Digitalization, Modularisation and Sensors Application of a Deep Excavation Project in Urban District of Hong Kong

Gavin SH Toh[1], John Latter[2], Alan WL Wan[3]
Dennis TS Ho[1], Elaine CL Chan[1]
[1] Lambeth Associates Limited, Hong Kong
[2] Mandarin Oriental Hotel Group
[3] Gammon Construction Limited

ABSTRACT

The redevelopment of the Excelsior Hotel site included a 3-level basement that required excavation up to 17m. The design of the temporary works consisted of contiguous pipe piles braced by five layers of lateral support to provide stability to the pipe pile wall cofferdam, efficient groundwater cut-off and to control ground movement impact to the adjacent ground and buildings. The adjacent buildings comprised the World Trade Centre, five residential dwellings built in the 1960s, and an existing link bridge structure that required to be supported within the excavation area. This paper will discuss the collaborative and digital approaches in the design and planning of the method and sequence of the work, modularization of the shoring system, and the use of scanning and sensor monitoring devices – that will showcase and promote modern construction for Hong Kong deep excavation work. The collaborative and digital approach streamline the construction work process by first building in the virtual work before the real world. The buildability, safety, and quality of the actual implementation are greatly improved.

1 INTRODUCTION

With the advancement of technology, digital applications are used to design deep excavation work. Digital Information Modeling (e.g., BIM) 3-Dimension is a norm in the industry and plays an important role in the design, planning, and management of construction process. The 3D BIM model provides virtual constructability reviews in deep excavation such as construction plant/equipment access, practical sequence of work, identification and resolution of clashes, and define standardized shoring module and fabrication details.

The application of digital scanning technology to generate actual site condition and as-built alignment provide reliable and accurate information for design and planning of the next construction phase, such as, the basement and superstructure work. Digital instrumentation sensors have been in used in the industry for a few years and its monitoring data is becoming more reliable and gives confidence to the relevant stakeholders. Toh et al. (2019) outlines benefits and prospects of integrated application of modularisation, digitalization, and sensors that combines processes and people from the design and planning to construction.

This paper presents the collaborative and digital approaches of deep excavation work and how these approaches have improved safety and quality of the construction work.

1.1 Project Background

Located at the former Excelsior Hotel, a new office building will be developed in the urban district of Causeway Bay. The proposed redevelopment includes a 32-storey high building structure with a 3-level basement supported by raft foundation. A footbridge will be built to connect the office block to the World Trade Centre Hong Kong and an existing footbridge to La Foret shopping centre in Chee On building will be reconnected. Refer to Figure 1 & 2 for photo of the old Excelsior Hotel and location of the project, respectively.

Figure 1 The former Excelsior Hotel

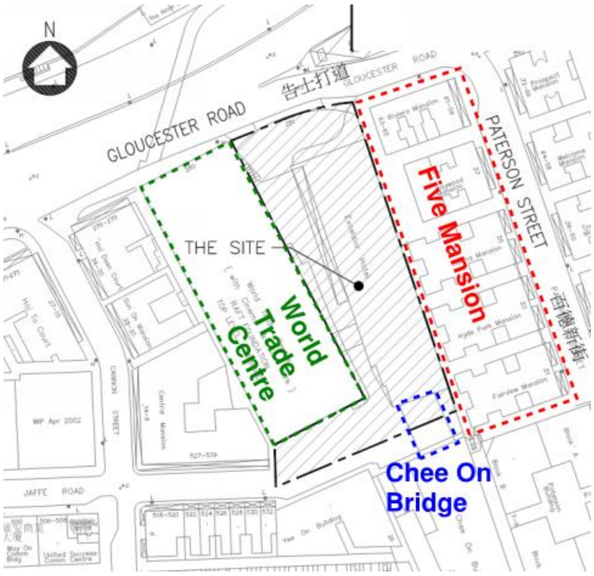

Figure 2 Site Location Plan

2 EXCAVATION DESIGN FOR THE REDEVELOPMENT OF EXCELSIOR HOTEL

2.1 Site Location and Adjacent Sensitive Structure/ Utilities

In the urban district of Causeway Bay, the site is in proximity to existing buildings and utilities. The site is approximately 110m in length and 45m in width. The minimum clear distance from the site boundary to the adjacent World Trade Centre and the closest residential block built in 1960s is 7m and 2.5m, respectively.

2.2 Excavation and Lateral Support Design

The excavation and lateral support (ELS) consisted of pipe pile wall with shear pins as the temporary vertical wall with grout curtain to provide water cut-off to the excavation. Five layers of struts were adopted for the construction of 3 levels of basement with maximum retaining height of 17m. The excavation level is generally at -12.8mPD and -15.8mPD for lift pit areas. Pre-loading of struts were applied to minimize the lateral deflection of the pipe pile, and the impact to adjacent structures and utilities. The layout plan and sections of the cofferdam with strutting arrangement are shown in Figure 3, 4 and 5, respectively.

