CEDD INNOVATION SERIES



Off-Site Prefabrication for Building Construction inside Caverns

Foreword

Civil Engineering and Development Department (CEDD) maintains a steadfast commitment to engineering excellence in infrastructure development, continually playing a pivotal role in shaping Hong Kong into a leading city in Asia.

CEDD acknowledges the importance of collaboration with academia and the construction industry in fostering innovation and technological advancement. Through University-Government-Industry (UGI) partnerships, we have been advancing and adopting innovative construction technologies, materials and nature-based solutions in our engineering projects. This integrated approach aims to build a more livable and climate-resilient city, while achieving co-benefits that enhance productivity and promote environmental sustainability.

The successful adoption of these innovative solutions showcases how cutting-edge innovative engineering technologies and stringent construction protocols from both international and local contexts can be seamlessly integrated to achieve excellence.

I would like to commend the project teams for their tremendous efforts in pioneering novel technologies to effectively overcome Hong Kong's complex site constraints. I also extend my sincere appreciation for the exemplary spirit of collaboration among the project teams, the academia and industrial practitioners, which has been instrumental to the success of these innovative solutions. The adoption of these advancements has not only enhanced construction safety but also improved programme and cost efficiency, resulting in significant time and cost savings.

As always, CEDD is committed to fostering innovation and collaboration for driving the delivery of resilient, safe and sustainable infrastructure in Hong Kong. This CEDD Innovation Series documents these achievements, with a view to inspiring the local construction industry with proven practices and forward-looking solutions.



Mr. FONG Hok-shing, Michael, JP.
Director of the Civil Engineering and Development Department

Abstract

The objective of this publication is to provide an overview of the application of off-site prefabrication in the construction of buildings inside caverns.

This innovative method, designed to effectively overcome the constraints of building construction inside caverns, was first introduced in Hong Kong under the CEDD Contract No. GE/2022/14 (GE) – Joint Cavern Development at Anderson Road Quarry Site (JCD) for the reprovisioning of the Public Works Central Laboratory (PWCL) and building of Government Records Service's Archives Centre (AC).

This publication summarizes key considerations during the different stages in planning, design and construction issues for off-site prefabrication in caverns, aiming to:

i. provide a brief introduction on planning, design and execution of off-site prefabrication for building construction inside caverns.

ii. highlight the key challenges and benefits of using off-site prefabrication method for construction of buildings inside caverns in this project.

Contents

Title Page

Foreword

Abstract

List of Figures **5**

1 Project Background **6**

2 Off-site Prefabrication **7**

2.1 Overview 8

3 Project Challenge **9**

3.1 Tight Project Implementation Timeframe 9

3.2 Close Proximity to Residential Development 9

3.3 Restricted Site Conditions in Caverns 10

3.3.1 Height and Surrounding Restrictions 10

3.3.2 Access and Logistic 10

3.4 Limited On-Site Storage Area 11

4 Off-site Prefabrication – Problems and Solutions **12**

4.1 Introduction of Prefabricated Steel Module 12

4.2 Tight Construction Programme 14

4.3 Cavern Headroom Limitation 15

4.4 Cavern Access Limitation 16

4.5 Other Benefits 17

5 Resource Planning **18**

5.1 Delivery Route and Buffer Storage 18

5.2 Installation Schedule 18

5.3 Centralized Management Platform 19

6 Conclusion **20**

List of Figures

Figure 1.1 - Aerial Photo with Photomontage of the Completed Buildings 6
Figure 1.2 - Layout Plan of the Project 7
Figure 1.3 - Cross Sections of the Project 7
Figure 1.4 - Photomontage of the Completed Buildings 7
Figure 2.1 - Off-site Prefabricated Modules used for Building Construction 8
Figure 3.1 - Fast Tracked Project Timeline 9
Figure 3.2 - Layout Plan Showing Adjacent Development Sites 9
Figure 3.3 - Illustration of Lifting Operation inside Caverns 10
Figure 3.4 - Illustration of Low-rise Nature of Cavern Buildings 11
Figure 3.5 - Limited On-Site Storage Area 11
Figure 4.1 - Conceptual Scheme for On-site Fabrication 12
Figure 4.2 - Conceptual Scheme for Off-site Prefabrication (Cont.) 12
Figure 4.3 - Conceptual Scheme for Off-site Prefabrication (Cont.) 13
Figure 4.4 – Conceptual Scheme for Off-site Prefabrication (Cont.) 13
Figure 4.5 - Programme of Prefabricated Steel Module and In-situ Construction 14
Figure 4.6 - Programme of Prefabricated RC Module 15
Figure 4.7 - Use of AGV for Off-site Prefabricated Modules Delivery 16
Figure 4.8 - Use of BIM Simulation Technique for Installation Planning 16
Figure 4.9 - Environment of the Off-site Prefabrication Factory 17
Figure 5.1 - Delivery Route and Buffer Storage Site for Off-site Prefabricated Modules 18
Figure 5.2 - Installation Sequence and Schedule Planning 19
Figure 5.3 - Tracking of Off-site Prefabricated Module Progress in 4S CMP 19

1 Project Background

The Joint Cavern Development at Anderson Road Quarry Site (JCD) project – comprising the reprovisioning of Public Works Central Laboratory (PWCL) and building of Government Records Service's Archives Centre (AC) - is located at Tai Sheung Tok which was previously formed under the Anderson Road Quarry (ARQ) development site at Sau Mau Ping, Kowloon East. The site falls within the Strategic Cavern Areas (SCVA) no. 28 – Tai Sheung Tok and the ARQ, which ceased operation in July 2017 and is currently under development. The ARQ development site is planned for medium- to high-density housing with supporting commercial, government, institutional and community facilities, as well as open spaces and amenity areas.

Under this project, four caverns, each approximately 30m (H) x 30m (W) x 90m (L) together with associated adits are to be constructed. Drill and blast method was adopted for cavern excavation, starting with construction adits facing On Yu Road towards the back of the caverns and then gradually moving towards portal area. Once the cavern excavation work is completed, the future PWCL and AC buildings will be constructed inside the caverns and at the portal area. Aerial photos, layout plans, cross sections and photomontages of the completed view of the project are shown in Figures 1.1 to 1.4.

