmental model. Considering the terrain, roads, pipelines, buildings and other conditions around the foundation pit, the vertical and horizontal retaining structure of foundation pit are reasonably arranged. Because of the intuitive visualization of 3D model, the owner and the various designers can communicate with each other by using BIM model, so as to find the problems in the design for further feasibility studies and optimization. Even in the latter construction process, if some deficiencies are found in the program, the BIM model can also be used for adjustment, which can help improve efficiency and maximize the value of BIM.

3.3 Collaborative design

In the design process of foundation pit, BIM technology can provide a good design platform for the designers who are specialized in building, structure, foundation, foundation pit and other specialties. The collaborative design can be achieved by setting the collective sharing of central document of a project. Each professional designer can use suitable BIM modeling software to establish a BIM model related to the certain specialty. After linking and synchronization with the central document, the newly added or modified information from each specialty will be automatically added to the central document. Therefore, other specialties can view the models at any time, the information sharing is achieved, and unnecessary design changes are reduced.

3.4 Deepening design

Compared with the conventional graphic design method, BIM technology has an advantage in 3D design of conventional components (such as piles, walls, supports) during the design of foundation pit. In addition, BIM technology has a prominent advantage in the design of some complex nodes or members, such as latticed column, stiffening battened plate under trestle beam, steel bars at the haunched node of support, etc. With BIM software, these complex components can be generated into a new component by the parametric design. This kind of component is similar to the block file in CAD (Sackey et al., 2014). The component can be arranged arbitrarily in the model and it can be quickly modified by adjusting the parameters. Meanwhile, the total amount of materials required in different conditions can be counted, which can significantly save manpower and materials, as well as facilitate construction management and cost control.

3.5 Collision checking

Collision checking is one of the most mature applications of BIM technology. The super high-rise buildings have a large number of complex pipelines, so the collision problem between pipelines or beam and column need to be addressed (Kim and Yu, 2016). However, there are a lot of upright post piles and laced columns in the vertical support structure of foundation pit. With the BIM model, the spatial relationship between upright post piles and engineering piles, laced columns and the underground structure can be more visually fed back to the designers. Therefore, the transferring of design information between specialties is strengthened and the design and construction quality are improved.

3.6 Construction process simulation

The biggest difference of foundation pit project from other construction works lies in earthwork construction (Clevenger and Khan, 2016). Due to the limits from surrounding environment, site or vertical support system, the earth excavation program shall be considered during the design of foundation pit. The earth excavation program involves arrangement of unearthed positions, earthwork excavation sequence, lane design, etc. The use of BIM technology for simulation of 4D construction process can fully demonstrate the program so as to enhance communication and improve work efficiency.

4. Example of applying BIM technology in foundation pit design

4.1 Project review

The project of Changsha Zhongqing Square Center is located in Changsha Peace Avenue. The north side of the foundation pit is close to a high-rise building, and the south side is adjacent to the subway tunnel. Therefore, the foundation pit design is difficult, and there is a high requirement on the design accuracy. Because the total area of foundation pit is too large, it is divided into three parts for construction. The foundation pit in the middle buffer area is selected for design and research by BIM technology. The foundation pit is 123m long, 63m wide, 23m deep averagely, and 24.1m deep locally. The foundation pit adopts diaphragm walls on three sides, and cast-in-site bored piles on one side as the envelope. And four rows of inner supports are set for horizontal supporting. The soil layer is shown in Table 1.

Table 1: Soil mechanical parameters

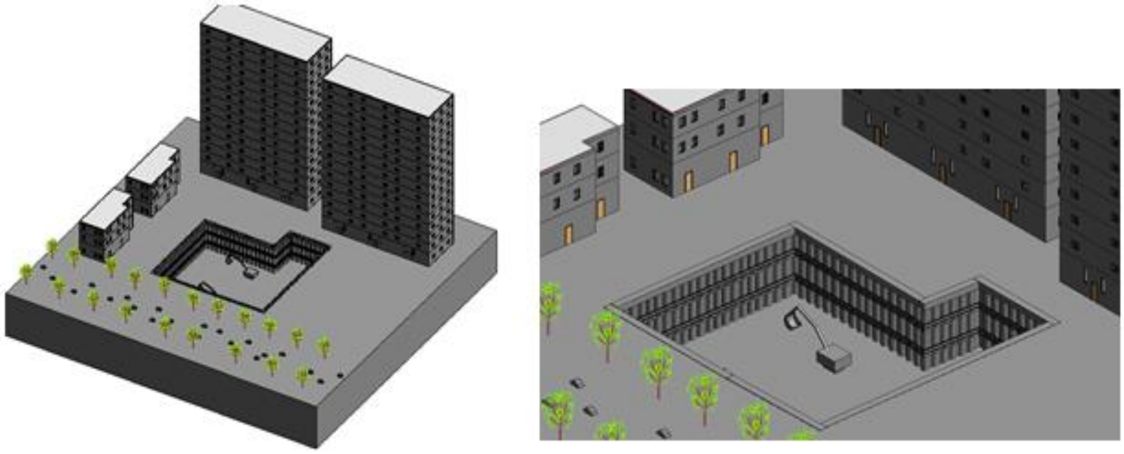
Seril	Soil	γ (KN/m^3)	*c* (KPa)	*φ* (^{o})	K (m/d)
1	clay silt	17	8	8	0.05
2	sandy silt	20.5	15	32	0.5
3	sandy silt	20.2	9	32	0.5
4	fine sand	20.5	0	32	5

