Application of collaborative modelling method in Pile-Beam-Arc of Subway station

Qingfei Luo 1, Quan Cao 1, Wei Li 2,*, Chunsheng Zhao 3, Qingwei Xue 4 and Mengheng Zhang 5, Peng Shen 6

1 School of Railway Transportation, Shanghai Institute of Technology, Shanghai, China.
2 Shanghai Tongsui Civil Engineering Technology Co., Ltd., Shanghai, China
3 Power China Railway Construction Co., Ltd., BeiJing, China
4 Sinohydro Engineering Bureau 4 Co., Ltd., Xining, China
5 Shanghai No.1 Metro Operation Co., Ltd., Shanghai, China
6 Shanghai Mechanized Construction Group CO., Ltd., Shanghai, China

*Corresponding author e-mail: weiliyy@126.com

Abstract. Taking Pile-Beam-Arc of Harbin Metro Line 2 Shengzhengfu station as an example, through the Midas GTS NX, different methods are used to establish the numerical model of PBA method. The results show that the quality of the model generated by the collaborative modelling method is better and the modelling efficiency is higher. The specific embodiment is that the number of units generated by the collaborative modelling method is less than that of auto-solid method, and the operation time of the model is reduced. The quality of the model generated by the collaborative modelling method is better than that of auto-solid method, which improves the model convergence and accuracy. The efficiency and application conditions of collaborative modelling method are better than those of plane element expansion method.

1. Introduction

Pile-Beam-Arc method has been widely used in subway station construction because of its small impact on urban traffic, small surface settlement and low cost. At present, there are some achievements in surface settlement law [1,2,3], construction mechanics research [4,5,6], construction key technology [7,8,9] and so on. Most of these achievements are obtained by combining the calculation results of finite element model with the field measured data. Therefore, the efficiency of establishing the finite element model and the accuracy of its results are particularly important.

There are two main modeling methods of MIDAS GTS NX, which are plane element expansion and auto-solid. The plane element expansion method can generate hexahedral elements with good quality, but its application conditions are higher, which the structure of the model is more regular and the steps are more complicated. While the auto-solid method can quickly partition irregular structures, with high efficiency and low application conditions, but the quality of the generated mesh is poor. There are two kinds of problems in the previous model of PBA, which are poor grid quality and over simplification of steel tube column. The main reason for the poor mesh quality is that the model adopts auto-solid method, which results in many poor quality elements in the model, which affects the accuracy of the model. Due
to the shape and location of steel tube column, it is not conducive to simulation of steel tube column, so beam element or 3D element converted according to equivalent stiffness principle is often used to simulate steel tube column. Using beam element to simulate steel tube column can easily lead to abnormal stress concentration at the joint of top longitudinal beam and steel tube column, which will affect the calculation results of the model. According to the principle of equivalent stiffness, the cross-section of the converted steel pipe column is rectangular, which is too different from the original circle. It leads to the difference of partial stress and deformation of steel tube column, which is not conducive to the fine analysis of steel tube column.

Therefore, in order to improve the modeling efficiency and the accuracy of the model results, the collaborative modeling method is proposed. This method can make full use of the advantages of the plane element expansion method and the auto-solid method, and can quickly mesh, get high quality elements, which improves the modeling efficiency, model convergence and accuracy.

2. Numerical modelling

2.1. Engineering overview
The Shengzhengfu station of Harbin Metro Line 2 is 192.3m long and 21.3m wide. The station is a double-layer station, which is constructed by single-layer four guide PBA method. The soil near the station is mainly composed of silty clay and sandy soil. The station is located at the intersection of Zhongshan Road and Zhongxuan street. The station is arranged along Zhongshan Road to transfer with the planned Metro Line 4. The basic information is shown in Figure 1.

2.2. Auto-Solid generation model
Midas GTS NX’s auto-solid function can quickly divide irregular geometry. In this method, tetrahedral and pentahedral elements can be used as transition elements and hexahedral elements as main elements. The advantage of this method is that it can generate meshes quickly for irregular geometry. It does not need to control the size of the entities in it too much, but only needs to control the size of key parts. Its disadvantage is that it is easy to generate many poor quality elements, which are tetrahedral and pentahedral element as transition units. It tends to have great influence on the operation, such as long operation time, poor convergence and inaccurate operation results.