This project marks Hong Kong's first use of caverns for non-infrastructure facilities in combination with innovative construction methods. Off-site prefabrication has been adopted to shorten the construction period, thereby reducing impacts on the public during construction, particularly after the population intake of the ARQ development site.

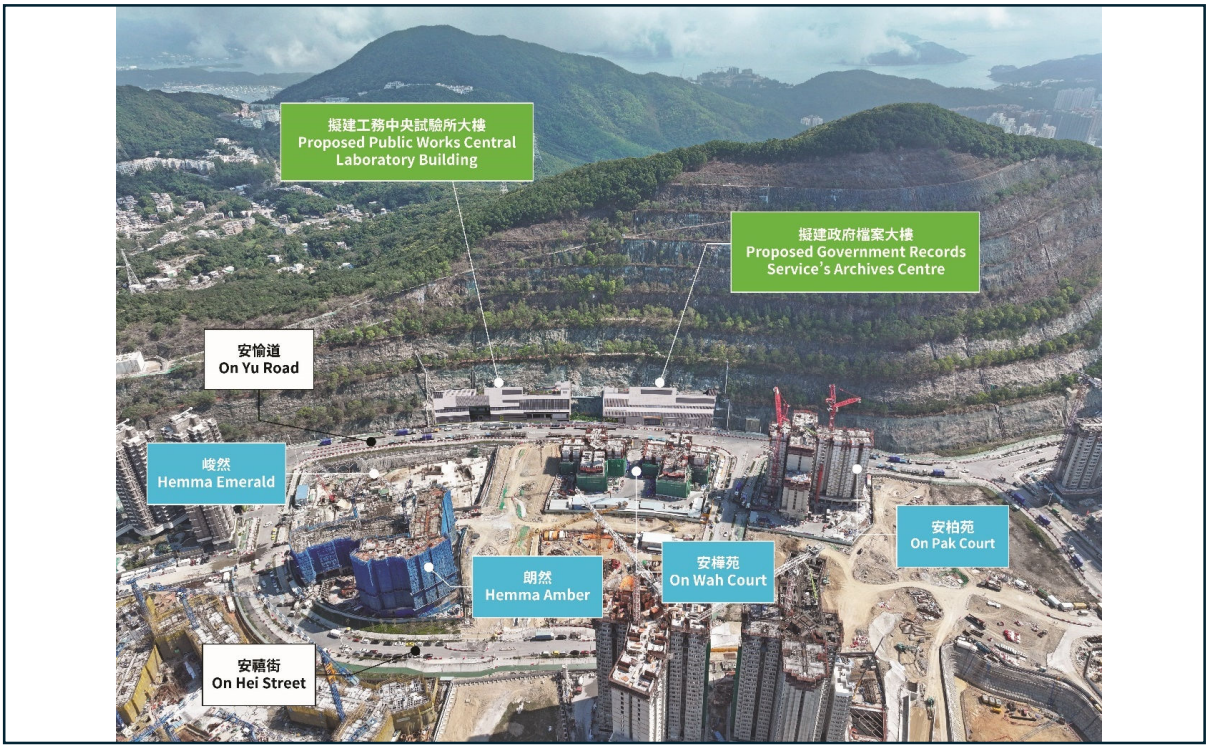


Figure 1.1 - Aerial Photo with Photomontage of the Completed Buildings

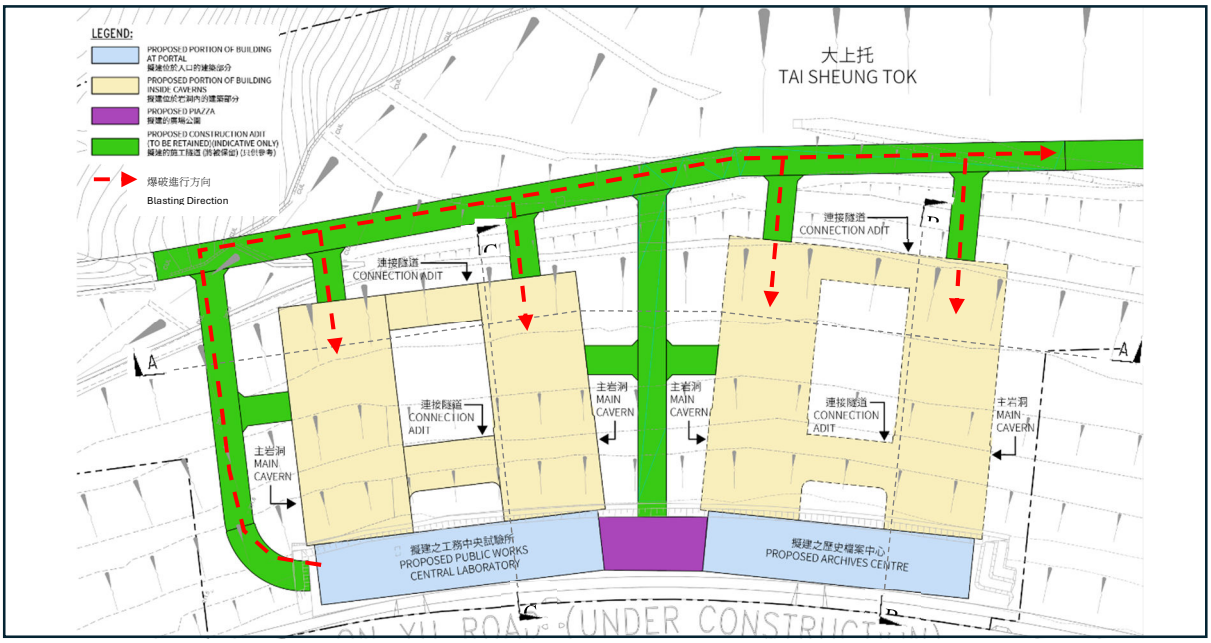


Figure 1.2 - Layout Plan of the Project

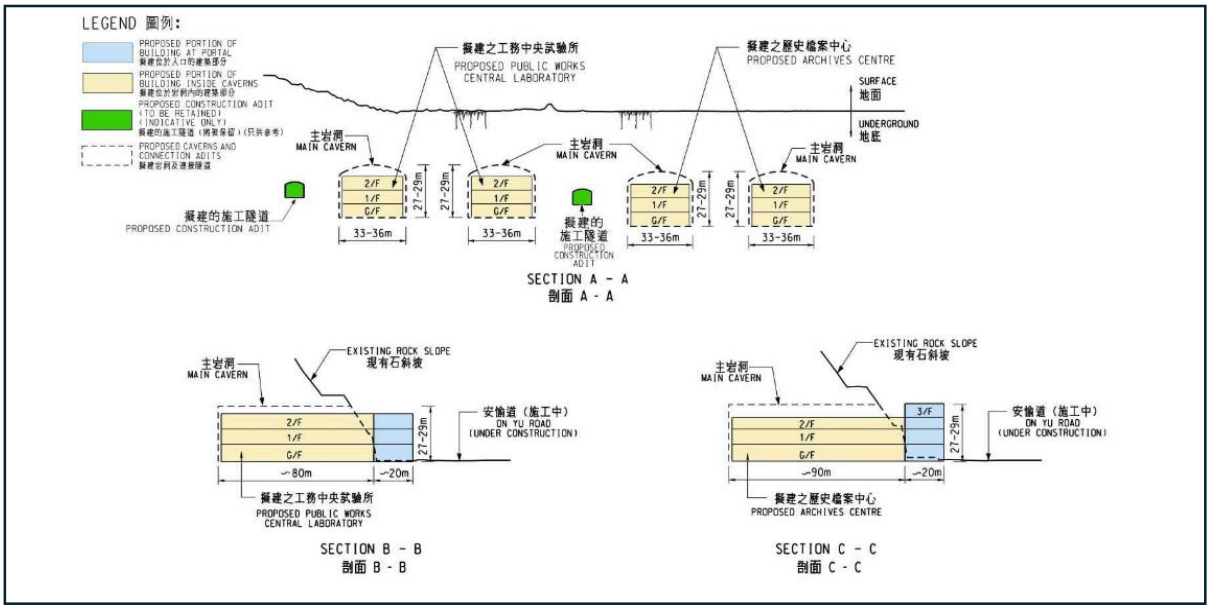


Figure 1.3 - Cross Sections of the Project



Figure 1.4 - Photomontage of the Completed Buildings

2. Off-site Prefabrication

2.1 Overview

Off-site Prefabrication is an innovative approach for building construction. Based on the principle of "factory fabrication followed by on-site assembly," off-site prefabrication helps address several current challenges facing by the local construction sector. In this method, free-standing integrated modules (complete with finishes, fixtures, and fittings)—are produced and put together in a factory. By shifting on-site construction activities to a regulated factory environment, most of the building work can be completed off-site. As a result, the impact of adverse weather, limited labour availability, and site restrictions can be greatly minimized. Moreover, off-site prefabrication enables better production quality control and enhances construction productivity, safety, and environmental sustainability.

Recently, an increasing number of projects across Hong Kong are demonstrating the immense potential of off-site prefabrication for building works. Despite the extensive use of off-site prefabrication for building construction in both public and private housing sectors, building construction using off-site prefabrication method inside cavern has not been demonstrated. Therefore, during