Analysis and modelling of the construction of a large urban cavern using the micro-tunneling pipe arch method

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ABSTRACT: The planning and construction of caverns with large cross-sectional areas as part of underground railway projects in loose rock pose a number of geotechnical and logistical challenges. This thesis develops a suitable tunnelling concept for this type of construction project. To this end, various options are compared using FE calculations and the selected option is mapped in a BIM model, including the construction process.

KEYWORDS: cavern, loose rock, FE calculation, BIM

1 INTRODUCTION

Urban construction projects in loose rock pose particular challenges due to limited space, low overburden, existing buildings, the need to minimise settlement and a high groundwater level.

When planning large caverns, additional structural measures are necessary to enable safe tunnelling with as little settlement as possible. Large cross-sections are often divided into several partial excavations [1]. Another option being investigated in this thesis is microtunneling pipe arch method. In this technique, steel pipes with relatively large diameters are installed over the cross-section to be excavated and connected to each other. This forms a pipe arch that dissipates the load of the rock during construction, thus protecting the excavation area and minimising any displacement [2]. A BIM model enables the representation of individual construction phases and thus the verification of feasibility in the restricted space. In addition, a BIM model can also be linked to FE calculations to save on labour [3].

The aim of this work is to develop a feasible tunnelling concept for the cavern and the launch shaft required for construction. The feasibility is assessed by using FE calculations, a BIM model and a construction process simulation.

2 MAIN BODY

In order to carry out the investigations and understand the results, extensive literature research was conducted to explain the fundamentals of various topics. These include geotechnical material models, empirical settlement calculations, various construction methods and the fundamentals of both FE and BIM modelling. The subsoil, the creation of the subsoil model and the construction project are then described.

The building site has a layered structure. The top layer consists of gravel. The water table is located in this layer. Below this are alternating layers of sand and clay of varying thicknesses. The cavern has a length of 45 m. The cross-section specified in the scope of thesis has a width of 17 m, a height of 13 m and an area of 180 m². The cavern is being excavated from a centrally located shaft. It should also be noted that one of the tunnels connected to the cavern has already been excavated using a TVM and will be demolished again in the area of the cavern. The overburden is 13 m.

Based on the literature research, FE investigations are carried out in the form of 2D slice models with the aim of finding a suitable excavation variant. Further steps include dimensioning the shaft, determining the construction sequence, creating the BIM model and construction sequence simulation, and investigating the interface between the BIM model and FE calculations. The investigations have shown that microtunneling pipe arch method is not suitable for this construction project. Instead, the tunnelling will be carried out using compressed air.

2.1 Cavern

Due to the size of the cross-sectional area, the cavern will be constructed using the core construction method. First, lateral elm tunnels will be created and secured using temporary dome stems. Then the central tunnel will be excavated and secured, and the dome stems will be removed again. The individual tunnels themselves are divided into crown and heading. The cross-sectional division is shown in Figure 2-1. The previously constructed TVM tunnel is also taken into account in the FE model.

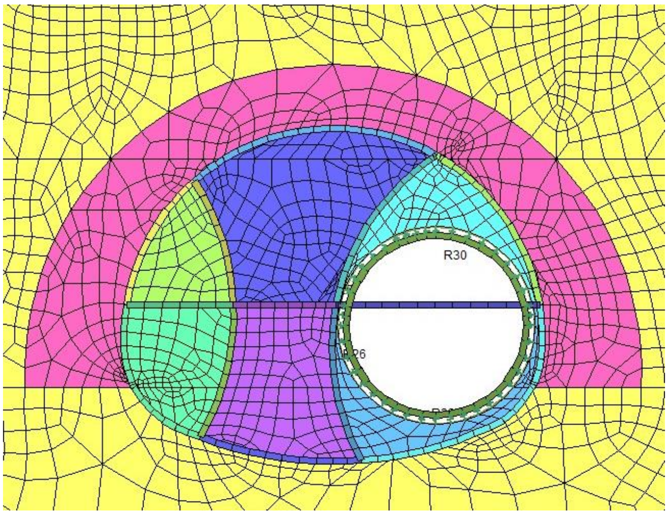

Figure 2-1: selected cavern cross section

Various soil improvements, such as freezing and jet grouting umbrellas of various sizes, are being investigated to reduce settlement. After weighing up the effect on settlement reduction and the expense, the jet grouting umbrella shown in Figure 2-1. is selected. Settlements of 37 mm occur. These require further investigation as they could jeopardise the stability of the existing buildings.

