Integration of 3D models of structures and geological composition as an underground infrastructure model

Toshiaki Hakoda 1, Syoichi Nishiyama 2, Takaki Omori 3, Tadahiko Okumura 4, Mamoru Narusawa 5 and Nobuyoshi Yabuki 6

1 Coactivation Office, JGC Japan Corporation
2-3-1, Minato Mirai, Nishi-ku, 220-6001 Yokohama, Japan
2 Engineering Headquarters BIM/CIM Development Group, OYO Corporation
3-14-10, Sotokanda, Chiyoda-ku, 101-0021 Tokyo, Japan
3 Construction Management Department, Urban Infrastructure and Engineering Division, Nikken Sekkei Civil Engineering Ltd.,
1-4-27, Koraku, Bunkyo-ku, 112-0004 Tokyo, Japan
4 Geo-space Engineering Center,
Engineering Advancement Association of Japan
3-18-19, Toranomon, Minato-ku, 105-0001 Tokyo, Japan
5 Facility Management Department, ESCA-SC
7-1, Tsubaki-cho, Nakamura-ku, 453-0015 Nagoya, Japan
6 Division of Sustainable Energy and Environmental Engineering,
Graduate School of Engineering, Osaka University
2-1, Yamadaoka, Suita, 565-0871, Osaka, Japan

1 hakoda.toshiaki@jgc.com, 2 nisiyama-syoichi@oyonet.oyo.co.jp,
3 oomorita@nikken.jp, 4 okumura@enaa.or.jp, 5 narusawa@esca-sc.com,
6 yabuki@see.eng.osaka-u.ac.jp

Abstract. To develop three-dimensional (3D) models as examples of the infrastructure model concept which would be useful for the operation and maintenance or design and construction of underground facilities we integrated 3D models of the geological composition, the structure and the lifeline facilities (water supply and sewerage system, city gas line, electrical power and communication lines) for the underground mall named ESCA in Nagoya City, Japan. In addition to the above 3D models, 3D structural models of tunnels of the underground railway passing underneath ESCA are developed based on as-built drawings in cooperation with the transportation authority of Nagoya City, and settlements occurred by that construction are visualized in 3D models from a record of the construction of tunnels of that subway. ESCA built out a 3D data platform with browser software for daily maintenance and planning of modification work of the underground mall.

1. Introduction
Creating a digital platform of three-dimensional models of buildings has become quite common in advanced cities in the world, although most underground facilities and lifelines including geological composition are not modeled yet because of insufficient information for these.

The Geo-space Engineering Center (GEC) of the Engineering Advancement Association (ENAA) of Japan has organized a Committee for the Integration of Underground 3D models (CIU) and its Working Group (WG) with engineering consultants, OYO Corporation (OYO) and Nikken Sekkei Civil Engineering, Ltd. (NSC), a construction company, Shimizu Corporation (SMZ) and an engineering company, JGC Corporation (JGC) in 2017. CIU decided to proceed by directing the WG to collect sample data, including information on the geological composition to be used for the preparation of a 3D model of underground facilities. CIU selected ESCA underground mall connected to the west entrance of Nagoya.
Station in the Tokai area of Japan (Figure 1. shows a location map of EDCA), as NSC had already created a 3D model of the ESCA underground mall and parking lot in 2016 for the simulation of seismic strengthening works and an evacuation plan of the mall for shoppers and guests in emergency cases. Figure 2. shows a section of the 3D model of the geological composition and 3D structural model of ESCA.

Before commencing the modeling work by the WG, ESCA-SC (the owner of ESCA) joined this study and issued Employer’s Information Requirement (EIR) and the WG made a BIM Execution Plan (BEP) for this modeling work.

Figure 1. Location map of ESCA next to the Nagoya Station

Figure 2. Section of 3D geological composition and 3D structural model of ESCA
2. Procedure of 3D modelling for ESCA underground mall

A list of software packages used for the modeling of each object is shown in Table 1. 3D models are developed by the WG for each object and integrated into one model.

| Model                                      | Software                        |
|--------------------------------------------|---------------------------------|
| Structure of ESCA underground mall and parking lot | ArchiCAD, Revit, AutoCAD       |
| Geological Composition                     | GEO-CRE, OCTAS Modeler         |
| Ground Anchors                             | Revit                           |
| Lifelines                                  | AutoCAD, Revit                  |
| Integration of models                      | Navisworks                      |
| Tunnels of subway                          | Rhinoceros, Revit               |

2.1. Development of geological composition for the ESCA underground mall

Before making a detailed image of the geological composition of the land immediately below the ESCA underground mall, the WG checked the existing public geological report for a wider area around the Nagoya Station. After that, the WG utilized OYO’s software named “GEO-CRE” for geological comparison work, and the “OCTAS Modeler” for solid modeling work based on the data of twelve borehole logs given by ESCA-SC dated in 1969 before the commencement of construction of the ESCA underground mall.