the Early Contractor Involvement (ECI) stage for the JCD project, the project team discussed with the prequalified tenderers on the use of off-site prefabrication method for building construction inside the caverns. In spite of some physical limitations, such as limited height, restricted delivery access, limited storage areas, the Contractors had proposed various methods to demonstrates the feasibility for using off-site prefabrication method inside caverns.



Figure 2.1 - Off-site Prefabricated Modules used for Building Construction

3. Project Challenge

3.1 Tight Project Implementation Timeframe

The project is subject to an extremely tight implementation timeframe. The investigation stage began in December 2021. At that time, the land occupied by the existing PWCL had been earmarked for handing over for housing and other beneficial uses by FY2026/27.

To meet this extremely tight programme, fast-tracked construction approaches were adopted, including the adoption of Design-and-Build Works Contract with Early Contract Involvement (ECI) and off-site prefabrication were adopted. With these fast-tracking strategies in place, it only took approximately 20 months from the start of the investigation stage of the consultancy agreement to the commencement of the works contract (Figure 3.1).

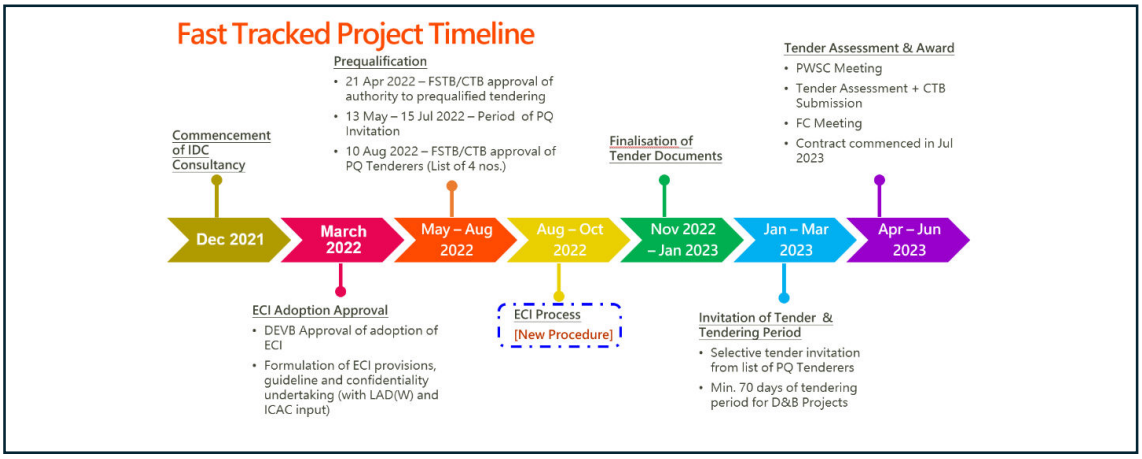


Figure 3.1 - Fast Tracked Project Timeline

3.2 Close Proximity to Residential Development

The project site is located less than 60 metres from residential development, i.e. on the opposite side of On Yu Road. It had been anticipated that residents of those developments would begin moving in during the construction period. Therefore, the project has planned stringent mitigation and monitoring measures to address potential impacts on nearby sensitive receivers and to minimise any nuisance that might be caused to the public arising from the construction works (Figure 3.2).



