# Application of BIM in Deep Excavation Projects

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## Abstract

This paper presents a Taipei MRT project as an example to illustrate the process and benefit of using BIM in a deep excavation case. The BIM concepts that are being used in this project include, (1) transforming and integrating soil boring information and soil profiles data into a comprehensive 3D models, (2) establishing 3D BIM for excavation and its strutting system, (3) detecting conflicts between interfaces, such as support and hoist systems, and creating a 4D construction simulation model by integrating construction schedule into the original 3D BIM model, and (4) creating and displaying the structure model, design and construction drawings, and quantity calculation sheets with the support of other compatible software. BIM is expected to bring a more direct and visual display and presentation of information for construction progress, and to make construction control and management simpler and more efficient. The project in the paper could be a reference for other geotechnical design and construction cases.

**Keywords:** BIM, Deep excavation, Taipei MRT

## 1    Introduction

The development of integrating Building Information Model (BIM) into the life cycle of construction projects has been grown rapidly in recent years. Many infrastructure projects have started to require and include BIM in the contracts for almost every stage, for example planning, basic design, detail design, construction, and operation and maintenance. In the traditional 2D design, conflicts among different professional disciplines were difficult to discover. Many errors were omitted even with regular meetings between each party. With the introduction of BIM, and its 3D object model and database, it becomes possible to detect conflicts in a 3D model and to simulate construction sequence in a 4D scheme. Its application has been widespread from building, pipeline, drainage/sewage, land development, structure, bridge, mechanical and electrical projects, to geotechnical engineering. There is also an array of commercial software that has been developed to support BIM platform and make integration of analyses and database possible. The visualized presentation of 3D BIM model, along with its supporting software and APIs, and 4D scheduling, the use and development of BIM in engineering projects can be far beyond imagination. This paper presents a deep excavation case in a Taipei MRT project where the application of BIM in geotechnical engineering is demonstrated. The BIM concepts were implemented to (1) create 3D borehole model and fence diagram to present soil layers in a 3D environment, (2) build 3D excavation and support system model, (3) detect conflicts between support system, plates, and drainage culverts, and (4) simulate construction progress with (4D). The background of the project is first overviewed followed by the BIM application. Concluding remarks are made at the end of the paper.

## 2    Project Overview

This project is the extension of an existing MRT line, as shown in Figure 1. It begins from the working shaft of the end track of the operating red line, goes along Xin-Yi Road and Fu-De Street, then follows Zhong-Po South Road to the end-track working shaft in Yu-Cheng Park. The total length of the extension project is about 1.42 km, which includes tracks, an underground station with cross-passage, two sections of TBM tunnels, and an end-track shaft. The net length of the underground station is about 330 m. The station, together with the ventilation shafts and exits, would be constructed using the cut-and-cover method. The two sections of the TBM tunnels include one from west end of the cross-passage to the east end of existing working shaft with an average length of about 490 m, and the other from east end of the station to the west end of end-track working shaft with an average length of about 520 m. Both tunnel sections consist of two single-tube tunnels for up- and down-track lines.

The geotechnical issues and conflicts that are encountered in the project include connection to an operating line, pipelines and culverts distributing over the designed station, TBM under passing existing buildings, and proximity of TBM tunnels (MAA, 2015b).