It is necessary to control the size of solid before generating mesh by auto-solid. Among them, the size control of steel tube column and pile foundation: the XY plane is divided into 8 parts, and the dimension of Z axis direction is controlled by 1m. Dimension control of other station structures: four parts are divided in Y-axis direction (model width is 6.5m), and dimensions in other directions are controlled by 1m. Soil size control: the x-axis direction of soil outside the station is divided by linear gradient, which is controlled from 1m to 4m, and the size of z-axis is controlled by 1m; the x-axis direction and z-axis direction perpendicular to the soil mass of the station are controlled by 1m: the y-axis direction of soil is divided into 4 parts, as shown in Figure 2.
Basic information of the model: there are 30703 elements (10380 elements in the station structure and 20323 elements in the soil), 17489 nodes. Among them, there are 7,722 hexahedral elements and 22,981 other types of units (tetrahedral elements, triangular prism elements and pyramid elements). The number of poor quality elements found through the elements quality inspection function of the software is 9797, including 4070 elements with poor quality in station structure and 5727 elements with poor quality in soil, as shown in Figure 3.

![Poor quality elements in station structure](image1)

(a) Poor quality elements in station structure

![Poor quality elements in the soil](image2)

(b) Poor quality elements in the soil

2.3. Collaborative modeling generation model

The modeling steps of the plane element expansion method are generating 2D elements - expanding meshes along a certain direction - generating 3D elements. The advantage of this method is that regular hexahedral elements can be generated, and the grid quality is good, but the applicable conditions are high. For the model with irregular embedded structure, such as steel tube column or pile foundation, the
model can not be extended in the same direction, which has a great impact on the subsequent model coupling, so this method is invalid.

Combining the advantages of plane element expansion method and auto-solid method, a collaborative modeling method is proposed to divide the model of PBA. The auto-solid with high efficiency and low applicability is adopted in irregular embedded structures (steel tube column and pile foundation). At the same time, entities are generated in the surrounding parts and the size is controlled. For other structures, the plane element expansion method with high mesh quality is used. The key point of this method is the coupling problem between the plane element expansion method and the auto-solid method. Therefore, to ensure that the 3D elements expanded by plane element is consistent with that generated by previous auto-solid, it is necessary to do size controls at the junction of them.

The operation steps can be divided into five steps: (a) establish solid in the pile structure (or embedded structure) and its surrounding. (b) size control is carried out around the pile structure (or embedded structure) to ensure that the 3D element formed by the expansion of plane element can be coupled. (c) The 3D element is generated by auto-solid for pile structure (or embedded structure). (d) 2D elements are generated for other parts of the model. (e) The 2D element is expanded to generate 3D element, and then the mesh group is merged. The modeling steps of collaborative modeling method are shown in Figure 4.

For the convenience of comparison, the size control of the model is the same as that of the auto-solid method. Basic information of the model: there are 19495 elements (7288 elements in station structures and 12207 in soil), 19336 nodes. Among them, the number of hexahedral elements is 13,833, and the number of other types of elements is 5242. In addition, the number of poor quality elements is 3177, including 2793 elements in station structures and 384 elements in soil, as shown in Figure 5.

![Figure 4. Steps in the collaborative modeling approach](image)

![Figure 5. Poor quality elements in models generated by collaborative modeling](image)

### 3. Model quality comparison

According to the comparison in Table 1, under the same size control, the number of elements in the model generated by auto-solid is larger, 11208 more than that of collaborative modeling method. The
main reason is that auto-solid method will produce more transition elements with smaller size, which will increase the total number of elements and increase the calculation time.

According to the comparison in Table 2, the number of elements with poor quality in the model generated by auto-solid is 9797, which is three times as much as that of collaborative modeling method. And the number of poor elements generated by the former method accounts for 31.9% of the total number of elements, which is also far greater than 16.3% of the latter. The main reason is that most of the models generated by collaborative modeling method use plane elements to expand to 3D elements, which generate more hexahedral elements with good quality.

| Modeling method       | The number of elements in station structures | The number of elements in soil | The total number |
|-----------------------|---------------------------------------------|--------------------------------|------------------|
| Auto-Solid            | 10380                                       | 20323                          | 30703            |
| Collaborative modeling| 7288                                        | 12207                          | 19495            |

4. Conclusion

By comparing the quality, modeling efficiency and applicable conditions of the models generated by different modeling methods, the following conclusions can be drawn:

1. Under the same size control, the number of model elements generated by collaborative modeling is less than that generated by auto-solid because some structures of collaborative modeling method adopt plane element expansion, so the operation time of model is reduced.

2. The collaborative modeling uses the expansion of plane elements to generate a large number of hexahedral elements with good quality, while the auto-solid produces some poor quality tetrahedral and pentahedral elements. Therefore, the quality of the model generated by the collaborative modeling is better than that generated by the auto-solid, so that the convergence and accuracy of the model are improved.

3. Because some structures of collaborative modeling method adopt auto-solid, which can reduce the time of dividing the whole model. At the same time, the applicable conditions of auto-solid are relatively low, which improves the application rate of plane element expansion method. Therefore, the applicable conditions and modeling efficiency of collaborative modeling are better than those of plane element expansion.

Acknowledgments

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