Figure 3.2 - Layout Plan Showing Adjacent Development Sites

3.3 Restricted Site Conditions in Caverns

3.3.1 Height and Surrounding Restrictions

The limited headroom and spatial constraints within the cavern would significantly affect the typical installation arrangements for off-site prefabricated modules that have been commonly adopted on a conventional high-rise building using tower cranes. Cavern headroom, with consideration of striking a balance on cost effectiveness, has restricted the feasibility of on-site lifting operations, especially for the uppermost storeys, due to the limited lifting angle (Figure 3.3).

To ensure buildability, construction methods and the availability of practical lifting machinery (e.g., cranes, lifting gantries) must be considered at the early design stage. For instance, if a mobile crane is to be set up within the cavern, the space it occupies would

substantially reduce the mobility and logistics for those construction activities inside the cavern, given that the cavern width is only approximately 30m wide.

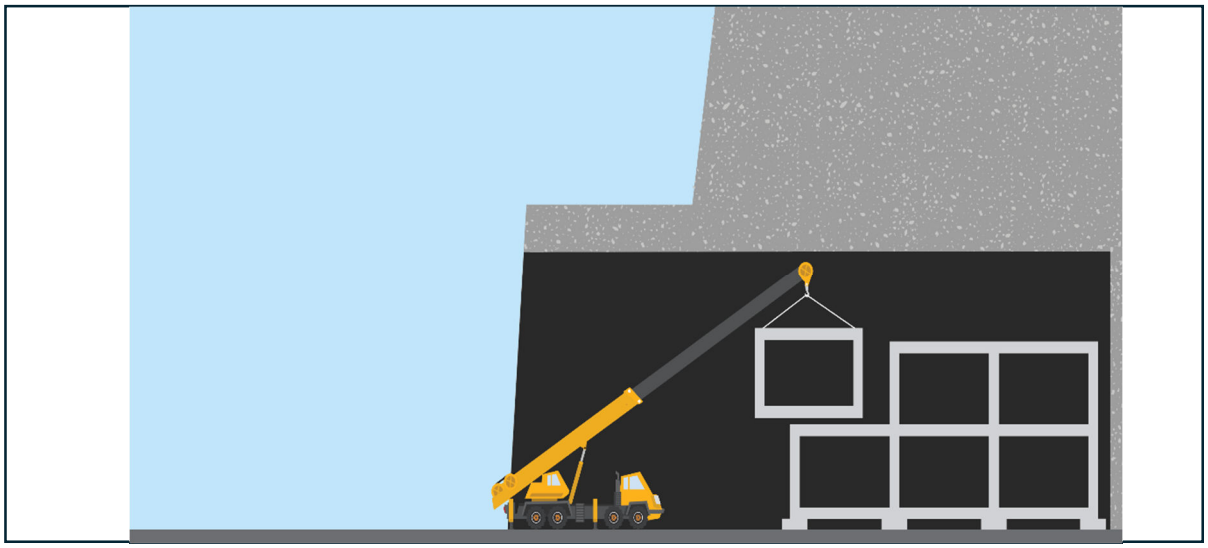


Figure 3.3 - Illustration of Lifting Operation inside Caverns

3.3.2 Access and Logistic

The confined nature of caverns inherently restricts delivery access and logistics for assembling the off-site prefabricated modules . The installation sequence is generally unidirectional, progressing from the farthest point of the cavern toward the portal area, which requires careful planning of the works (Figure 3.4).

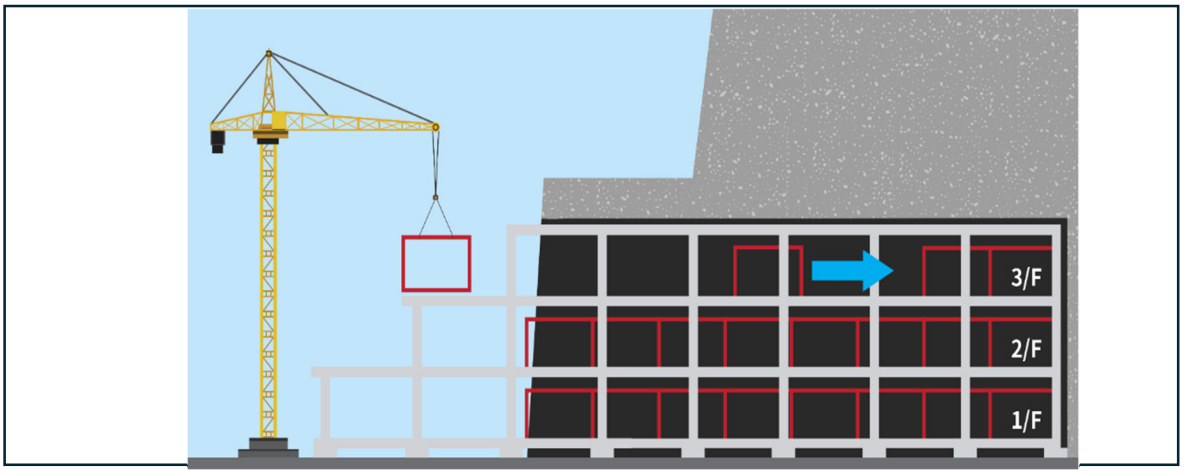


Figure 3.4 - Illustration of Low-rise Nature of Cavern Buildings

3.4 Limited On-Site Storage Area

A major constraint is the severely limited on-site storage area, which consists of only approximately 200m x 20m of surface land at the cavern portal, overlapping with the footprint of the portal building (Figure 3.5). Material stockpiling must be adjusted dynamically to accommodate the congested site layout. This introduces a significant challenge to the project, particularly in terms of storage and logistics for the off-site prefabricated modules.



