Eurasia Journal of Science and Technology
ISSN: 2663-1016
DOI: 10.61784/ejst3016

AUTOMATIC GENERATION OF PILE-STRUT BRACING STRUCTURE OF EXCAVATION FROM BIM

YiMing Liu*, BaoHua Chen

Shenzhen Research and Design Institute of China Academy of Railway Sciences, Shenzhen 518054,Guangdong, China.
Corresponding Author: YiMing Liu, Email: 1013719403@qq.com

Abstract: BIM has been widely used in the construction engineering. At present, in the field of excavation engineering, BIM is mainly applied in the scheme presentation and construction simulation. There is little research work on structural analysis model of excavation generated by BIM. For pile-strut bracing structure of excavation, this paper proposes the IFC-based method of generation of structural analysis model from BIM. The model conversion program is developed in this paper. Through an excavation project in Shenzhen, the program application results verify the rationality of the model conversion method and the applicability of the model conversion program. This paper is helpful to the application of BIM in excavation design, and it is of great practical significance to improve the current design method of excavation.
Keywords: Excavation engineering; Pile-strut bracing structure; BIM (building information modeling); Structural analysis model; IFC (industry foundation classes)

1 INTRODUCTION

At present, BIM has been increasingly widely used in scheme presentation [1], construction simulation [2], project management [3], etc. In recent years, in the field of building engineering, research has been carried out in the use of BIM to generate structural analysis model. Deng et al [4] proposed a method for automatic generation of building structural models based on the IFC standard, and developed the IFC structural model server. Zhang et al [5] proposed a method for modeling three-dimensional solids based on AutoCAD graphics engine and converting solids to surface models, and verified the rationality of the method by Revit with examples. Huang et al [6] established a collaborative application platform for PKPM series software using IFC standard and developed an IFC interface to realize the conversion of PKPM software data into IFC format data. Wang et al [7] proposed an automatic model conversion method based on the building structural design information model and developed model conversion interface for structural analysis software ETABS. Wang et al [8] using AutoCAD as the development platform, developed IFC structural model conversion software based on structural analysis software 3D3S.
At this stage, in the field of excavation engineering, BIM is mainly used for scheme presentation and simulation of construction process [9]. There is little research work on the interface between BIM and the current design work method. For pile-strut bracing structure of excavation, this paper proposes the IFC-based method of generation of structural analysis model from BIM, and develop the model conversion program. The research in this paper contributes to the promotion and application of BIM in the design of excavation, and has some practical significance for improving current design methods of excavation.

2 BIM AND STRUCTURAL ANALYSIS MODEL OF EXCAVATION

2.1 BIM Model of Excavation

At present, there are many BIM software, such as ArchiCAD and Revit, which can build the BIM model of excavation. This paper adopts the more widely used software ArchiCAD to build the BIM model of excavation.

2.2 Structural Analysis Model of Excavation

At present, the three-dimensional analysis methods of pile-strut bracing structure of excavation are continuous medium finite element method and m-method. The former method studies the excavation including soil as a spatial system and comprehensively analyzes the internal force and deformation of the retaining structure. Although this method is theoretically mature, the calculation workload is large and the cost is high. The m-method [10] is based on the principle of m-method in the elastic foundation beam method. In the m-method, the soil body is considered as the soil spring unit in the excavation and the soil and water pressure outside the excavation, the retaining structure is regarded as a series of beams supported on a series of elastic bearings, the horizontal and vertical retaining system can generally be simulated by using the beam unit. The m-method is a practical method for design of excavation with clear concept and few calculation parameters. In this paper, the structural analysis model of m-method is used as the structural analysis model of excavation. Structural analysis model of m-method is shown in Figure 1.
Based on the BIM and structural analysis model of excavation, this paper studies the automatic generation of pile-strut bracing structure of excavation from BIM.