Furthermore, since most of the Taipei MRT network within the central downtown area is already completed, the project is the one that was planned to extend to the edge of the Taipei basin where rock depths vary significantly. The geological formation along the project alignment is thus rather complex and it would be quite beneficial to adopt BIM to create a visual and integrated platform for every professional discipline. The BIM model was created during the design stage (MAA, 2015a) to detail the complicate interaction between underground structure and soil layers, as shown in Figure 2.
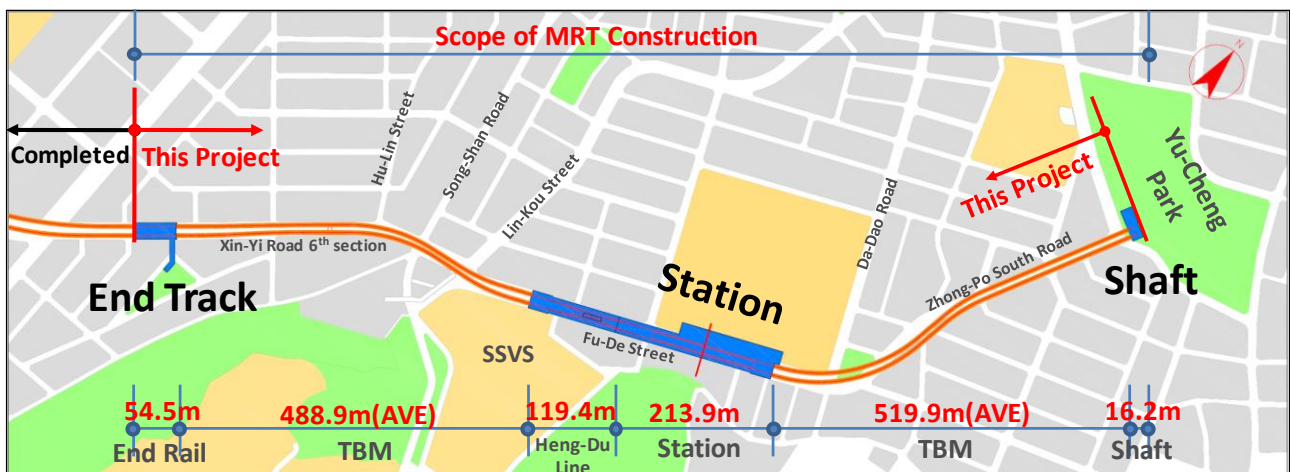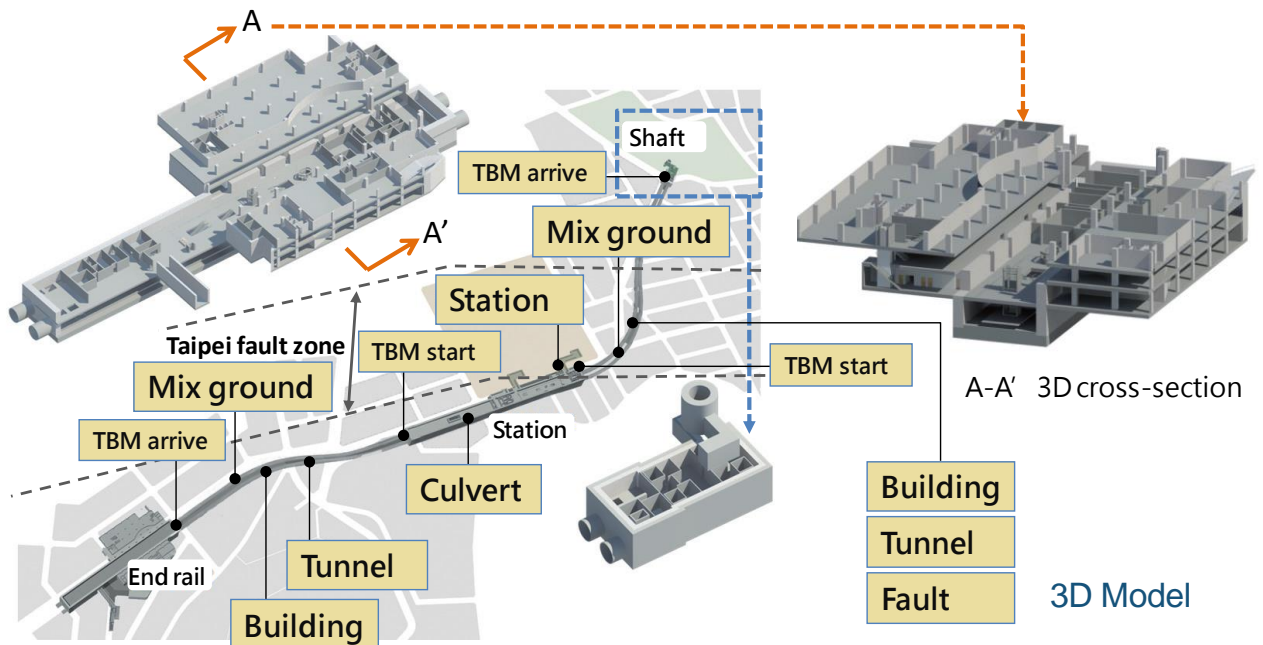


**Figure 1:** Project map

**Figure 2**: Interaction between underground structure and soil layers

## 2.1 Ground Layer and Groundwater

The project site is located on the edge of Taipei basin. The basin was formed by the collapse of several thrust faults at the foothill's region in the northern Taiwan. It was formed roughly two to three million years ago during the Pliocene and Pleistocene Epoch. The geological formation of the site is mainly the Holocene alluvium, which consists of gravel, sand, and clay. The surface layer along the alignment belongs to the Song-Shan Formation, which consists of 6 interbedded clayey and sandy soils. Its engineering properties can be referred to Chin et al., (2006).

Taipei Fault, a non-active fault classified by the Central Geological Survey, is the closest fault near the project site, as shown in Figure 3. It is a thrust fault that goes in the direction of east-south with a 70 degree dip to the south-east direction. The width of the fault is about 70 m, and about 170 m in total if its fracture zone is included (eg., Lee at el, 1999; MAA, 2013b).

The project is in Xin-Yi District. According to the geological analysis report of the region (MAA, 2013a), the site is consisted of mainly silty clay, sandstone, shale, and their interbedding. The project site is located at the plan region adjacent to foothills region, with Xiang Shan (Elephant Mountain) on the east. The depth of bedrock ranges from 17 m to 31 m, and the depth of the groundwater table from 1.3 m to 2.8 m. The water pressure measured is similar to the static water pressure, as shown in Figure 4.
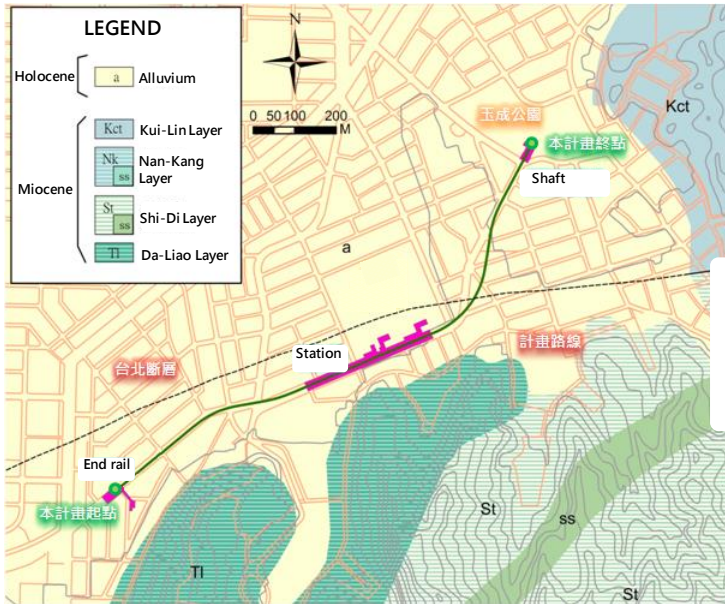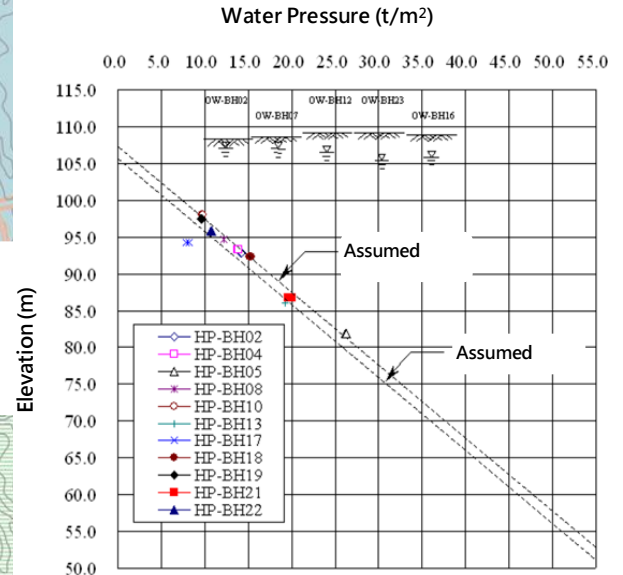
**Figure 3:** Geological map of project site



