A TIM-based Method of Automatic Generation of FE Models for Pit Engineering

Lisheng Chen¹, Zhiyi Li¹, Taili Chen¹, Guoqiang Zhao¹, Yi Shen²,*

¹ Shanghai Urban Construction Municipal Engineering (Group) Co., Ltd., Shanghai 200065, China
² Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai 200092, China
*E-mail: shenyi@tongji.edu.cn

Abstract. BIM (Building Information Modeling) technology has developed rapidly in many fields of civil engineering. However, in pit engineering, the method of automatically generating FE models by BIM models is not as mature as that in tunnel engineering. There are still some problems in it, such as the lack of stratum data and construction data, the limit of geometric models, and the weak of the integration of numerical results with BIM platform. To solve these problems, this paper presents a TIM (Tunnel Information Modeling)-based solution, which is more specific to underground engineering. Firstly, a normalized numerical pit model is built. TIM models, stratum data and construction data, all these required by numerical model are integrated in iS3 platform. Then a program is developed to obtain the data that has been supplemented or modified from the databases and automatically draw the profiles, then generate the input files to automatic calculation. The integrated TIM/FEM software based on iS3 platform is developed to import the result files to finish the post-processing and schemes assessment and optimization. This method is successfully applied in the pit project of Haikou Wenmingdong Tunnel, shortens the modeling time, and improves the modeling quality and the integration level of TIM/FEM.

1. Introduction
BIM (Building Information Modeling) technology has been widely used in many fields of civil engineering due to its integrated information, unified data standards, and the support of multi-party collaborative work, which can realize the digital management of the whole life cycle of a project. However, compared with architectural engineering, there is still a gap of its application in underground engineering such as tunnels and pits.
Many scholars have carried out relevant researches on the applications of BIM in pit engineering: Hammad et al.[1] proposed a new 4D model for the automatic identification of construction site of pits; Luo et al. [2] provided a method to improve the efficiency and accuracy of checking process of deep pit construction plans; Wu et al.[3] developed a BIM-based monitoring method for deep pits; Li et al.[4] provides a BIM-based automated safety risk recognition mechanism for the pre-construction stage of pits. Many scholars achieved the applications of BIM in pit engineering [5-7]. These researches have used BIM technology into design and construction stage. However, the finite element analysis (FEA), which is important for the safety, has not been linked with BIM, and modeling and result viewing can only be operated in the finite element software. The information in the BIM platform has not been used, and it is valuable to carry out the research on the BIM-based FEA. Based on BIM technology, TIM (Tunnel Information Modeling) technology proposed information solutions
to the specific problems of underground engineering. It considers stratum, construction and FEA that are ignored by BIM. Meschk et al. [8], Alsahty et al. [9] and Ninic et al. [10] carried out researches on the link of TIM and FEA of underground projects such as tunnels and presented methods of structural analysis by means of TIM-based numerical modeling. However, most of these researches focused on tunnel projects, and few on pit projects. In addition, their focus of automatically modeling was only on geometrical pre-processing, that is, stratum data or construction data were missed. Therefore, the research is still in the preliminary stage, and there is still a large room for the improvement in modeling efficiency and accuracy.

This paper presents a TIM-based method of automatic generation of FE Models for pit engineering. For its preparation, a normalized numerical pit model is built, and all required data are integrated in iS3 platform [11]. Then, a program is developed to obtain the data from the databases for drawing the profiles and calculating automatically. Finally, the results files are input to iS3 platform again for post-processing and scheme analysis. This method is applied in the pit project of Haikou Wenmingdong and of certain significance for TIM technology to be further integrated into pit engineering.

2. Project profile

2.1. Basic information

Wenmingdong tunnel is located in Haikou city, starting from the west intersection of Bailong Road and Wenmingdong Road, then crossing west Binjiang Road and Nandujiang Road and end at the intersection of Qionghshan Avenue and Second Dongheng Road. The total length of it is 4380 m, of which the tunnel section is 2720 m and the connecting road is 1660 m. In the land section, slope excavation, SMW piles, bored piles, waterproof curtain and underground diaphragm walls are used for support, while bored pile, waterproof curtain and SMW piles are used in the river section. Steel sheet pile and mud pipe bag are used in the cofferdams in the river section. The maximum depth of the pit is 22.6 m, which requires strict control of pit deformation and ground settlement. Adverse geological conditions have a great impact on the bracing system, especially for pit-in-pit, as is shown in figure 1.

![Diagram of Wenmingdong tunnel layout](image)

**Figure 1.** Layout of pit-in-pit.

2.2. Automatic modeling

For automatic modeling, a normalized numerical pit model should be built first, and all the data required by it should be integrated. Then the program should be developed to obtain these data from
the databases, and automatically finish the modeling and calculation in order to reduce the workload. The results should also be integrated into the TIM platform, so as to achieve the purpose of information management of whole life cycle of a project in one platform.

Normalized Numerical Pit Model. The normalized numerical pit model is to standardize the data needed for modeling. The data depends on models and finite element software. The normalized numerical model is suitable for the pits with bracing system of retaining walls + supports, and FLAC is selected as the software. According to its modeling steps and characteristics, the required data are divided into four categories: geometric parameters, structural parameters, stratum parameters and construction stages parameters.

The geometric parameters include the width and depth of a pit, which is used to determine the boundary of the model, as shown in figure 2. According to its size and the average distance between nodes, the number of nodes n and m in the horizontal and vertical directions can be determined.

![Figure 2. The sketch of a pit model.](image)

2.3. Data integration
Unlike architectural engineering, the normalized numerical pit model requires stratum data and construction data. In this paper, 2D GIS data, 3D BIM data and project databases are integrated by iS3(infrastructure Smart Service System) to build a unified iS3 model, and the iS3-config tool is used to associate these data with the database of DigitalObject, as shown in figure 3.