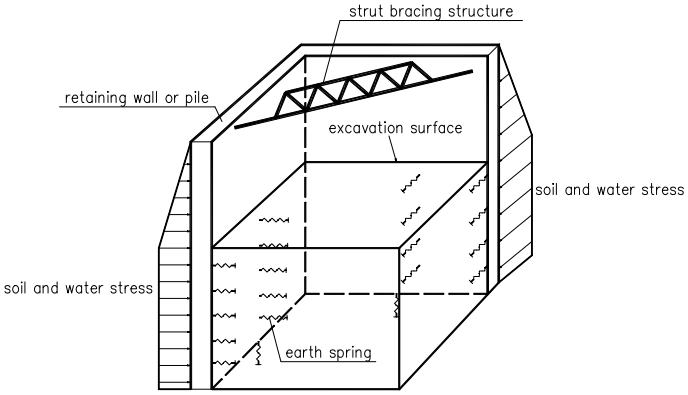

Figure 1 Structural Analysis Model of M-method

3 FORMAT FILE OF BIM AND STRUCTURAL ANALYSIS MODEL OF EXCAVATION

Selecting the appropriate format file of BIM and structural analysis model of excavation is the prerequisite and foundation for the automatic generation of pile-strut bracing structure of excavation from BIM.

3.1 Format File of BIM

In this paper, IFC standard file is used as the format file of BIM. IFC standard [11-14] is a widely accepted standard for product data exchange and sharing in the construction industry. More and more BIM software (e.g. ArchiCAD, Revit) are announcing their support for this standard. It provides a common building model and open data exchange standard to realize the collaboration between different design software in different disciplines and phases of the building life cycle.

The core technical content of IFC standard is divided into two parts: one is the description of engineering information, and the other is the transmission of engineering information. In this paper, IFC standard is briefly described as follows.

3.1.1 Description of engineering information.

The IFC standard uses the formal data specification language EXPRESS to describe construction engineering information. Language EXPRESS is fully defined in the STEP (Standard for the Exchange of Product Model Data) standard [15-16]. The information description of the IFC standard is divided into four levels, from bottom to top, namely resource level, core level, shared level and domain level, as shown in Figure 2. Each level contains several modules, and related engineering information is described in one module (e.g., geometry description module).

The resource layer defines the basic information of the model (e.g. materials, geometric topology, etc.); the core layer defines the overall framework of the information model (e.g. relationships between engineering objects, positions and geometry of engineering objects, etc.); the sharing layer defines the information exchanged across disciplines (e.g. walls, beams, columns, doors, windows, etc.); and the domain layer defines the information in their respective domains (e.g. piles, steel stranded wires, etc.).

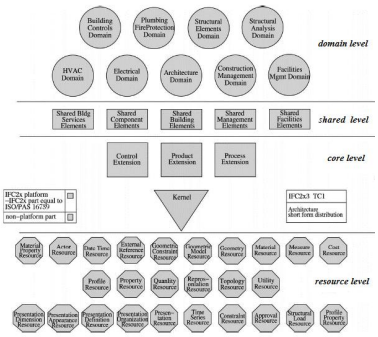

Figure 2 Information Description Hierarchy of IFC

3.1.2 Transmission of engineering information

The IFC standard exchanges information through a standard format file —a neutral file. A neutral file is a plain text format file that can be viewed and edited with an ordinary text editor. The file starts with "ISO-10103-21;" and ends with "END-ISO-10103-21;".There are two sections in the middle: a header section and a data section. The header segment starts with "HEADER;" and ends with "ENDSEC;" and contains information about the neutral file itself, such as the file description, the IFC standard version used, etc. The data segment starts with "DATA;" and ends with "END-ISO-10103-21;".The file data segment starts with "DATA;" and ends with "ENDSEC;", which contains the project information to be exchanged. The neutral file of a column is shown in Figure 3.