Figure 3.5 - Limited On-Site Storage Area

4. Off-site Prefabrication – Problems and Solutions

4.1 Introduction of Prefabricated Steel Module

A non-typical prefabricated steel module approach is adopted for this project. In general, in-situ reinforced concrete (RC) structural elements are constructed first. Following the completion of the RC frame for each floor, non-structural prefabricated steel modules with partially completed Electrical and Mechanical (E&M) and Architectural Builder's Work and Finishes (ABWF) works are lifted into position and then delivered laterally using Automated Guided Vehicles (AGVs) or electric trolleys. After the prefabricated steel modules are positioned correctly, stitching and grouting works are carried out (Figures 4.1 to 4.4).

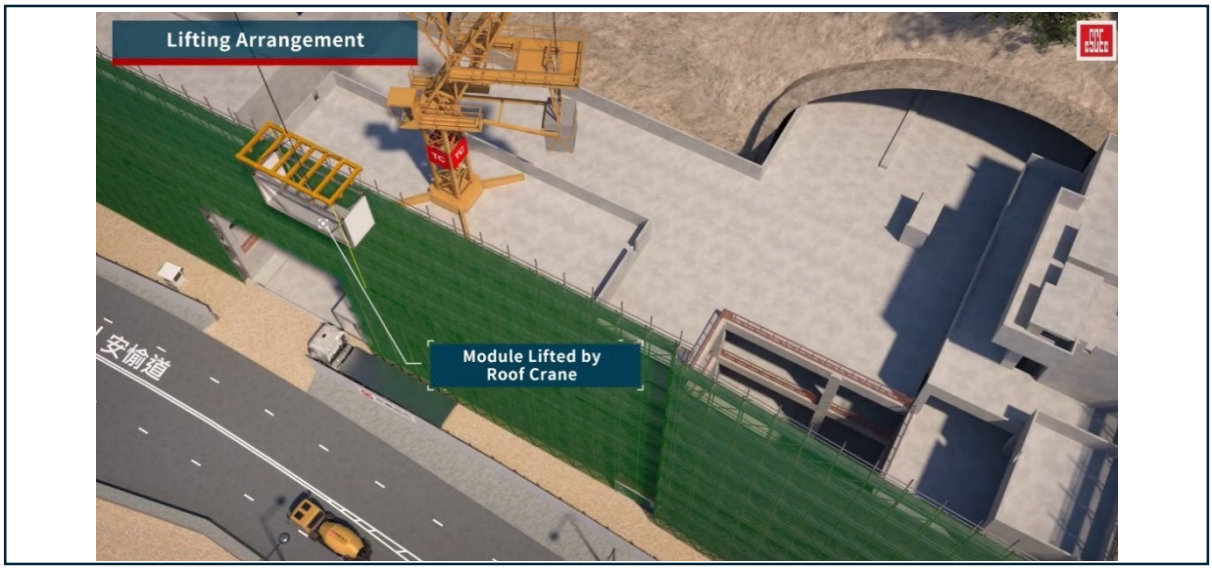


Figure 4.1 - Conceptual Scheme for On-site Fabrication



Figure 4.2 - Conceptual Scheme for Off-site Prefabrication (Cont.)

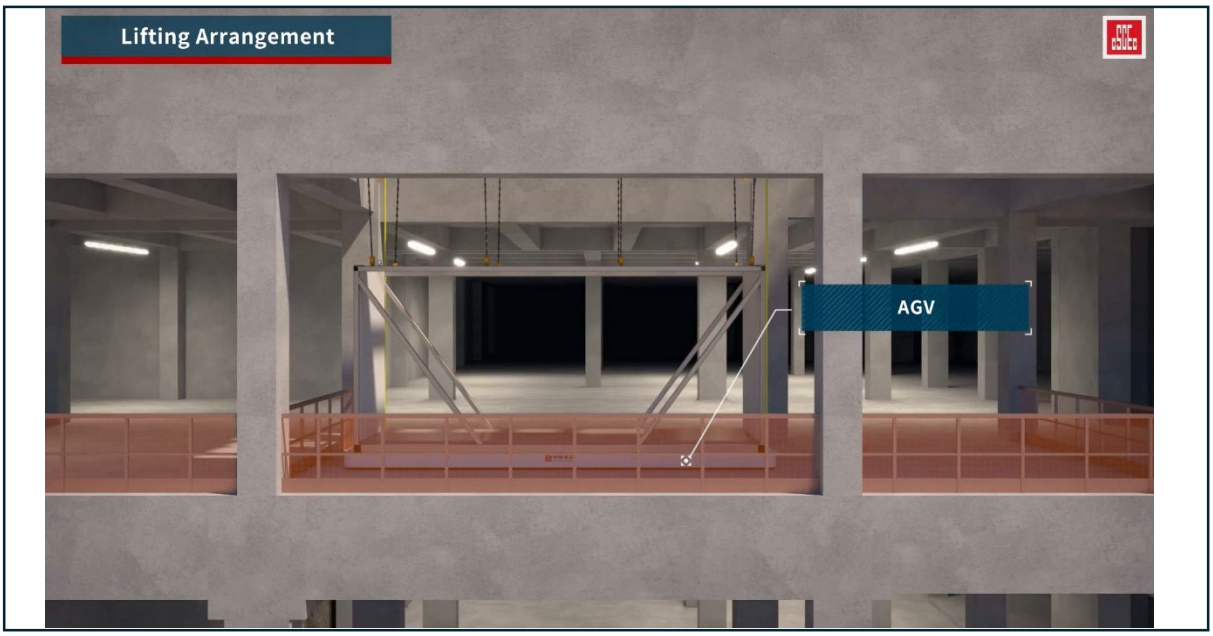


Figure 4.3 - Conceptual Scheme for Off-site Prefabrication (Cont.)