**Figure 4:** Water pressure plot

## 2.2 Deep Excavation of Station

The cut-and-cover method was employed for constructing the station where diaphragm wall (D-wall) was selected as the retaining wall that was constructed using MHL (Masago Hydraulic Long-bucket) accompanied by pilot-hole method for facilitating excavation in rock layers. After excavation of one panel trench was finished, the rebar cage was installed and concrete was then poured via tremie pipe to complete the D-wall panel. Once the D-wall work was finished, the following construction sequence included king-post installation, decking, and sequential station excavation and strutting to the designed depth.

The major issue of using cut-and-fill method was its impact to the traffic, which required a sophisticated traffic control plan that took into account of environmental limits, such as ground condition, road width, adjacent buildings, and pipeline distribution (MAA, 2015c). The contractor should select appropriate equipment accordingly to keep up with the schedule.

One of the largest issues that may be encountered at a MRT deep excavation project is conflicts with existing underground pipeline that would affect the construction layout and thus traffic control plan. However, these challenges can be mitigated by insuring good scheduling, construction quality control, and planning (MAA, 2015c; 2016).

This study chose deep excavation of the underground station in the project to demonstrate how BIM resolved geotechnical issues involving significantly varying depths of rock layers, D-wall excavation, king-post layout, conflicts between strut system and drainage culvert, and traffic control planning. The application of BIM in geotechnical engineering included: (1) creating 3D ground layer and fence diagram from borehole data, (2) setting D-wall, king-post, and strut layout in 3D BIM model, (3) applying commercial software Revit to detect conflicts with existing drainage culverts and 4D scheduling, and (4) applying graphical programming software Dynamo to generate 3D strut system model automatically in Revit.

## 3 Application Of Bim in Geotechnical Engineering

### 3.1 3D Borehole Logging

Normally, borehole information is presented in plan layout and cross-section logging for geotechnical engineers to evaluate ground condition for future analysis and design. However, for projects that cover larger area, it is difficult to picture the overall geological condition. Therefore, it is preferable to use commercial software to organize and create a 3D model of the layers. The detail procedure implemented in this study is shown in Figure 5, and explained as follows.

(1) gINT data

Establish borehole database, including NE coordinates, elevation, and profile in Microsoft EXCEL files (.xls).

(2) GMS (Groundwater Modeling System) software

This software is able to read input borehole data in .xls format and create 3D ground layer model, as shown in Figure 6. Cross-section profile can be taken from the model at any chosen place as shown in Figure 7 for the selected cross-section A-A' and B-B'. The 3D fence diagram of boreholes and that along the project alignment is as shown in Figure 8 and 9, respectively.

(3) ArcGIS 3D software

Since GMS is also able to read shapefiles, a vector data type file generated by ArcGIS, the GIS software can be used to process the model, such as stratifying the model with topography map, contour, and aerial photos.

(4) Naviswork software

Naviswork supports a wide range of file types, which make it possible in the future for integrating and displaying models from different disciplines on one platform. However, there are still issues to be solved, such as data loss and trouble editing in the model when converting Revit files into Naviswork files.
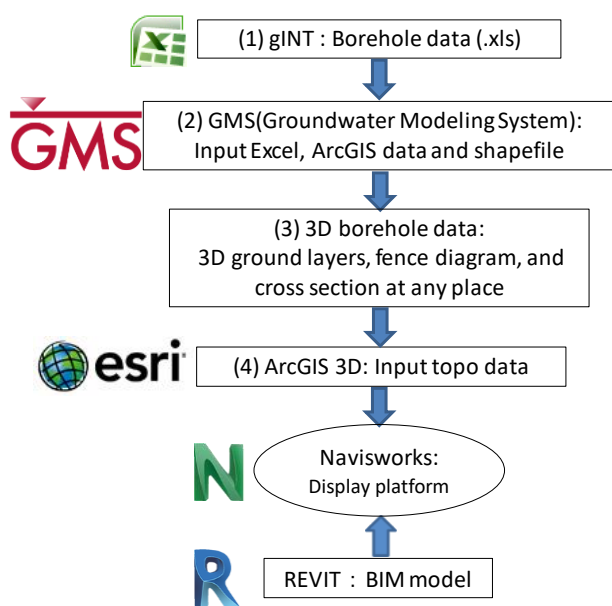