2.2 BIM model

Another focus of the thesis is the BIM model, the construction process simulation and the interface between BIM and FE calculations. … shows the building model. Together with the subsoil model, it forms the BIM model. The parameters for the BIM model were selected with regard to subsequent FE calculations (material, reinforcement, etc.). In addition, each component is assigned a parameter for the construction phase and, in the case of temporary components, also for the demolition phase. In a schedule, the same parameters are assigned to the individual processes of the construction sequence. By linking this schedule to the BIM model, the construction process simulation can be created.

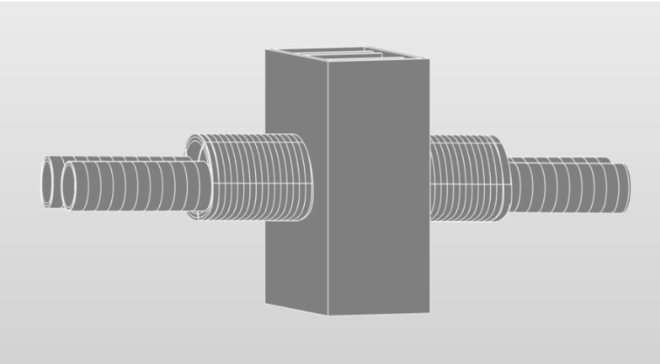

Figure 2-2 BIM model

Investigations into the possible linking of BIM models and FE-calculations show that it is technically possible to transfer information, e.g. on geometry or materials, from the BIM model to FE calculation programmes in various ways. However, FE calculations must first be performed for the construction project under investigation. The BIM model can then serve as a basis for subsequent FE calculations.

3 CONCLUSION

The developed tunnelling concept is fundamentally feasible, but it is very complex due to various geotechnical and construction logistics challenges, such as settlement reduction, limited space and complex water management. Neither the planning nor the construction work involved is a conventional task. Detailed and careful planning is therefore required. This includes coordinating the construction process, developing the compressed air concept, selecting the equipment, dimensioning the shaft and designing the drainage concept. The BIM model significantly supports the process by providing a realistic representation and collision testing in all construction phases.

In this thesis, the costs were not taken into account when selecting the tunnelling concept. However, these would be very high due to the complex compressed air tunnelling and extensive drainage measures, especially in relation to the comparatively small structure dimensions of only 45 m in length.

Further investigations are necessary in the subsequent planning phases. These include the effect of settlement on the load-bearing capacity of the existing buildings, further investigations for the water drainage concept with regard to the range of the wells, and investigations for the jet grouting shield.

Taking the above points into account, the developed tunnelling concept provides a solid basis for the subsequent planning phases.

4 OUTLOOK

FE calculations are already standard practice. The focus is usually on the actual tunnel construction, i.e. the outer and inner shells. There is a need for development in 2D calculation, particularly for settlement reduction measures, especially microtunneling pipe arch method. There are already a few approaches for 3D models, but these are more complex than 2D models, which would be sufficient for preliminary design.

In the construction industry, the implementation of a digital twin of a structure is becoming increasingly important. In order to map the structure throughout its entire life cycle, the reactions of both the structure and the subsoil to external influences or component damage must be taken into account. The bidirectional interface between BIM models and FE calculations is particularly helpful for this. There are already options for data transfer using various file types and, in some cases, direct interfaces between two programmes, but for the most efficient use possible, a uniform interface for different programmes would have to be created. This interface would not only transfer data from the BIM model to the FE model, but also feed the calculation results back into the BIM model.

The general development of artificial intelligence (AI) can also be utilised in this context. There are countless possible applications for this, such as automated plausibility checks by comparing with other calculations or grouping components according to the reinforcement required.

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