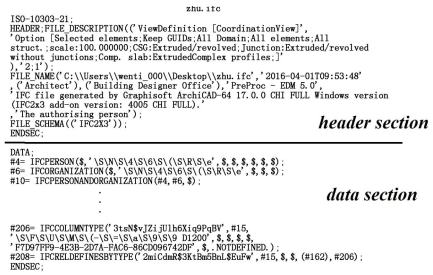

Figure 3 Neutral File of a Column

3.2 Format File of Structural Analysis Model of Excavation

The structural analysis model of m-method is generally built using the finite element software SAP2000. The s2k format file is one of a text format file generated by SAP2000. The s2k format file is clear, easy to read and write, and can be opened directly by word processing software such as writing pad and notepad. At the same time, the s2k format file is stable and not easy to make mistakes in the model conversion process. This paper adopts the s2k format file as the model conversion file.

The s2k format file uses several different TABLEs to completely describe the information of the model, such as point numbers and coordinates that use the TABLE: "JOINT COORDINATES". One part of the TABLE describes the software default information, such as SAP2000 software version, analysis standards, etc.; the other part of the TABLE describes the various definitions of the model information, such as the geometric properties of the model components, model constraints, loads, etc. Part of the typical s2k format file is shown in Figure 4.

Figure 4 A s2k File

4 PROGRAM DEVELOPMENT

On Visual Studio 2010 platform, using Visual C++ development tools, we developed our own model conversion program ArchiCAD To SAP2000 to realize automatic generation of pile-strut bracing structure of excavation from BIM.

4.1 General Agreements

To standardize the model conversion process and increase the applicability of the procedure, the following conventions are proposed for modeling with ArchiCAD.

(1) In order to facilitate the retaining structure, column, crown beam and strut of excavation can be connected normally in the vertical direction in SAP2000, the design elevation of crown beam and strut are the elevation at its neutral surface, while the top elevation of retaining structure and column are taken as the elevation at the neutral surface of the crown beam and support respectively.

(2) In order to facilitate the crown beam, waist beam and strut to be connected properly in the horizontal direction in SAP2000, the horizontal positioning axis of the above-mentioned components is their horizontal centerline.

(3) The model soil assumes uniform, horizontal distribution within layers, and each layer of soil is built using the ArchiCAD plate modeling module.

(4) To facilitate the addition of soil spring to the retaining structure, the IFC description attribute "TC-N" (N is a natural number) is added to the soil layer (slab) in ArchiCAD.

(5) In order to add soil and water pressure load to the retaining structure, the soil and water pressure surface of the retaining structure in ArchiCAD is established by deformation body modeling module, and the IFC description attribute "N" (N is a natural number) is added.

4.2 Program Development

The general flow chart of the program development is shown in Figure 5. The details are described as follows.
(1) Importing the IFC file generated by software ArchiCAD into the program to read and store the end point coordinates, section, material, constraints and load information of each structural unit of BIM model of excavation.
(2) Entering and storing the physical and mechanical properties of the soil in manual interactive input interface.
(3) The all information above is written to the file in s2k format.
(4) When the program ends, the s2k file is generated and saved.
(5) Importing the above s2k file into the software SAP2000 to generate the structural analysis model of excavation.

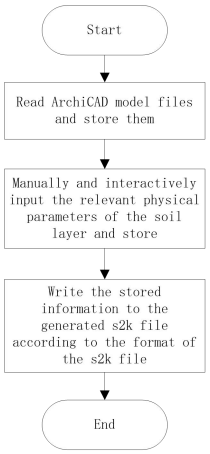

Figure 5 General Flow Chart of the Program

The conversion program ArchiCAD To SAP2000 including three modules:
(1) IFC file reading and parsing module: Load Ifc File;
(2) manual interaction module: Add Constraint and Add Load;
(3) s2k file generation module: Export s2k. The main interface of the program is shown in Figure 6.
(4)

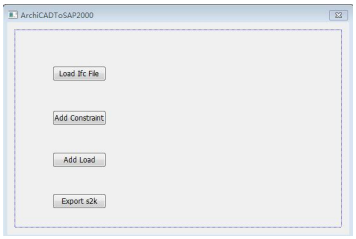

Figure 6 Main Interface Of The Program

5 PROJECT EXAMPLE

Taking the excavation project of ICBC building in Shenzhen as an example, the accuracy and applicability of the model conversion program developed in this paper are verified.