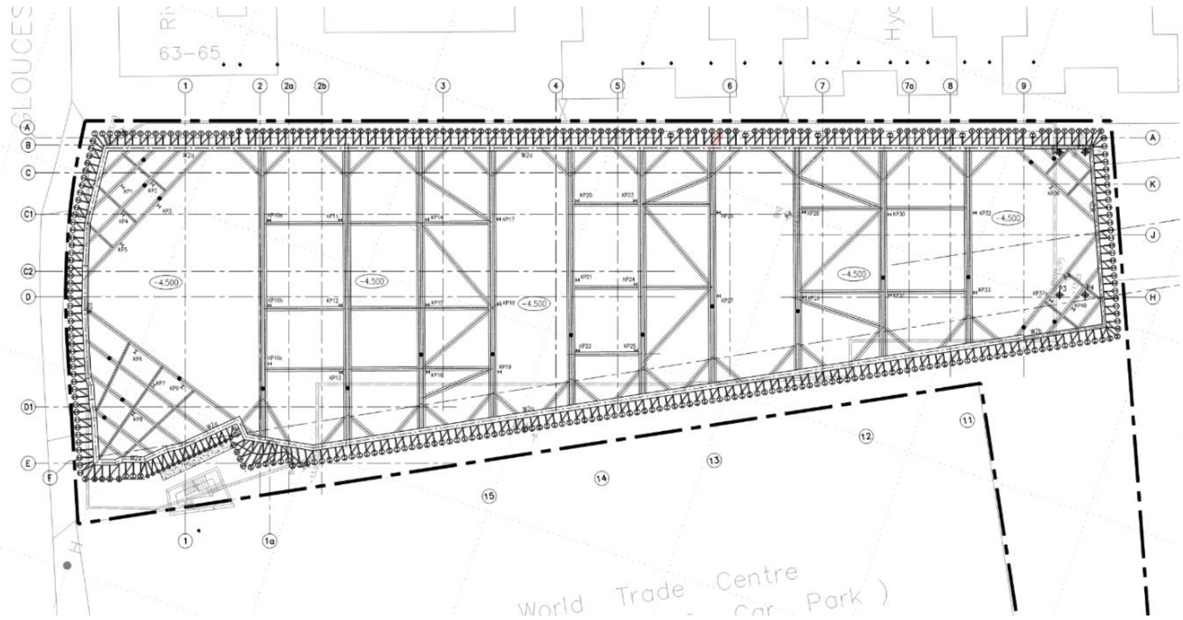

Figure 3 Layout Plan of the ELS

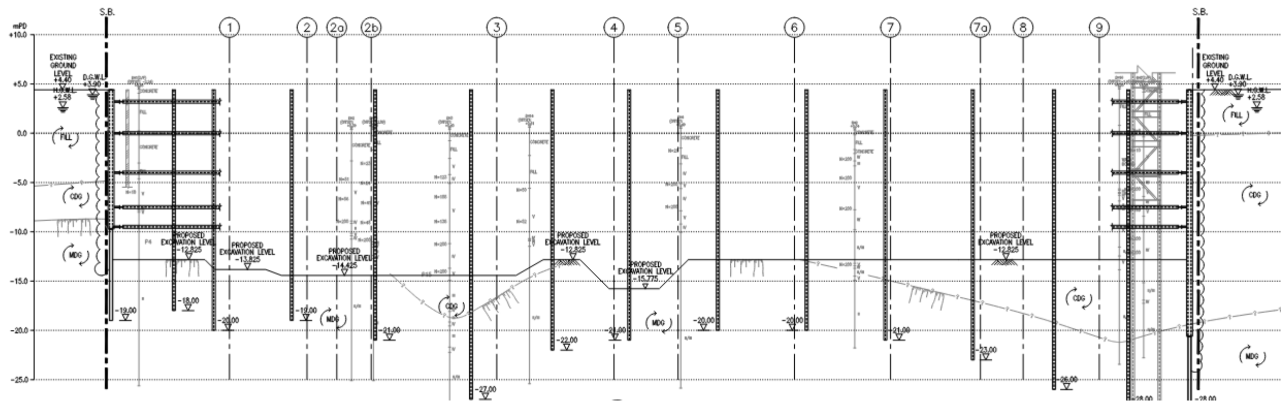

Figure 4 Longitudinal Section

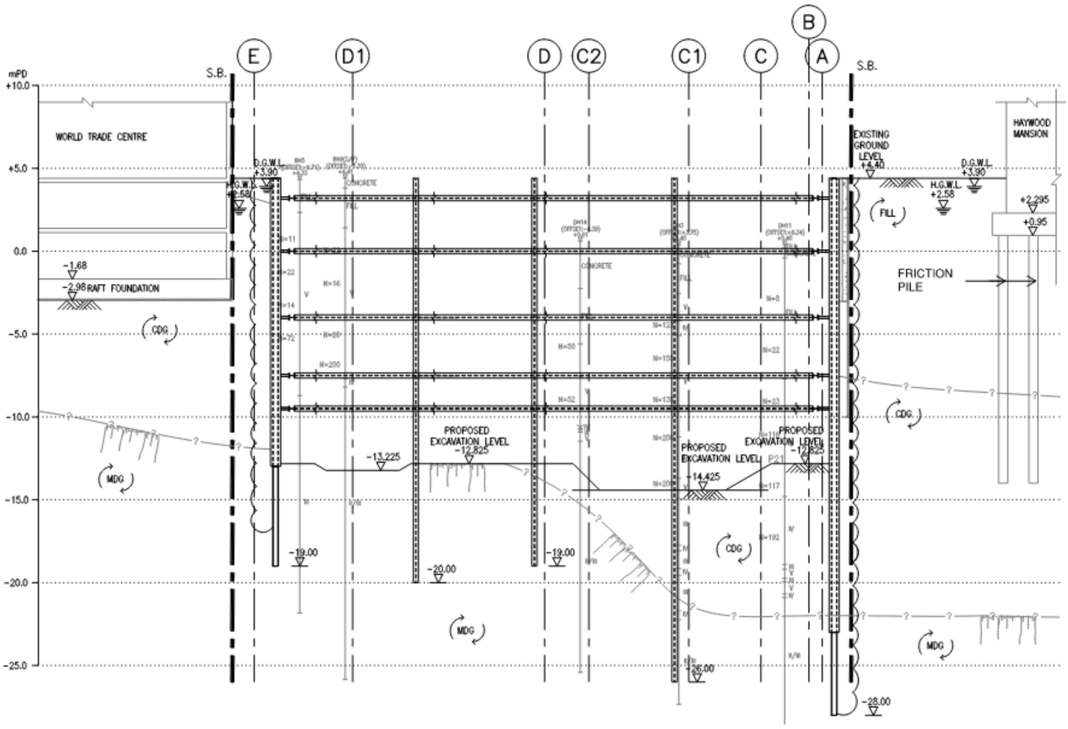

Figure 5 Cross Section

3 INSTRUMENTATION MONITORING SYSTEM

As the development is situated in a busy commercial district with adjoining operating offices and domestic buildings, a comprehensive system of instrumentation was set up to closely monitor any effect induced by the construction works. Instruments included inclinometers, vibration check points, tilting markers, standpipes and piezometers, ground and building settlement checkpoints. These were installed at all sensitive receivers, such as the 5 residential mansions and the World Trade Centre.