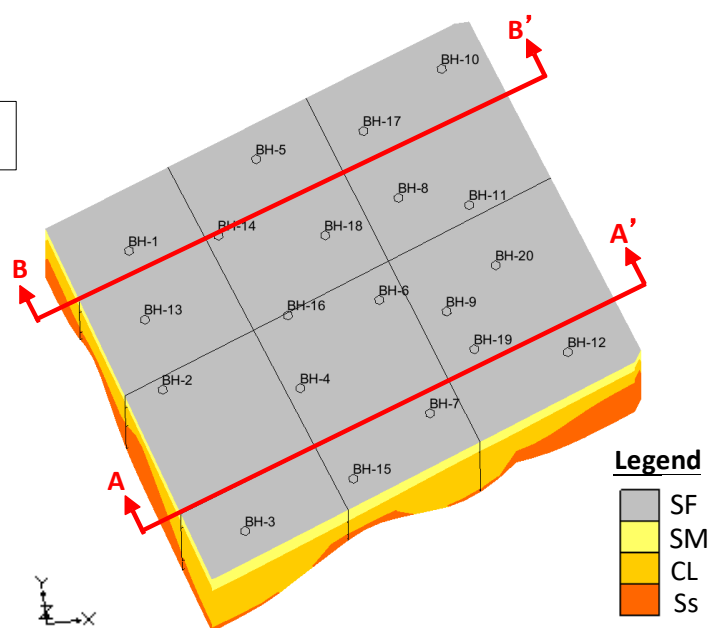**Figure 5**: Flow chart for building BIM model
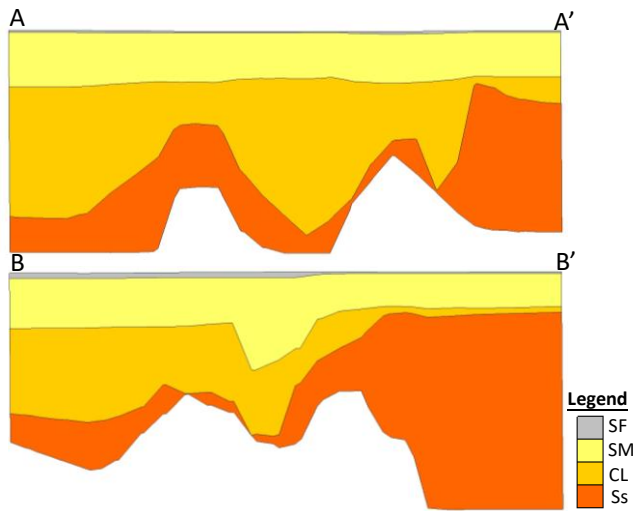


**Figure 6**: 3D ground layer

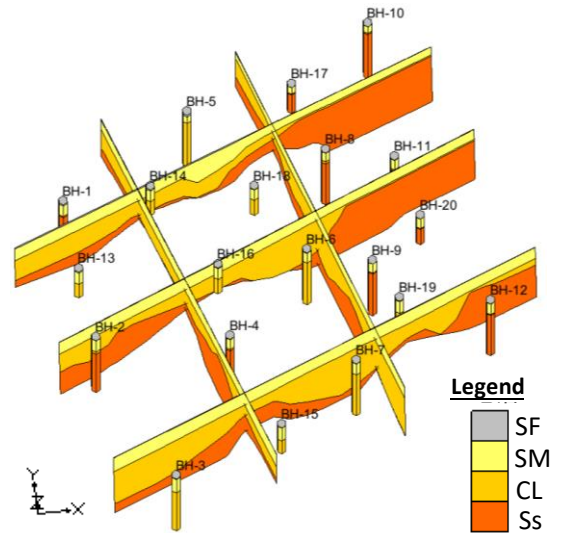**Figure 7:** Profile of AA' and BB'