5.1 Project Summary

The excavation is located in the central area of Houhai, and the plan location is shown in Figure 7. The building has a four-story basement, the excavation depth is 20.0 m, and the perimeter of the excavation is 289.0 m. The site stratigraphy is relatively uniform, and the physical and mechanical property indexes of soil layer is shown in Table 1.

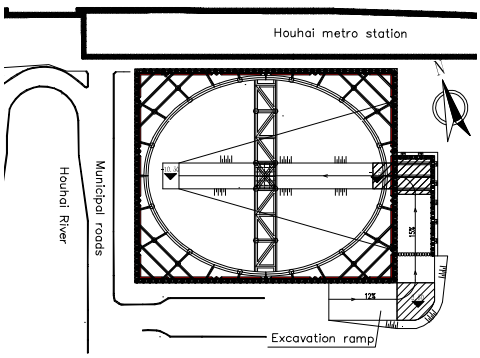

Figure 7 Plane Position of the Excavation

Table 1 Physical and Mechanical Property Indexes of Soil Layer

Soil	Layer thickness (m)	Severe (kN/m^3)	Cohesion (kPa)	Angle of internal friction (degree)	m value (kN/m^4)
Manual filling	8.4	18.9	12.0	16.0	4.72
Organic clay	2.5	17.1	14.0	5.0	1.40
Gravelly clayey soil	37.0	18.5	24.0	22.0	9.88

The excavation adopts the pile-strut bracing structure. The pile adopts the form of occluded piles, formed by 1.2m diameter reinforced concrete piles and 0.2m arrangement of the same diameter plain concrete piles occluding each other; the strut adopts three reinforced concrete ring strut. The typical support profile of the subway side of the excavation is shown in Figure 8.

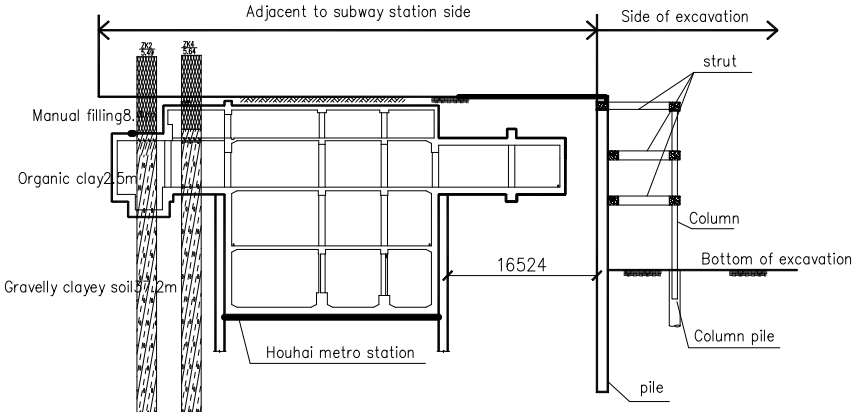

Figure 8 Retaining Profile of the Excavation at Metro Side (Unit: mm)

5.2 BIM Model of Excavation

The BIM model of the excavation built by ArchiCAD is shown in Figure 9. The BIM model of pile-strut bracing structure of excavation is shown in Figure 10. Because the plain concrete piles are not subjected to earth pressure, it can not be built in the model as shown in Figure 10.