Gammon’s GEOMON system was used as the primary means of instrumentation and monitoring data management. GEOMON is a robust web-based data monitoring and reporting system. The system comprises an instrumentation database server, web server and associated scripting engine to store, retrieve and tabulate, graph or generate PDF reports of the monitoring data. Shall any instrument reach a Response Level, the system will automatically alert all Gammon’s supervisors.

Real time monitoring adopting digital instrumentation sensors included strain gauge and inclinometer were set up to monitor the performance of the deep excavation and provide confidence to the values measured. Comparison of the predicted and measured magnitude of the maximum lateral displacement of the wall had been carried out to verify model assumptions in PLAXIS. Figures 6 and 7 show cross sections with two real-time inclinometer INC7 and INC10 readings and two conventional inclinometer INC2 and INC5 readings. For INC7 and INC10 near World Trade Centre, the predicted and measured wall deflection are comparable, implying the ELS design can resemble the actual site condition. For INC2 and INC5 near the residential mansions, the predicted wall deflection is generally larger than the measured wall deflection, which verifies the performance of the ELS. Below the final excavation level, the predicted wall deflection is much greater than the measured wall deflection, which may be attributed to a better than predicted ground condition.

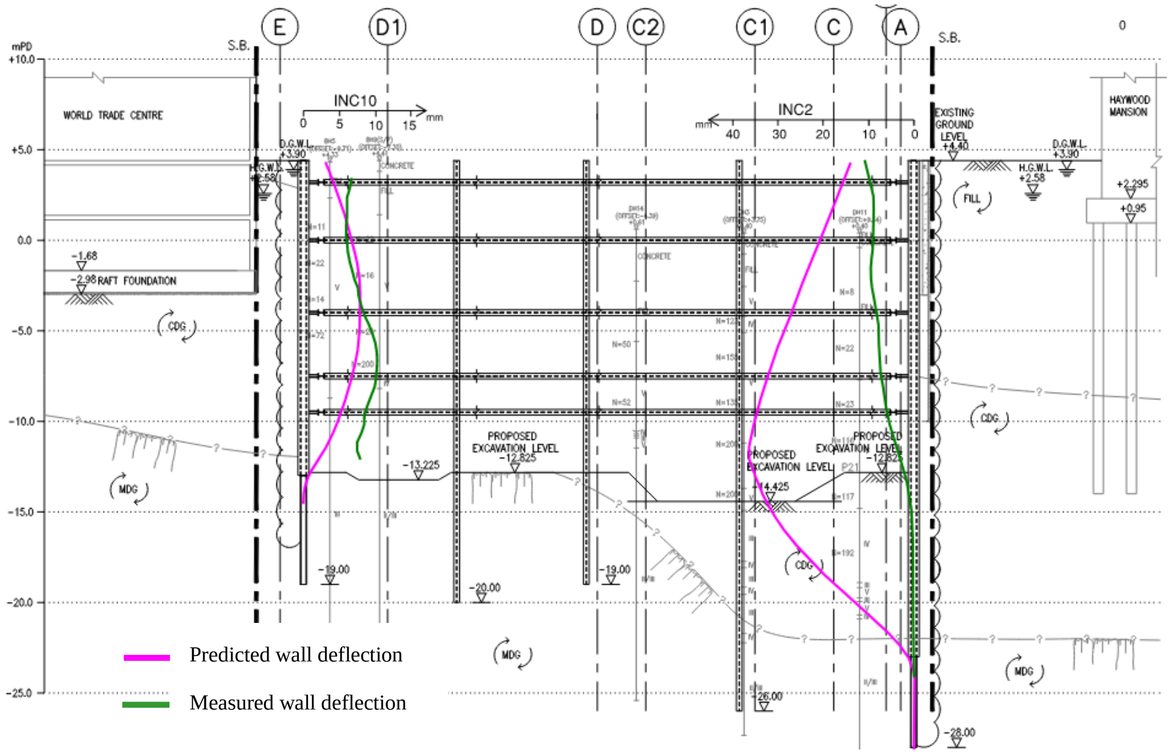

Figure 6 Section with Predicted and Measured Wall Deflection

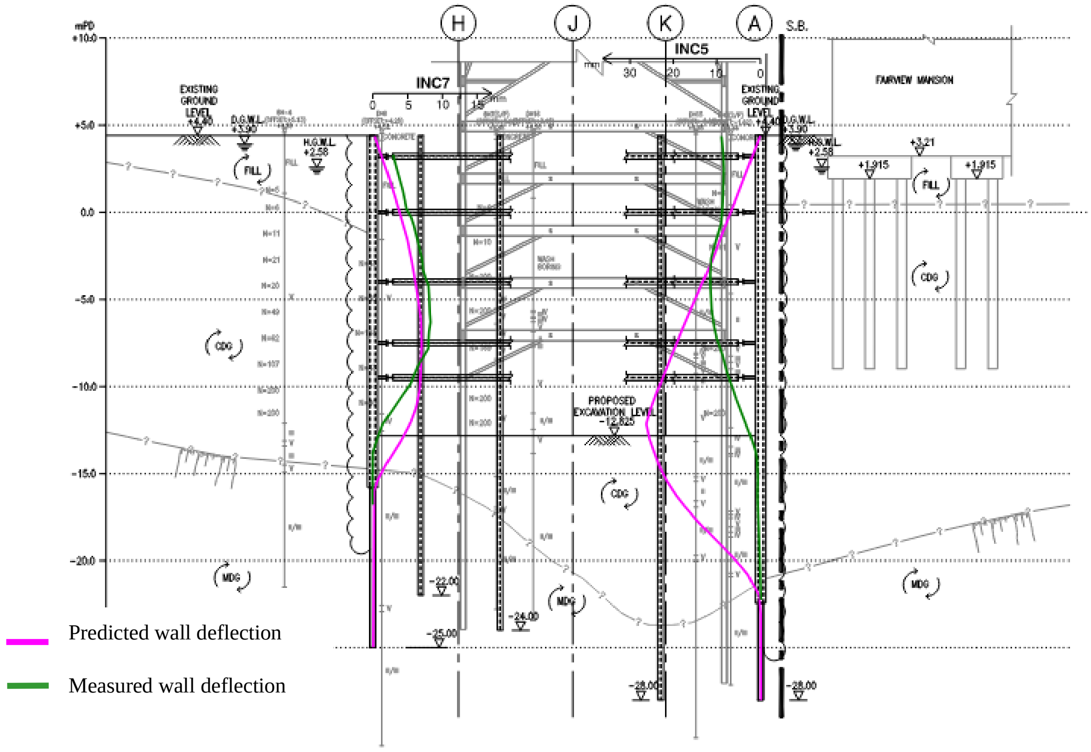

Figure 7 Section with Predicted and Measured Wall Deflection

Other real-time instrumentation included vibration monitoring of the existing Chee On Bridge that had been temporarily supported during the excavation. CCTV was installed at the bridge to monitor real time the condition of the cladding. Set up of the vibration monitoring and the CCTV at the bridge are shown in Figure 8 and 9.