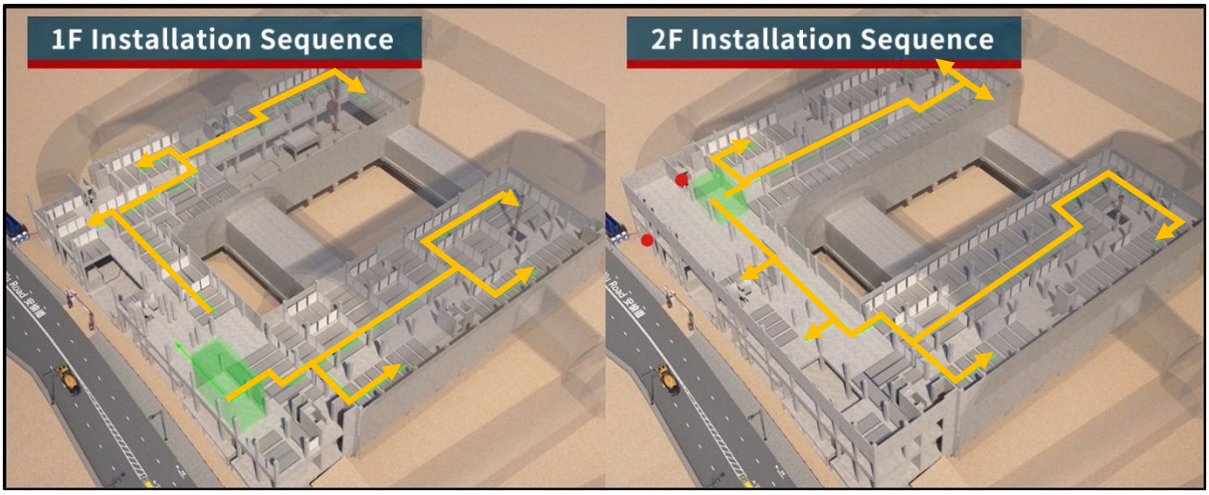


Figure 4.4 – Conceptual Scheme for Off-site Prefabrication (Cont.)

4.2 Tight Construction Programme

Unlike typical office-type buildings, the PWCL has unique operational requirements that demand extensive coordination with the end user.

The project allows only approximately four years to complete the construction of the entire new PWCL. This includes cavern excavation, building construction, architectural works, building services installation and fire service installation (FSI) works, as well as relocation of laboratory equipment and furniture, and the demolition of the existing PWCL building at Kowloon Bay.

The adoption of the prefabricated steel modules enables the parallel fabrication of steel modules that equipped with architectural and building services finishes alongside the RC structure. This results in a time saving of six to nine months when compared with conventional in-situ construction. (Figure 4.5).

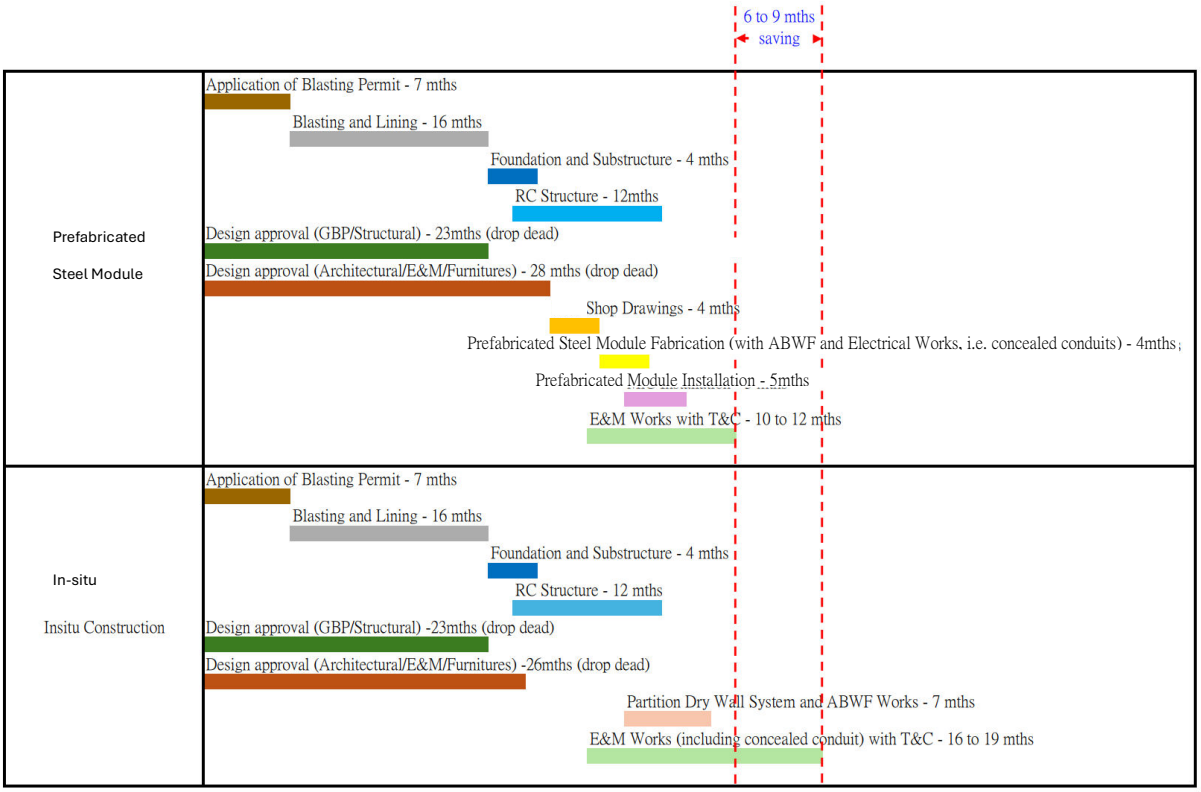


Figure 4.5 - Programme of Prefabricated Steel Module and In-situ Construction

A critical review was also carried out to decide on the adoption of different off-site prefabrication approaches. Before fabrication of the modules, acceptance of most designs is required (e.g. General Building Plans (GBP), structural, architectural, Electrical and Mechanical (E&M), and ABWF and furniture). Under the traditional prefabricated RC module approach, the design approval is required within 18 months from the start of the contract (Figure 4.6), due to the nature of the prefabricated RC modules forming part of the structural components. For the prefabricated steel module approach, construction of the RC structural frame can begin once the GBP and structural designs have been accepted. Detailed designs for architecture, E&M and furniture, which require significant end-user coordination, can be carried out in parallel with construction of the RC structural frame (Figure 4.5).