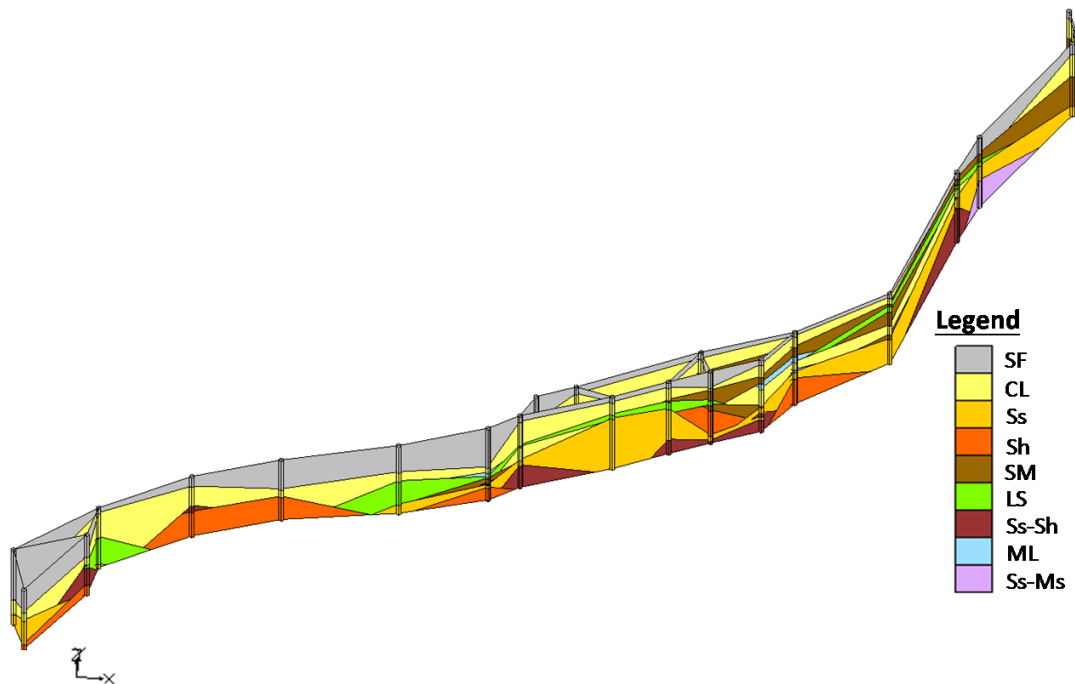**Figure 8**: 3D fence diagram



**Figure 9**: Strip 3D fence diagram

### 3.2 The 3D BIM model of Strut System

Most of the strut systems in excavation works are temporary structures. Determination of king-post locations is a critical stage in design. Things to be considered during construction and determination of layout of king-post include conflicts with tracks, platform, pipelines, and other critical structures. The spacing of king-posts would further affect the spacing and size of struts, D-wall displacement, building protection measures, and monitoring plan.

This study created a 3D BIM model for deep excavation of the station. Design parameter can be extracted from the model, including length and thickness of D-wall, concrete strength, NE coordinates,

size of strut and rebar, size of king-post, and etc. The BIM model is shown in Figure 10, and Figure 11 presents the in top view. Figure 12 shows the longitudinal section (ie., cross-section A-A') of the model, and Figure 13 shows the transverse section (ie., cross-section B-B') and its corresponding 3D view. In the future, the Navisworks software can be used to detect conflicts between king-posts and other structures, such as tracks and platforms. It enables each professional discipline to present their design on the same platform for discussion and coordination. However, the actual locations of pipeline are not often as shown on the shop drawings. Therefore, good construction management is still required for the quality and safety of work.
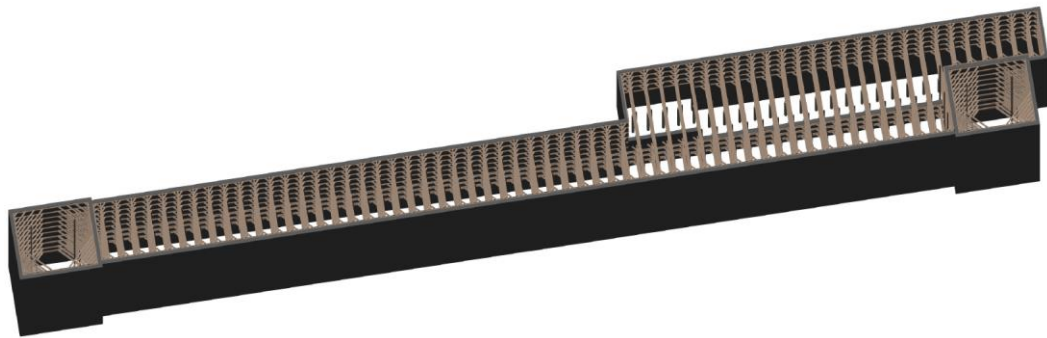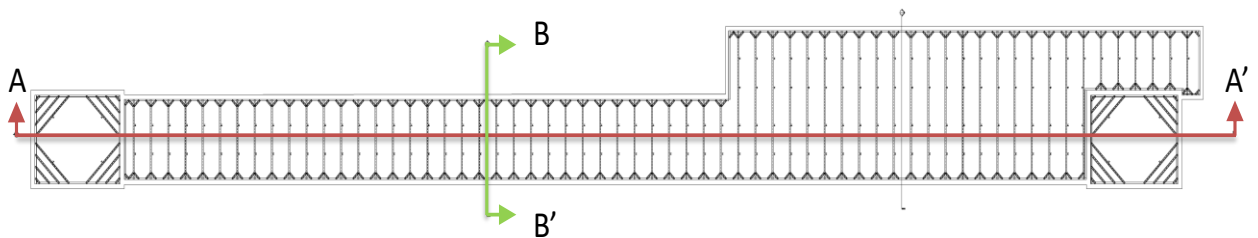


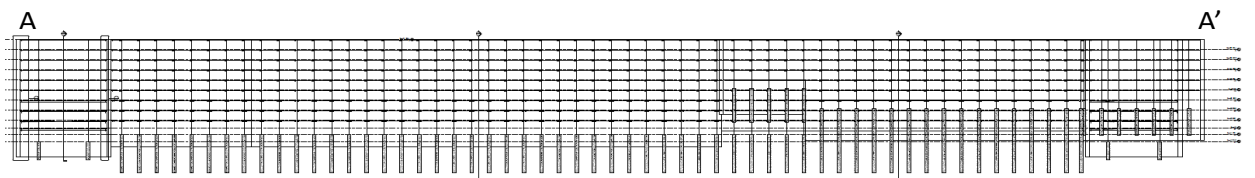**Figure 10**: Strut system 3D model



**Figure 11:** Strut system map



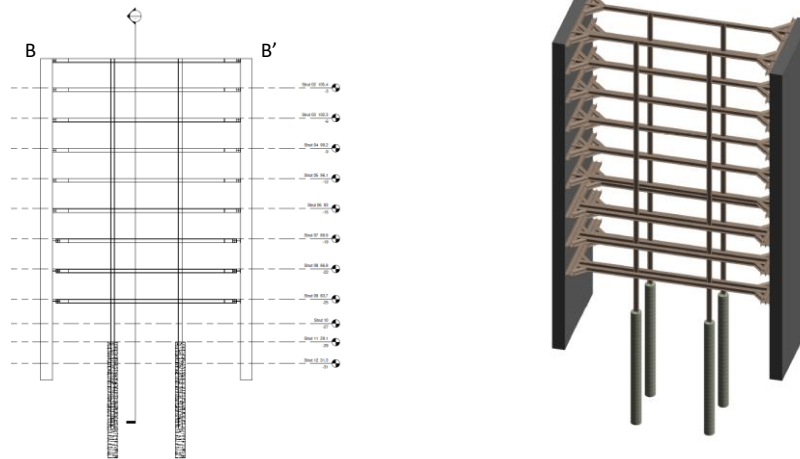**Figure 12:** Strut system model A-A' profile

**Figure 13**: Strut system model B-B' profile

### 3.3    Conflict review and 4D scheduling

In the cut-and-cover excavation for the station, an inner strutting system was introduced. It includes horizontal support, lagging, bracket, bracing, king-post, and decking. Usually, conflicts would occur during the first stage of excavation between strut systems and existing pipelines. In order to maintain the function of these pipelines, they have to be either diverted or protected.