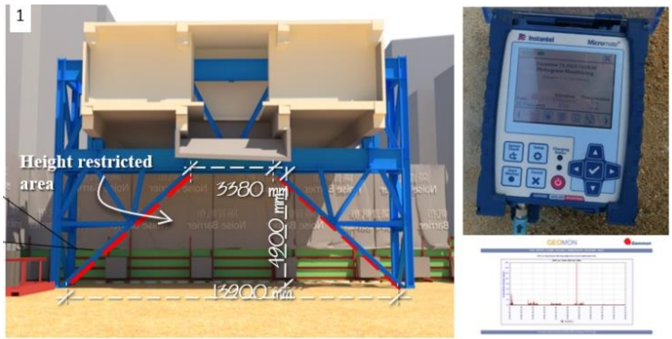

Figure 8 Real Time Vibration Monitoring for Chee On Bridge

Figure 9 CCTV Monitoring on Bridge Cladding

4 DIGITAL TECHNOLOGY APPLICATIONS AND INNOVATION

4.1 Application of BIM

Three dimensional BIM digital models were utilized throughout the construction project life cycle. Steel support and temporary steel platforms were modelled using BIM for clash analysis. The model is also updated concurrently for as-built steel deck supports and ELS vertical elements to evaluate for any further clashes with permanent structures. The example of clash analysis of the model and modification implemented in the design to eliminate clashes is demonstrated in Figure 10 and 11.

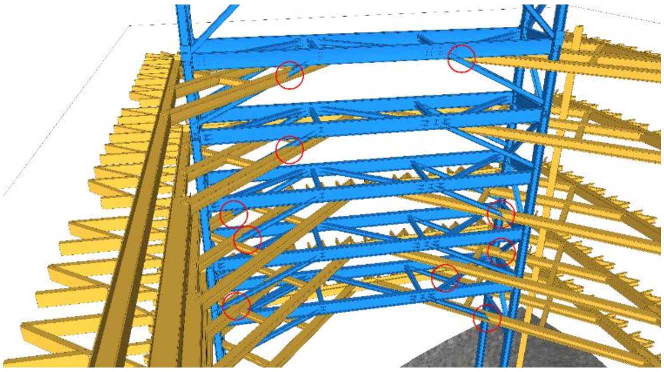

Figure 10 Clash Analysis for ELS

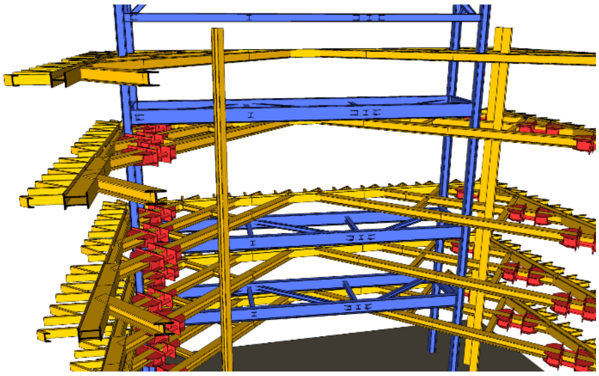

Figure 11 Revise ELS Design to Eliminate Clash

The BIM digital model provides insight into construction logistics that will greatly improve planning of plants and equipment movements and the provision of safe access routes for workers. Any construction issues can be resolved in the virtual world before the real world. The illustration shown in Figure 12 highlights the complexity of the logistic plan during the pipe piling work whereby without the digital model it would not be able to provide a realistic and practical construction work plan.

Apart from the site logistic planning, digital virtual model combined with existing and planned details help to work out a practical method and the sequence of the construction. In Figure 13 the BIM model combining with the sequence of work plan presented the construction planning with time digitally, and subsequently used for monitoring the progress during the actual work.