The procedure for analysis of the 3D geological model was made in accordance with “3D geological analysis manual Ver.1.5 2019” published by the 3D Geological Analysis Technology Consortium, Japan. The algorithm of interpolation of spacing for the calculation of the surface model is based on BS-Horizon (Fortran program for generating the geological surface using cubic B-Spline) (Masumoto et al., 2004).

Furthermore, the municipal office of Nagoya City allowed WG to use a historical record of construction for the subway running through underneath of the ESCA underground mall, then the WG was able to confirm the precise level of each layer of soil composition from the additional data provided by the borehole logs.

Figure 3. shows the soil conditions of the bottom level of ESCA resting on firm condition of bearing soil layers which were updated based on the borehole logs obtained from the transportation authority of Nagoya City in 2019.

**Figure 3.** Soil conditions of the bottom level of ESCA

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Ac: Holocene clay
D3U-c1: Atsuta formation upper layer clay (upper*)
D3U-s1: Atsuta formation upper layer sandy clay (upper*)
D3U-g: Atsuta formation upper layer gravelly clay (upper*)
D3U-s2: Atsuta formation upper layer clay (lower*)

(*: Local classification)
The 3D model of ground anchors was made with Revit from the discarded materials for construction of the retaining wall and combined with the 3D geological composition. The WG was able to confirm that the ground anchors reached into a firm layer. Figure 4. shows the soil conditions around the ground anchors which are assumed to be stable in a firm bearing layer of soil at the construction period of retaining walls.

Figure 4. Soil Condition Surrounding the Ground Anchors

2.2. Development and integration of lifelines and structural model of ESCA underground mall

A 3D structural model of the ESCA underground mall including the parking floor is developed by NSC based on as-built drawings. Lifelines into ESCA are buried beside the retaining wall of ESCA. In order to visualize lifelines and clarify the positions of tie-in points into ESCA, the WG developed 3D models of lifelines and combined these with structural models of ESCA. On the other hand, we recognized the difficulties posed by 3D modeling from complicated descriptions of 2D drawings for lifelines given by operators and local authorities, which would be a critical issue for 3D modeling in the future.

Figure 5. shows 3D models of lifelines of the southwest area of the ESCA underground mall.

Figure 5. 3D models of lifelines near ESCA
2.3. 3D modeling of the tunnels of subway and visualization of displacement during the construction of tunnels.

NSC utilized Rhinoceros (3D modeling software) to make a 3D model of tunnels and combined this with the 3D model of ESCA by Revit with adjustment of precise location surveyed by NSC in 2018. Figure 6. shows a combined 3D model of tunnels and ESCA underground.

OYO studied the published record of construction of the subway and recognized various methods of soil improvements were applied underneath of bottom slab of ESCA for avoiding the collapse of temporary small tunnels for construction (shown in Figure 7.) and that about 100 settlement gauges were set on the slab of ESCA for monitoring with hydraulically connected communicating tubes. Results of the monitoring of settlements are visualized on the slab of ESCA using Grasshopper of Rhinoceros as shown in Figure 8. and OYO confirmed the maximum value of settlement was 2.9mm.

![Figure 6. Combined 3D model of tunnels and ESCA underground mall](image)

![Figure 7. Visualized displacement during a construction of tunnels underneath ESCA](image)
3. 3D data platform for ESCA underground mall

NSC built out a 3D data platform of the ESCA underground mall as a supporting system for maintenance of facilities by staff of ESCA-SC with an easy user interface of the browser.

The portal image of this 3D data platform is shown in Figure 9, which contains an index of tenants with 3D images mapped on structural models of shops, above-ground objects, air-conditioning ducts on ceilings, reinforced structural members in the parking lot, equipment in machine rooms and various lifelines coming into the ESCA underground mall. Some 3D models are shown in Figure 10.

Figure 8. Visualized displacement during construction of tunnels underneath of ESCA

Figure 9. Portal site of the supporting system of ESCA
4. Conclusions

CIU and its WG had started integration work of 3D models of structures of the ESCA underground mall and their 3D geological composition with old 12 numbers of boreholes logs from 2018.

Through a process of integration, the WG fortunately obtained useful documents for updating a 3D model of geological composition from the transportation authority of Nagoya City and the WG learned the importance of data coordination with the public sector and private companies, and that updating a 3D model according to newly investigated survey data is essential to improve the reliability of the 3D modeling.

ESCA-SC has operated an underground mall and parking lot for more than 50 years besides the essential rapid railway called the Shinkansen and they are ready to plan a new development in the old west area of the Nagoya Station. In the planning of area development, integrated 3D models of underground objects would be very helpful for surveying, design consultants and construction companies to improve quality, cost-effectiveness and time efficiency.

An especially significant aspect of this study is believed to be the integration of the 3D modeling of the geological composition together with that of underground facilities.

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Whole reports written in Japanese of 3D modeling of underground information as an underground infrastructure model for the 2018 and 2019 fiscal years can be accessed through the website of ENAA GEC. (URL: https://www.enaa.or.jp/?fname=2018m-024.pdf, https://www.enaa.or.jp/?fname=2019m-032.pdf)

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