In this study, Revit was adopted to create the BIM model of the first-stage strut system with existing pipeline. The model is allowed to present the relative position of strut system and pipelines, and transform traditional 2D drawings into a more visualized 3D model. The BIM model creates a more convenient platform for communication among the contractor, engineers, and the client.

Once the BIM model is completed, one can employ Navisworks to simulate the construction sequence in 3D visualization and play 3D animation, as shown in Figure 14. The flow chart of producing 3D animation and 4D scheduling is shown in Figure 15. The 3D model allows users to review the locations of conflicts. The 3D simulation makes coordination easier by allowing engineers to prepare and present conflicts or issues to be discussed beforehand and make an interdisciplinary meeting run more effectively.

As shown in Figure 16, with the TimeLiner function in Navisworks, scheduling information can be integrated into the BIM model to create a 4D construction simulation.

As for the strut system of the cut-and-cover sections, this study tried to use BIM model to perform 4D simulation of the project, including traffic control issues. The construction procedures are (a) traffic control and construction of D-wall, king-post, and strut system for the south of the road, (b) traffic control and construction of D-wall, king-post, and strut system for the north of the road, and (c) regular traffic control and construction of working platform.
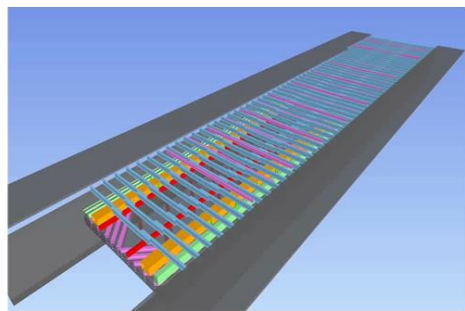
(i) 3D animation 1
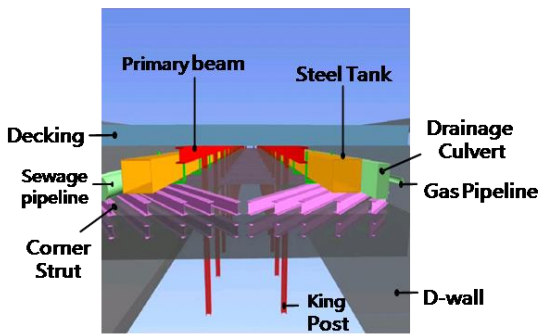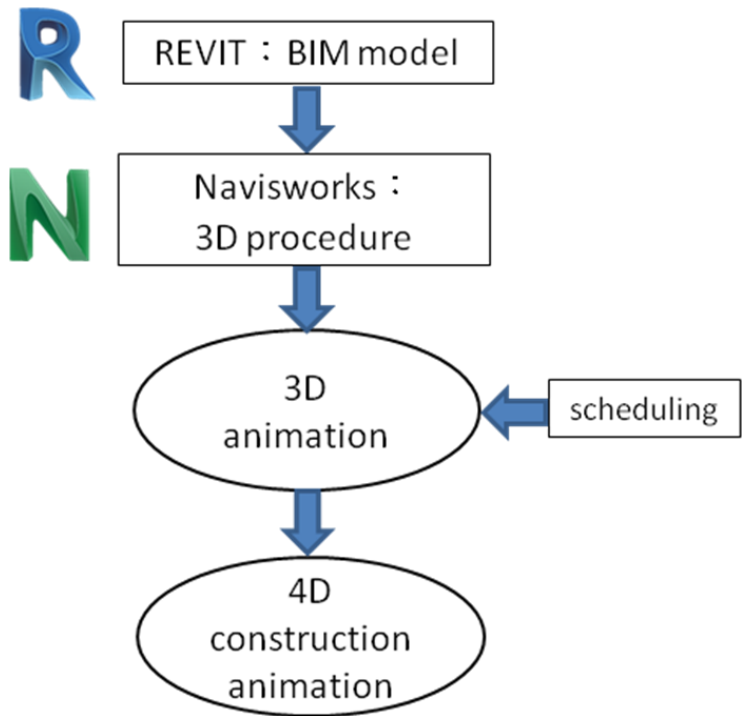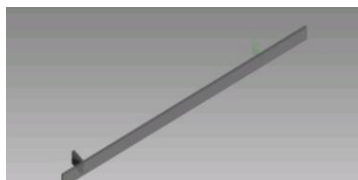

(ii) 3D animation 2

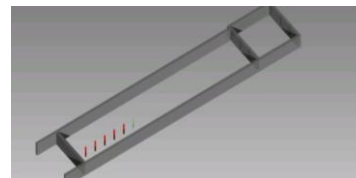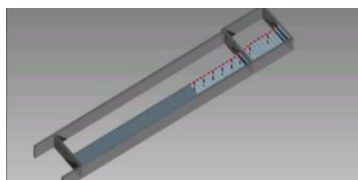**Figure 14**: 3D animation