4.2 BIM design results

By using Autodesk's BIM modeling software Revit Architecture and Revit Structure, the 3D design of foundation pit supporting is carried out. In addition, the models of supporting structure and basement structure, earth excavation model and model of steel bars at haunched node of support are completed.

(1) Model of retaining structure of foundation pit

With the software Revit Architecture and Revit Structure, 3D model of retaining structure of foundation pit is shown in Figure 1(a).



(a) *(b)*

Figure 1: BIM Model of foundation pit and earth excavation scheme

(2)Structural collision checking

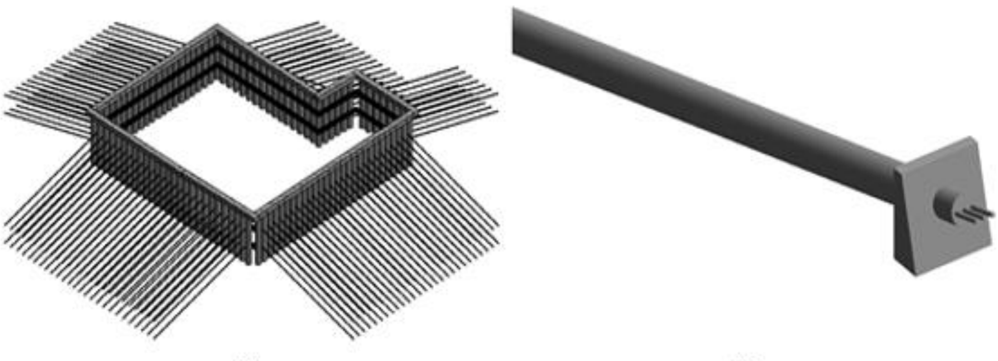
With the model of supporting structure, foundation model and model of underground structure, the collision checking function of BIM can be used to check the arrangement of supporting structure and whether there are conflicts between the structure and other building structures so as to make timely adjustments.

(3)Simulation of earth excavation program

Due to space limitations, during earth excavation, if the earthmoving ramp is set as a conventional straight slope, it is difficult to go down to the earthmoving elevation by avoiding the supporting structure in the case of the maximum slope. Therefore, the earthmoving ramp is designed to a curved ramp, so that it can go down to the desired elevation by both meeting the requirements of minimum slope and avoiding the supporting structure. However, the ordinary 2D drawings are difficult to make a clear bright explanation. The spatial 3D model established by Revit software can achieve this goal. The specific model is shown in Figure 1(b).

(4)Deepening design of complex nodes

According to design requirements, the family file of laced columns, battened plates under trestle, deepening design model of steel bars at haunched node of support can be established in Revit. By direct input of parameters, the required 3D node model can be automatically generated. The detailed model is shown in Figure 2.

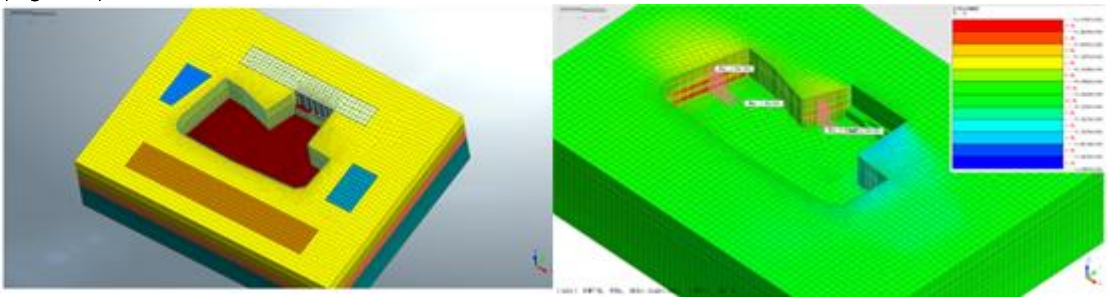


(a) *(b)*

Figure 2: BIM Model of excavation structural model and details

5. Combination of BIM technology with numerical simulation technology

The combination of BIM modeling technology with numerical simulation can make full use of the modeling accuracy by BIM technology. With numerical simulation, the simulation analysis and forecasting can be made on engineering problems. The numerical simulation and analysis results of BIM model are shown below. (Figure 3)