In view of the above, adoption of the traditional prefabrication of RC module may pose significant challenges for a design-and-build contract involving building with a non-typical layout, where time is required to tailor the design to suit the end user's operation needs. Therefore, the prefabrication of steel module scheme was finally adopted to provide additional time for design coordination (i.e. 23 months for GBP and Structural design, and 28 months for architectural, E&M, ABWF and furniture design).

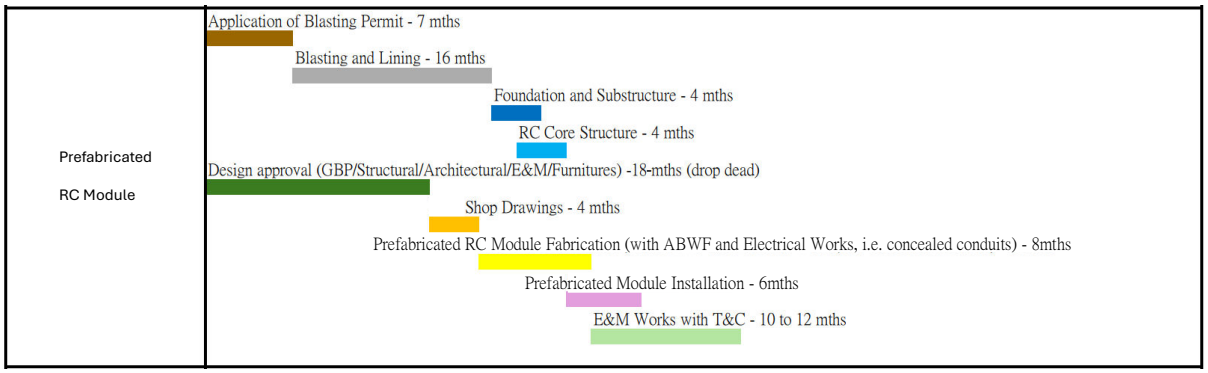


Figure 4.6 - Programme of Prefabricated RC Module

4.3 Cavern Headroom Limitation

One of the key challenges in constructing buildings within caverns is the headroom constraint, which significantly limits the lifting height for installation and the allowable weight of off-site prefabricated modules.

If the prefabricated RC module approach is adopted, the upper portion of the building cannot be constructed using the off-site prefabricated module if a mobile crane is used which would affect the adoption rate of the off-site prefabricated modules and consequently the construction time. Alternatively, a specially designed overhead gantry could be used to overcome the lifting height restriction, but this would incur additional costs for over-excavation of the caverns and gantry installation. Moreover, lifting heavy modules poses elevated safety risks, particularly in congested cavern areas.

With the prefabricated steel module approach, the RC structural frame serves as a delivery platform for module installation. Lateral delivery of modules at each floor level through portal openings eliminates reliance on vertical lifting and effectively avoids headroom limitations.

4.4 Cavern Access Limitation

Limited access from the cavern portal to the prefabricated module installation zone restricts sequencing flexibility and reduces the feasibility of multiple concurrent work fronts, thereby affecting installation rates and overall site progress. Under the traditional prefabricated RC module scheme, installation of the prefabricated modules must commence at the far end of the cavern and progress toward the portal, which greatly constrains the ability to deploy resources across multiple work fronts simultaneously.

With the prefabricated steel module approach, the completed RC structure serves as a delivery platform on each floor, allowing the prefabricated steel modules to be unloaded into designated areas on each floor and transported to their final position concurrently. To further enhance site operations, a tailor-made AGV system has been developed under this project to streamline module delivery, improve handling efficiency, and reduce manual handling requirements (Figure 4.7).

Additionally, to assess the difficulties in module maneuverability and optimize the installation sequence, a BIM simulation has been employed to model transportation and installation operations. (Figure 4.8).



Figure 4.7 - Use of AGV for Off-site Prefabricated Modules Delivery

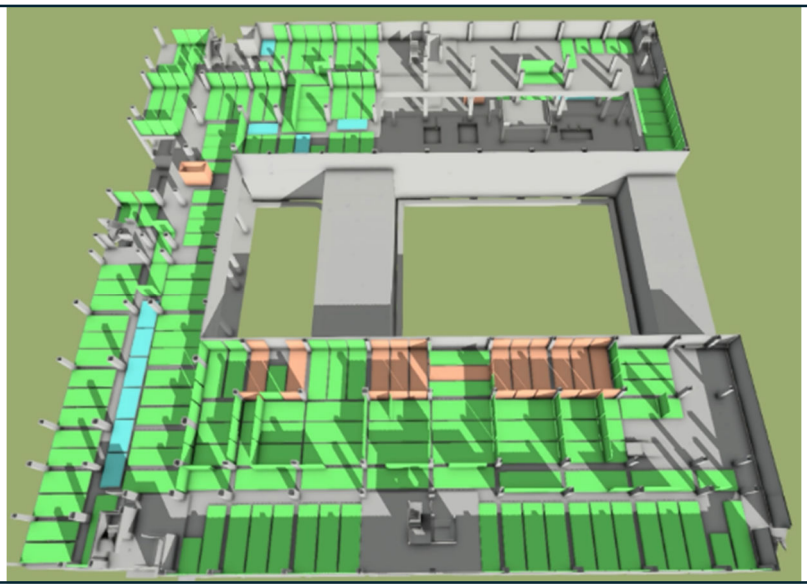


Figure 4.8 - Use of BIM Simulation Technique for Installation Planning

4.5 Other Benefits

The off-site prefabrication approach significantly reduces on-site construction activities, labour requirements, and associated nuisance to nearby residents. Factory-controlled fabrication improves quality consistency and enhances safety by minimizing work at height and work in confined spaces (Figure 4.9).