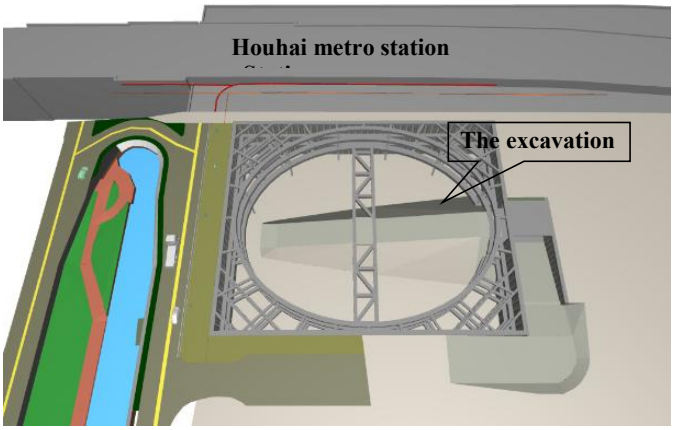

Figure 9 Building Information Model of the Excavation

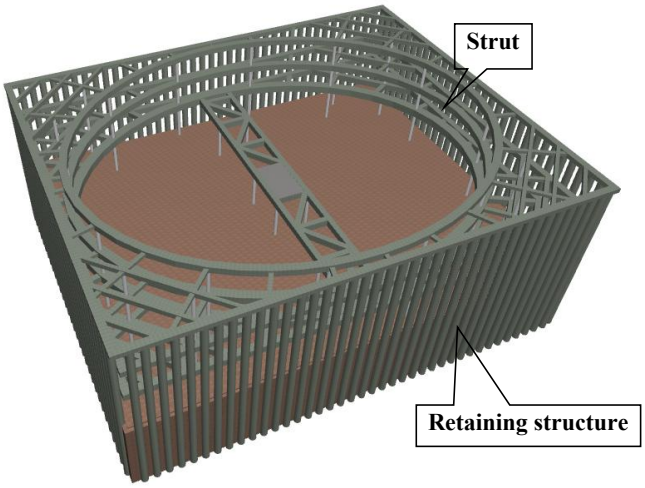

Figure 10 Building Information Model Of Pile-Strut Bracing Structure Of The Excavation

5.3 Generation of Pile-Strut Bracing Structure of Excavation in Sap2000

The BIM model of pile-strut bracing structure of excavation is exported in IFC format file. Start the program and click the IFC file reading and analysis module (Load IFC File), then select the above IFC file, and the program automatically analyzes and stores the end point coordinates, section, material, constraints and load information of each structural unit. Once the analysis is complete, click on the add constraint module of the manual interaction module, enter the soil spring stiffness value, and click on the add button when finished. Click on the add load module of the manual interaction module, enter the calculation parameters, and click on the compute button when finished. Finally, click on the SAP2000 s2k file generation module (Export s2k) to export the saved s2k file. The generated s2k file is imported into SAP2000 to automatically generate the structural analysis model of this excavation, as shown in Figure 11.

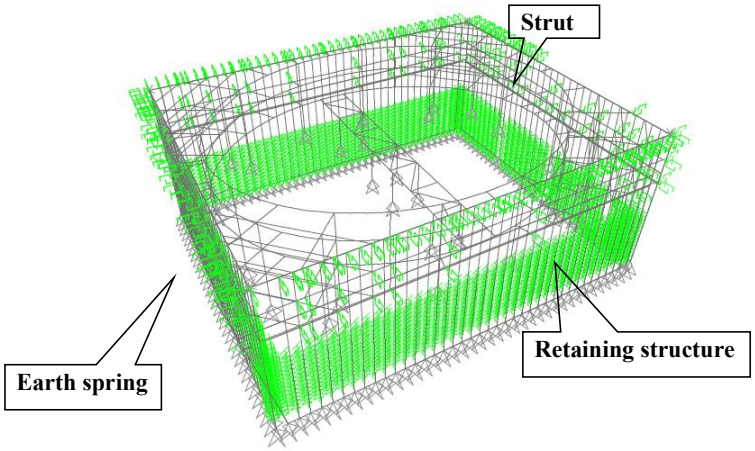

Figure 11 Structural Analysis Model Of The Excavation In Sap2000

6 CONCLUSIONS

This paper proposes the IFC-based method of generation of structural analysis model from BIM. The model conversion program is developed in this paper and verified by example through a excavation project. The conclusions and recommendations are as follows.