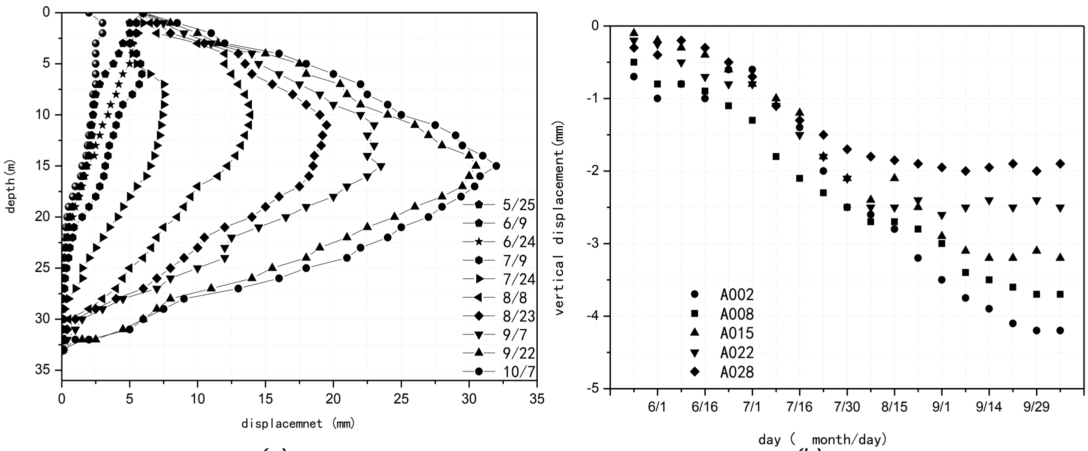


(a) (b)

Figure. 3 Foundation numerical simulation model and analysis results

5.1 Monitored data for the supports of the foundation pit

Figure. 4(a) shows the data monitored by the inclinometers on the side of the foundation pit near the high-rise building. A comparison of the monitored data with the simulated results obtained by the finite element model indicates that the results are similar. When the excavation of the foundation pit was at the bottom of piles, the monitored displacement was 31 mm as compared to the simulated displacement of 27.8 mm. This suggests that the analytical model and the selection of the constitutive relationship and parameters are suitable for producing reasonably conservative results.



(a) (b)

Figure 4: Pit horizontal displacement and settlement monitoring data

5.2 Monitored settlement of the high-rise building

Figure 4(b) shows the monitored settlement of the high-rise. At the beginning of the construction of the support piles, the settlement wasless than 1 mm. Therefore, the effect of the foundation pit construction on the settlement of the high-rise building during the initial construction stage can be ignored. As the excavation of the foundation pit continued, the settlement became deeper and was at the maximum of 4.25 mm when the excavation reached the bottom of the foundation pit. The average estimated settlement rate is from -1.2 mm/d to +0.35 mm/d, which is within the acceptable standards. Further, it can be seen from Fig. 15 that the settlement area of the high-rise building is larger between 30 June and 15 August. This can be attributed to the fact that the excavation of the foundation pit reached a point 17 m from the bottom of the Type A piles, which exceeded the embedded depth of the building's foundation and induced further settlement. At the late stage, when the excavation reached the bottom of the foundation pit, the settlement continued to increase, but the rate of settlement slowed down due to the strengthening of the foundation soil by the grout below the third support.

6. Conclusion

Appearance of BIM technology has brought a revolution in the construction industry. Through the application of BIM technology in the foundation pit design of buffer area of Wuhan Greenland Center, the BIM model reflects the advantages, such as 3D visualization, collaborative design, deepening design and construction process simulation, etc., which determines its future position in the construction industry. The popularization of this technology in deep foundation pit project still has some problems to be solved, and 3D design also has a long way to completely replace 2D design. However, this design mode will lead the design industry changing from simple geometric representation to building information integration model as well as from single specialty to collaborative design of various specialties. It has great significance for the future development of the construction industry.

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