With the digital 3D model, step-by-step visualization of work brings significant benefits on buildability. The example shown in Figure 14, involves heavy piling plants for the pipe piling work in a congested and low headroom condition. With digital visualization, suitable piling plants, maneuvering of the plants, sequence of the work, fatal and safe zone for workers were all sorted out and communicated in the digital environment before actual implementation. The digital imaging method prepared using formats familiar for the frontline workers were used for pre-work briefing.

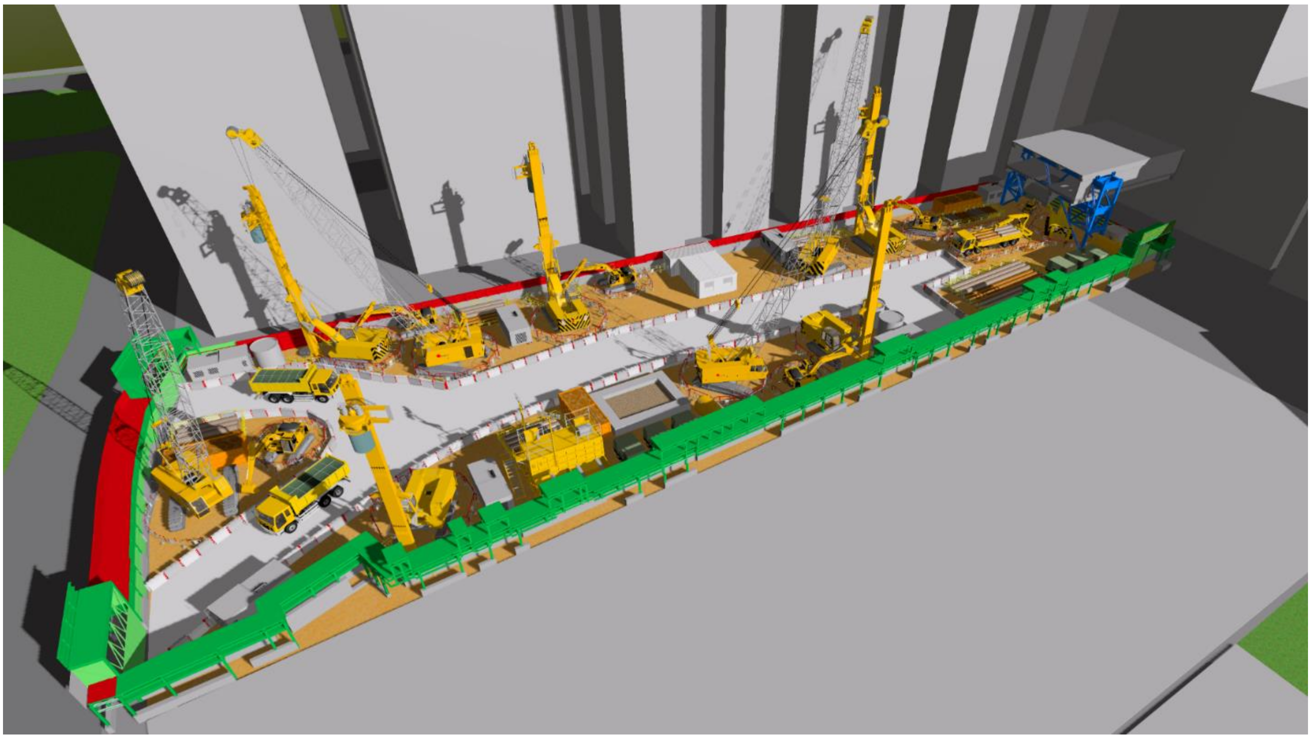

Figure 12 Digital Model on Logistic Planning

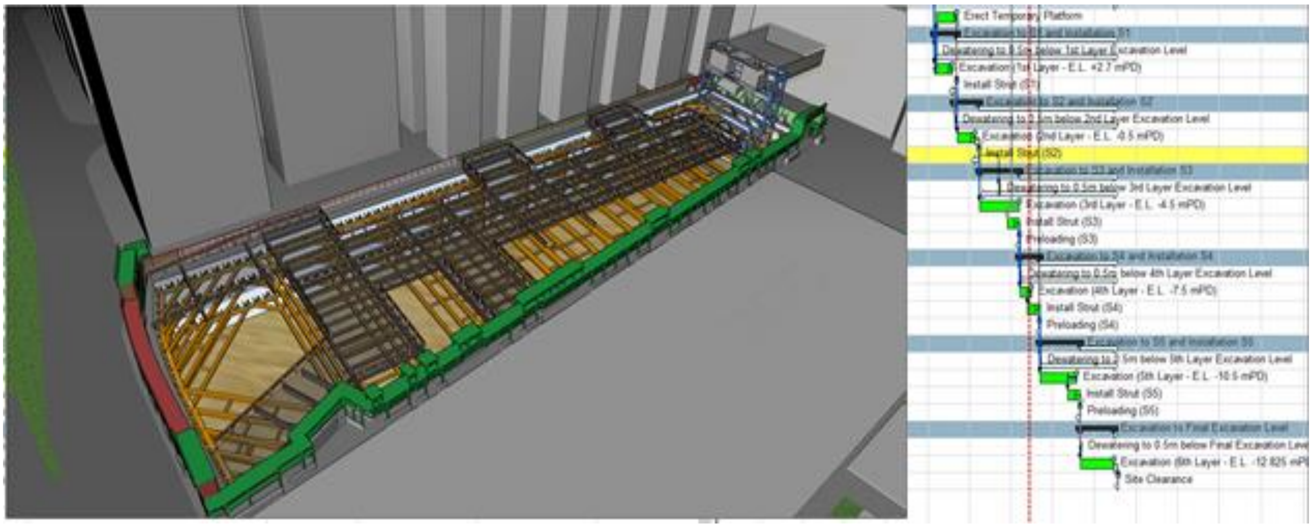

Figure 13 Combining Work Plan and Sequence in the Digital BIM Model

Figure 14 Pictorial Digital Method of Work

4.2 Laser 3D Scanning

A portable and compact handheld 3D scanner was used for monitoring site topography, progress monitoring and estimating excavation volume. Digital images shown in Figure 15 and 16. Survey points by LIDAR and colour imagery could efficiently and accurately be collected compared to conventional ground surveys. The latest ground profile of site could be obtained to verify the excavated volume of soil or rock. Apart from excavation volume, as-built structures could also be reflected from the 3D imagery. The as-built