(1) The model conversion results of geometric position and section information of each member of retaining structure, column and internal retaining system in BIM are correct. The model conversion results of soil spring restraint in front of pile and soil and water pressure load outside the excavation are correct. The model conversion results verify the applicability of the model conversion program.

(2) The application results of example verify the rationality of the IFC-based method of generation of structural analysis model from BIM proposed in this paper.

(3) The model conversion method and development procedure are only applicable to the pile-strut bracing structure of excavation, and it is recommended to study the model conversion method for other forms bracing structure of excavation.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Jun Su, Honghua Ye. The application of BIM-based design visualization in the German pavilion of EXPO 2010. Journal of Information Technology in Civil Engineering and Architecture, 2009, 1(1): 87-91.
[2] Bao-rong Jia. Exploration on the BIM technology application of Shanghai tower. CONSTRUCTION TECHNOLOGY, 2014, 43(app.): 254-258.
[3] Boya Ji, Zhenqiang Qi, Zhanyong Jin. BIM technology application in construction operation managemeng research—taking the Olympic village project as an example. Journal of Beijing University of Civil Engineering and Architecture, 2014, 30(1): 68-72.
[4] Xue-uan Deng, Zhiyong Zhang, Xila Liu. Automatic generation of structural model from IFC-based architectural model. China Civil Engineering Journal, 2007, 40(2): 6-12.
[5] Jianping Zhang, Yang Zhang, Xin Zhang. Methodolgy of 3D geometric modeling and model conversion of IFC-based BIM. Journal of Information Technology in Civil Engineering and Architecture ,2009, 1(1): 40-46.
[6] Jifeng Huang, Hanyi Zhang, Qi Nie. Application of BIM in structural design software. Journal of Information Technology in Civil Engineering and Architecture, 2011, 3(4): 58-62.
[7] Yong Wang, Jianping Zhang, Pengyi Wang et al. Model automatic transformation methods in architecture and structure designs. Journal of Architecture and Civil Engineering, 2012, 29(4): 53-58.
[8] Xuan Wang, Qie Hu, Huizhu Yang et al. Transformation technique of structural models based on industry foundation classes standard. JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE), 2014, 42(6): 836-843.
[9] Yiming Liu, Guonan Liu, Wentian Gu. Application of BIM visualization technology to foundation pit design. Railway Engineering, 2016, (6): 125-128.
[10] Jianhua Wang, Wei Fan, Weidong Wang et al. Application of 3D m-method in analysis of retaining structures of deep excavation. Chinese Journal of Geotechnical Engineering, 2006, 28(app.): 1332-1335.
[11] Tarandi V. Editorial: IFC-product models for AEC arena. ITcon, 2003, 8: 135-136.
[12] Kuining Qiu, Hanyi Zhang, Jing Wang et al. An introducetion of IFC by instances. Journal of Information Technology in Civil Engineering and Architecture, 2010, 2(1): 68-72.
[13] Hanyi Zhang, Kuining Qiu. An introducetion to shape representation and spatial structure of IFC by instances. Journal of Information Technology in Civil Engineering and Architecture, 2010, 2(2): 83-86.
[14] Lin Wang, Kuining Qiu. Analysis on IFC structure and data instances. Journal of Information Technology in Civil Engineering and Architecture, 2010, 2(4): 79-88.
[15] ISO10303-11. Industrial automation system and integration – Product data representation and exchange – Part 11: Description methods: The EXPRESS language reference manual.
[16] ISO10303-21. Industrial automation system and integration – Product data representation and exchange – Part 21: Implementation methods: Clear text encoding of the exchange structure.