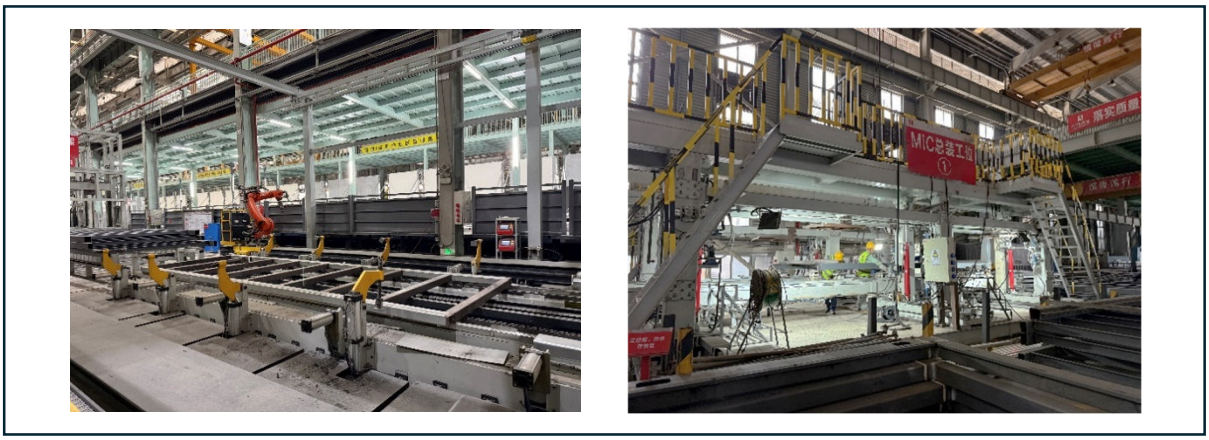


Figure 4.9 - Environment of the Off-site Prefabrication Factory

5 Resource Planning

5.1 Delivery Route and Buffer Storage

The delivery route for the off-site prefabricated modules has been thoroughly reviewed and planned in conjunction with a Traffic Impact Assessment, with the aim of mitigating potential impacts on the public.

Due to the extremely limited on-site space at this site, there is no capacity for temporary storage of the prefabricated modules. They must be transported directly to their installation locations upon arrival.

To support the high-volume installation process and alleviate congestion at site caused by frequent deliveries, an off-site buffer storage facility has been established (Figure 5.1).



Figure 5.1 - Delivery Route and Buffer Storage Site for Off-site Prefabricated Modules

5.2 Installation Schedule

In addition to BIM simulation for maneuverability and installation sequencing, a dedicated Construction Manager leads the overall installation planning. Three batches of off-site prefabricated modules (G/F, 1/F, and 2/F) are scheduled for delivery through temporary slab and wall openings on the north and south building structures, coordinated with the progress of RC frame construction (Figure 5.2).

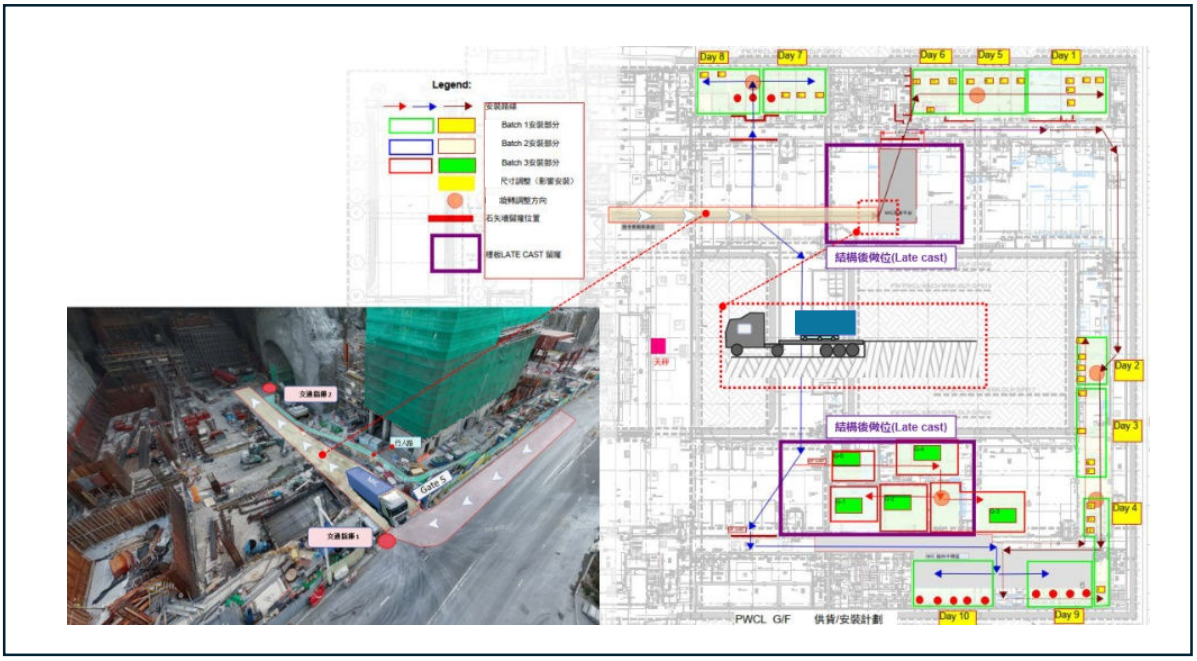


Figure 5.2 - Installation Sequence and Schedule Planning

5.3 Centralized Management Platform

In order to closely monitoring the fabrication and installation status of the off-site prefabricated modules, a unique QR code is installed on each module. Project team could track the status of different prefabricated modules instantly through an integrated Centralized Management Platform (CMP) within the 4S system (Figure 5.3).



Figure 5.3 - Tracking of Off-site Prefabricated Module Progress in 4S CMP

6 Conclusion

A non-typical off-site prefabricated steel modules are adopted in this project to tackle the project specific limitation namely, stringent design time for non-typical building under design and build contract, constraints of lifting height and horizontal logistic under cavern environment.

CEDD INNOVATION SERIES