ELS vertical elements, such as pipe pile walls and steel supports were scanned on site and extracted into the BIM model for clash detection with permanent structures. This not only saved manpower as only one surveyor was required for data taking and safety was also enhanced as surveyor did not need to walk into dangerous zone on site. With 3D scanning and BIM models complementing each other, it greatly helped project planning.

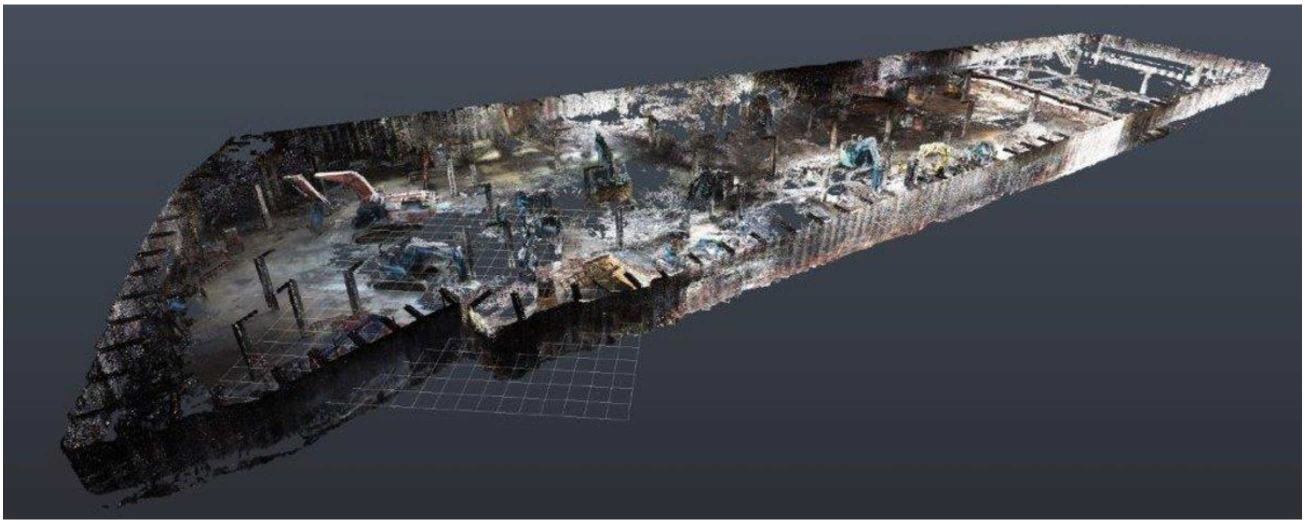

Figure 15 Laser 3D Scanning Imagery of the Construction Progress

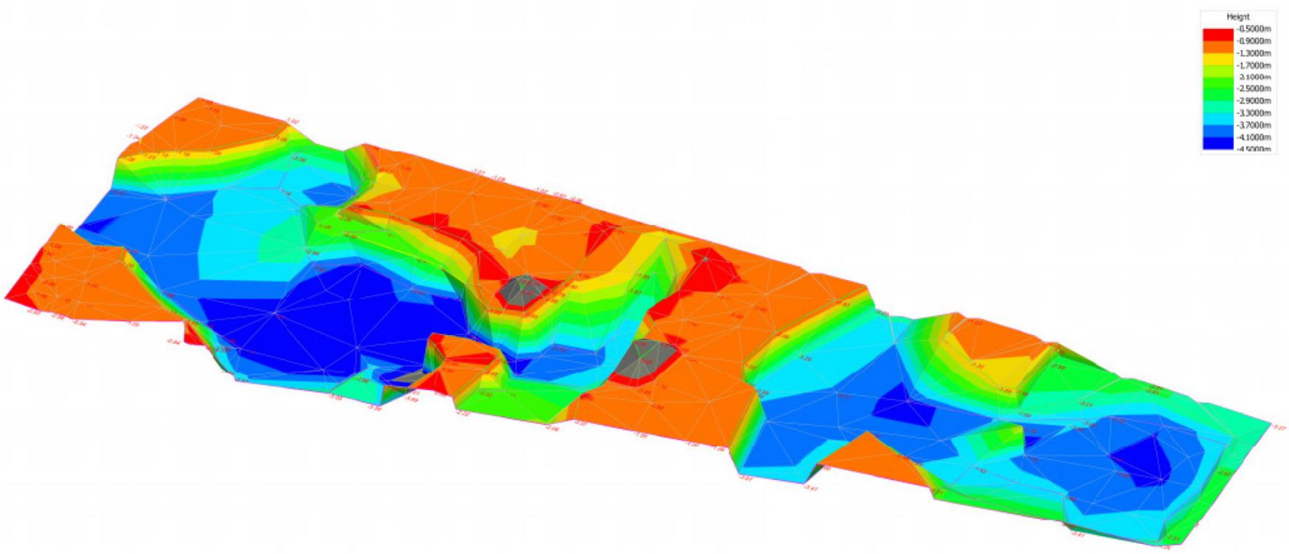

Figure 16 Topography of Excavation Profile from the Laser 3D Scan Imagery

4.3 Modularisation for ELS

An important aspect in buildability for deep excavation is modularisation of the shoring system. In modularizing the struts, integrated modules and components are planned and designed, manufacture and fabricated off-site in a factory using highly efficient machines and skilled labors under a stable and suitable environment. The modules are then logistically delivered to site for assembly – an application of DfMA (Design for Manufacture and Assembly). Other multi-functional components such as bolting arrangement, preloading brackets, lifting eyes, and provision for edge protection are integrated in the module during fabrication. This greatly reduces on-site welding.