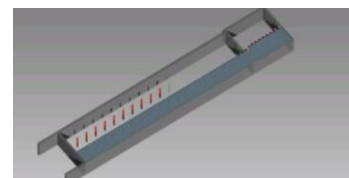**Figure 15**: Flow chart for creating 3D animation


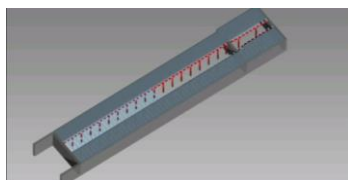(i) Animation-Diaphragm Wall Construction


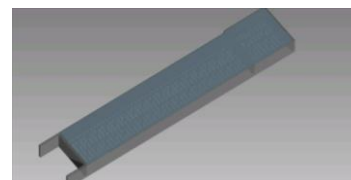(ii) Animation-Mid-Post Construction


(iii) Animation-Platform Construction


(iv) Animation-Mid-Post Construction


(v) Animation-Beam Construction


(vi) Animation-Strut System Finished

**Figure 16**: Construction 4D simulation of strut system

## 3.4 Application of Revit and Dynamo Software

BIM models are often subjected to change during planning and design stages where requirement and thus design are updated. Usually any changes to the model would involve modification of extensive amount of model elements, and mistakes are prone to happen. Dynamo, an easy-to-use and visualized

programming tool, backed by many researches and studies, has been adopted to create BIM models. It allows users to automatically generate BIM models and perform analyses.

This study used Dynamo to create BIM model of strut systems, and produced drawings and quantity calculation sheets automatically. The strut system was designed and calculated, and organized in an Excel format. Dynamo was then employed to automatically generate BIM model by reading design data from the Excel file. The procedure is shown in Figure 17.

Dynamo is able to perform the repetitive task of creating 3D horizontal strut, waling, and corner bracing models automatically in Revit. Therefore, one could edit the model by merely adjusting the design parameters in Excel and rerun the program. The automatically generated model using Dynamo is shown in Figure 18.

This program is also able to perform data analyses and deliver selected information and list of requested element quantities in BIM model, as shown in Figure 19. Furthermore, design drawings could be generated from BIM model, as shown in Figure 20.
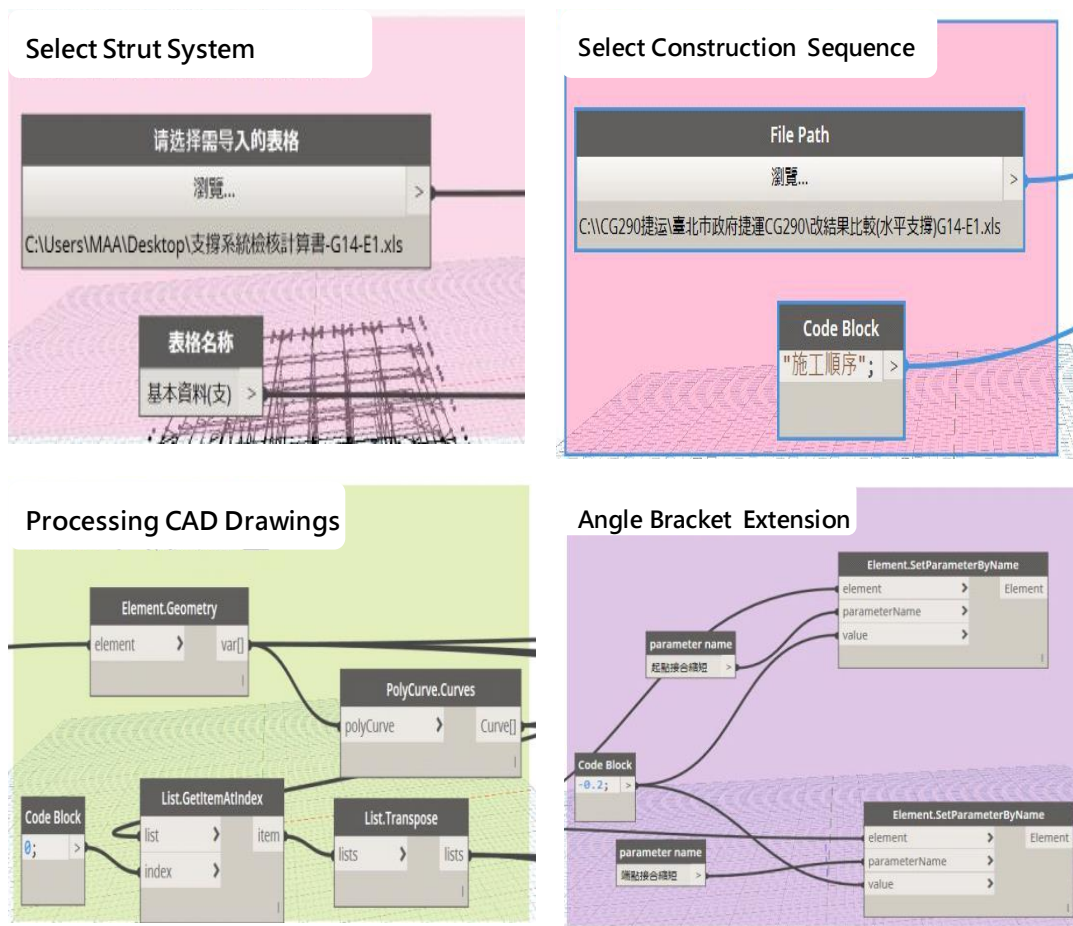