![Figure 3. Data integration](image)

2.4. Program design and functions
After finishing the preparatory work, the program based on iS3 platform can be developed. It is divided into four functional modules: Profile data input and integration module, Profile drawing module, Generation of input files and automatic calculation module and Scheme assessment and optimization module. The basic flow is shown in figure 4.
2.4.1. Profile data input and integration module. XML file, with its simple format, can be written or exported from BIM models through the program, so it is used as the intermediate file. After importing the data of profiles into iS3, data integration of profiles and projects can be completed through the characters such as "ID" and "Name", so as to automatically obtain the data needed for the numerical model. Compared with the complex hand operation of data input, this function greatly improves the efficiency and accuracy of numerical modeling.

2.4.2. Profile drawing. After data integration, DrawProfile, a plug-in iS3, can automatically draws the profiles and shows them visually in iS3 platform, as shown in figure 5. The bracing system, layers and other information can be viewed and checked.
2.4.3. **Generation** of input files and automatic calculation module. After checking or modifying the information, all the parameters needed for numerical simulation have been obtained and integrated. Based on the above parametric modeling standard, the program automatically generates the input files for FLAC in order to calculate and obtains the internal force and deformation of bracing system. The result files of each step are output in CSV format and then input in iS3 platform. The results of each step can be viewed not only in the tables, but also shown as auto-drawn diagrams of internal forces and deformation in the profiles that introduced above, as shown in figure 6. This module solves the lack of stratum data and construction data when automatically generating a FE model by a traditional BIM model, and shortens the modeling time, and realizes the integration of TIM/FEM to a certain extent.

![Figure 6. Bending moment drawing.](image)

2.4.4. **Scheme assessment and optimization module.** Based on internal forces and deformations of structures and design codes, the program can assess the scheme from both safety and economics. If the safety factor is lower than the requirements or too large that leads to poor economic benefits, the program will automatically adjust the scheme according to specific situation. It readjusts the relevant parameters of bracing system in the input files, then obtains new results after the calculation, and checks them according to the codes again. When safety is met, the program adjusts the parameters repeatedly until a relatively optimal economic scheme is obtained. The scheme optimization takes a lot of time to modeling and this module not only greatly save the time of repetitive operations and reduce the possibility of errors, but also considers both the safety and the economics of a pit scheme.

### 3. Conclusions

The method of automatically generating FE models by TIM models of pit engineering now exists many problems, such as the lack of data, the limit of geometric models. Also, the calculation results can only be viewed in FE software. These problems lead to the poor effect of automatic modeling and the low level of TIM/FEM integration. There is little research on the attempt of linking TIM and structural assessment of pit engineering, hence FE technology is difficult to take the advantages of TIM, which widens the gap between pit engineering and tunnel engineering. In order to solve the above problems, this paper presents a method of automatic generation of FE models and TIM/FEM integration post-processing for pit engineering.

For the pits with the brace system of retaining walls + supports and the FE software FLAC, a normalized numerical pit model is built, and the TIM models and the projects data are integrated in iS3 platform, which improves the level of visualization and integration of management and the reliability of calculation results, and lays the foundation for automatic generation and analysis of FE models. The program of automatic modeling is developed. It is a two-dimensional FE models of pit engineering including the data of geometry, structure, stratum and construction. The program can automatically call the input files and calculate, which improves the efficiency and reduce the
possibility of errors in the process of modeling. Then according to the results, the schemes assessment and optimization can be carried out automatically to ensure the safety and reduce the cost of the project, which can save a lot of repeated operation time. Based on iS3 platform, the integrated TIM/FEM software for pit engineering is developed. The results files can be imported in it and the internal force or deformation diagram of profiles can be automatically drawn and viewed without the help of FE software. The platform realizes the visualization of post-processing, and links TIM and structural analysis, and improves the integration level of TIM platform. The method of automatically generating FM models by TIM models in pit engineering and TIM/FEM integrated platform are applied in the pit project of Haikou Wenmingdong Tunnel, which can be used for reference to promote the application of TIM technology in pit engineering.

4. References
[1] Hammad A, Setayeshgar S, Zhang C, Asen Y 2012 Winter Simulation Conf., p 1-10
[2] Luo H, Gong P 2015 J. Intell. Robot. Syst., 79 (3-4), p 549-576
[3] Wu I C, Lu S R, Hsiung B C 2015 Visualization Eng. Vol 3, p 1-11
[4] Li M, Yu H, Liu P 2018 Autom. Constr. 91, p 284-292
[5] He J J, Wang S, Yao S Y 2016 J. Info. Technol. Civ. Eng. Arch. 8, p 55-59
[6] Peng S G 2012 J. Chongqing U. Sci. Technol.(Nat. Sci. Ed.), 14, p 129-131
[7] Zhou K 2019 Val. Eng., 38, p 186-188
[8] Meschke G, Freitag S, Alsahly A, Ninic J, Schindler S, Koch C 2014 Bauingenieur, 89 (11), p 457–466.
[9] Alsahly A, Gall V, Marwan A, Ninic J, Meschke G, Vonthron K M A 2016 World Tunn. Cong, p 3178-3186.
[10] Ninic J, Freitag S., Meschke G 2017 Tunn. Under. Space Technol, 63, p 12–28
[11] Zhu H H, Li X J, Lin X.D 2018 China Civil Engineering J., S1(01), p 1-12

Acknowledgments
The research is funded by the research project of Shanghai Urban Construction Municipal Engineering (Group) Co., Ltd and Shanghai Sailing Program (20YF1451400).