For the Excelsior redevelopment project, to facilitate the flexibility to re-use the modules, the size of the structural steel members was strategically selected. The length of each spliced segment was also capped to a maximum of 9m as the choice of delivery trailer was limited due to the busy Gloucester Road and the narrow site gantry. Using bolt and nut connections saved a total of 580 man-days of welding as compared with fully welded connections. In addition, the installation time for each strut layer was reduced by 3 weeks with bolt and nut connections.

In the design of each module, digitization consolidates design and detailing including connection, virtual assembly. Any issue with assembly is tackled early, which greatly improves workflow for off-site fabrication and on-site assembly – illustrated in Figure 17 and 18.

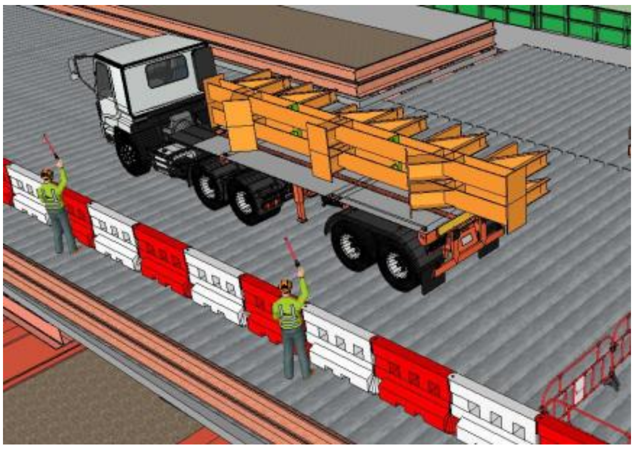

Figure 17 Digital Delivery of Modules to Site

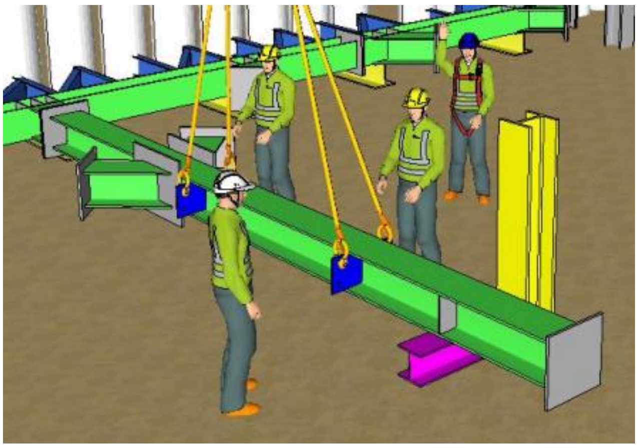

Figure 18 Digital Installation of each Module

Another application of DfMA has been implemented at the Excelsior Hotel redevelopment project is the modular steel access staircase. The steel staircase was designed and prefabricated with connections that could be easily assembled and removed at end of the project, hence, facilitating for reuse in other projects. The digital and actual connection assemble details are illustrated in Figure 19 and 20.


Figure 19 Actual Connection of the Modular Stair

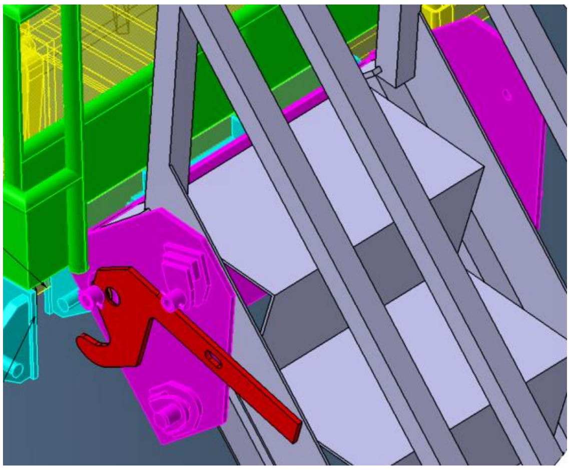
Figure 20 Digital Connection of the Modular Stair

4.5 Digital Sensor Detection

Automatic water detection sensors were installed 500mm above excavation level as in Figure 21 below. When abnormal water level is detected, automatic signals would be sent to site team and security guard at site entrance. This enabled fast remedial measures to be carried out to mitigate flooding risk on site.