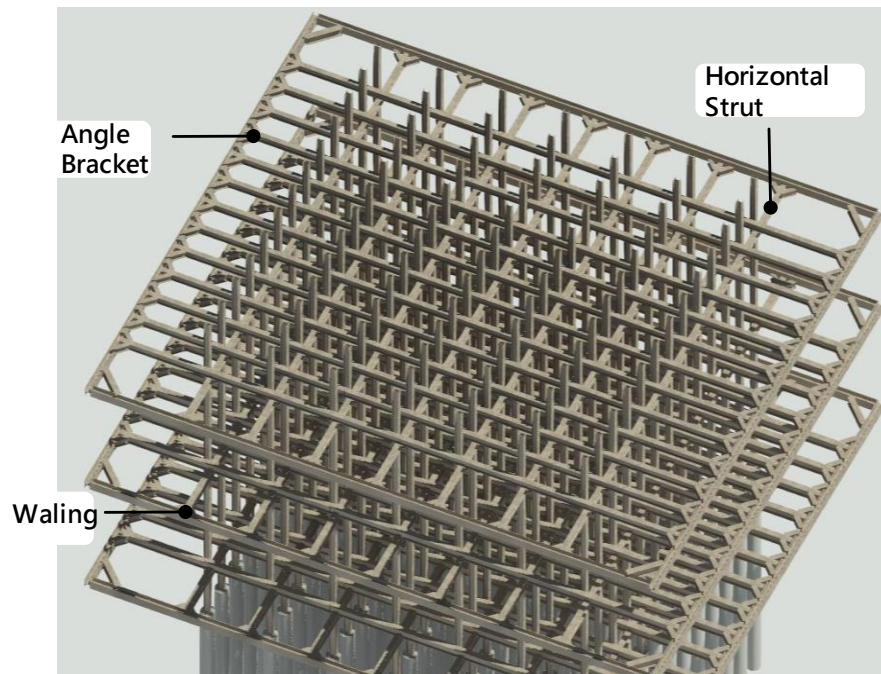**Figure 17**: Dynamo programming procedure

**Figure 18**: Model generated by Dynamo

## Material List

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| Rotation | Types | Quantity | Material | Length | Unit Weight | Total Weight |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
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| 0.00° | MAA大地部H型钢 | | 金屬 - 鋼 43-27 | 1.1313 | 94.00 kgf/m | 1.04 kN |
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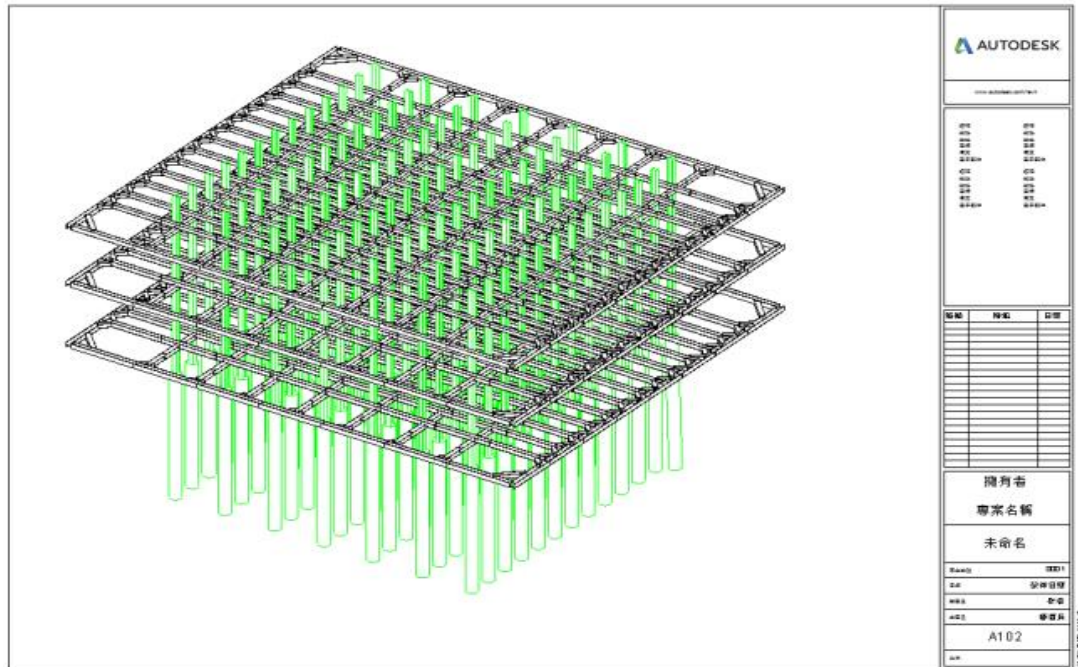**Figure 19**: Material quantity list

**Figure 20:** Design drawing generate by Dynamo

## 4 Concluding Remarks

Through combination of commercial software package, one is able to organize data, exchange files, produce quantity list, and detect 3D models via an integrated environment. The concept of 3D design has since been planted in construction and civil engineering industry, and may just change how designs are done in the future. As more and more BIM models are required by contracts in various construction projects, engineers are to equip with multiple new skill sets. This study introduces the application of BIM in geotechnical engineering, including (1) transform 2D boring log into 3D soil layer model, (2) create 3D model of excavation strut systems, (3) detect conflicts between strut systems and existing pipelines, and 4D scheduling, and (4) apply Dynamo to build BIM models automatically.

The early investment in developing BIM, including purchasing software, and enhancing engineers' programming skill, is significant. However, in the long term it can provide a convenient platform for discussion between various professional disciplines and reduce design and construction errors and possible penalties. In the future, it is expected that BIM is able to bring a more visualized 3D, and direct way into design, management, and construction supervision.

## 5 Acknowledgements

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