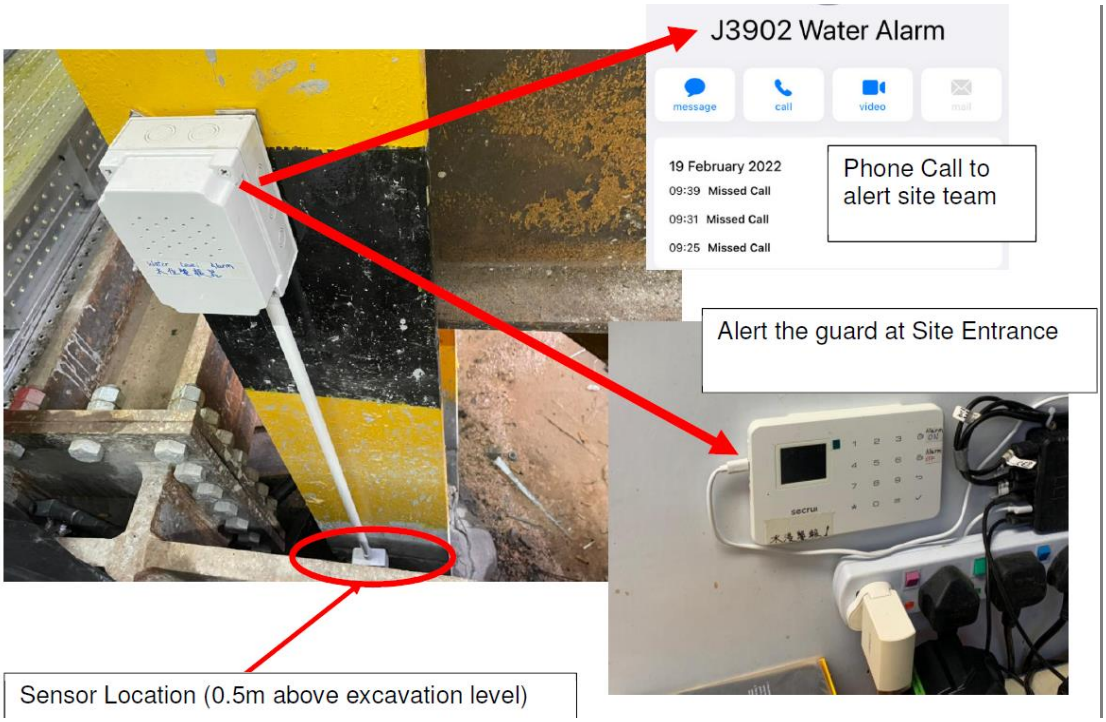

Figure 21 Water Detection Sensors

4.6 Core-bide Method for Drilling Through Underground Structure

The traditional down the hole hammer method for the pipe piling work may induce high levels of noise disturbance and vibration to surrounding area. In the Excelsior Hotel redevelopment project, the team has adopted tailor-made hybrid core bits welded with tungsten carbide to core out the existing heavily reinforced pile cap in one piece. Compared with the hard coring method, noise generated from core-bide method was significantly reduced considerably from 90dBA to 73dBA, while vibration induced was reduced from 20ppv to 5ppv. In addition, diesel consumption for this innovative core-bide method could be reduced by more than 90%, which greatly reduced carbon emission. The details of the core-bide method of drilling and comparison of the data with traditional method are given in Figure 22 and 23. The Core-bide method has received the Merit Award (Construction Sustainability) of the CIC Construction Innovation Award 2022.

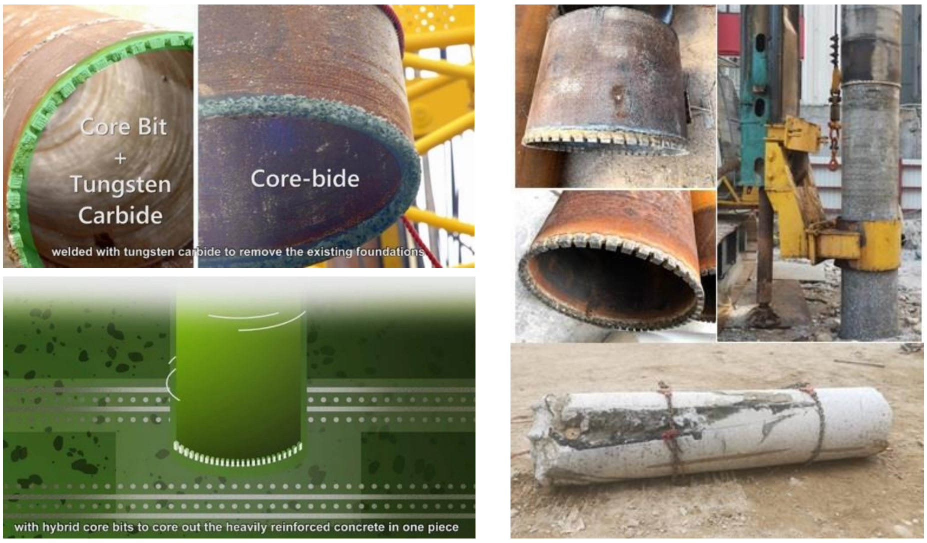

Figure 22 Core-bide Method for Drilling Through Existing Reinforced Pile Cap Underground

Description	Hard Driving Method	Sustainable Core-bide Method
Noise (dBA)	90	73
Vibration (ppv)	20	5
No. of Air Compressor	3	0
Productivity (days/pile)	4	2
Diesel Consumption (Liters)	916,800	57,300

Figure 23 Comparison Table for Core-bide Method and Hard Coring Method

5 CONCLUSIONS

The application using digitalization, modularization and sensors in the design, planning, and monitoring of the deep excavation work of the Excelsior Hotel redevelopment has been successfully implemented not just at the onset of the project, but also throughout the whole life cycle of the construction period. The continuous efforts and determination of the design and construction teams in a collaborative and digital approach is another important aspect to realize the full benefits of modern construction. The project has recorded zero safety incidents during the 850 calendar days of the construction, which has been considered as an outstanding safety performance. In addition, the project was completed ahead of the planned time.

ACKNOWLEDGEMENTS

This paper is published with the permission of Mandarin Oriental Hotel Group and Gammon Construction Limited. The support and participation of the project teams including Hong Kong Land (Project Management) Ltd, Ronald Lu & Partners (Hong Kong) Ltd and Meinhardt (C&S) Ltd are highly appreciated.

REFERENCES

Toh S.H., Ho C.N., Jenkins S.A., Tsui K.L., Lai, U.S. 2019 Integrated Application of Shoring Modularization, Digitalization and Monitoring Sensors in Deep Excavation Project. *Proc of Transformation in Geotechnical Engineering – Technology, Digital and Innovation.* The HKIE Geotechnical Division 39th Annual Seminar 2019.