CEDD INNOVATION SERIES

U-Shaped Tunnel Boring Machine

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 liveable 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 Yuen Long South New Development Area First Phase Development pioneers world's first U-shaped Tunnel Boring Machine (UTBM) for unilateral excavation, named "Bauhinia". The machine successfully constructed a 900-meter-long precast drainage box culvert alongside the Yuen Long Nullah and Kung Um Road. Operating within a constrained corridor inside a live drainage channel under asymmetric lateral loading, the UTBM functioned as a self-contained mobile manufacturing unit. It featured a patented load-balancing system, an all-weather design enabling year-round construction, and a 6-degree-of-freedom launching girder for precise segment installation. The UTBM significantly reduced frontline labour, boosted productivity, and achieved a zero-incident safety record. Recognized by both local and international awards, this innovation provides a replicable model for underground infrastructure construction in dense urban environments worldwide.

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1. Introduction and Background

1.1. Overview and Objectives

The Yuen Long South New Development Area ("YLS NDA") covers a total development area of about 185 hectares ("ha"). Through comprehensive planning and improvement of infrastructure, YLS NDA will be developed into a liveable and green community within the Northern Metropolis primarily for housing development meeting the territory's medium to long-term housing needs.

To create more development opportunities for the area and enhance the efficiency of land use in its vicinity, we have adopted "infrastructure-led" and "capacity-creating" approaches to implement YLS NDA in phases. Among the infrastructure works under the First Phase Development ("FPD") which commenced in 2022, the construction of a new drainage box culvert along the western bank of the Yuen Long Nullah (Figure 1), and simultaneously widening and upgrading the adjacent Kung Um Road (hereinafter referred to as "the Works") is one of the most challenging tasks.

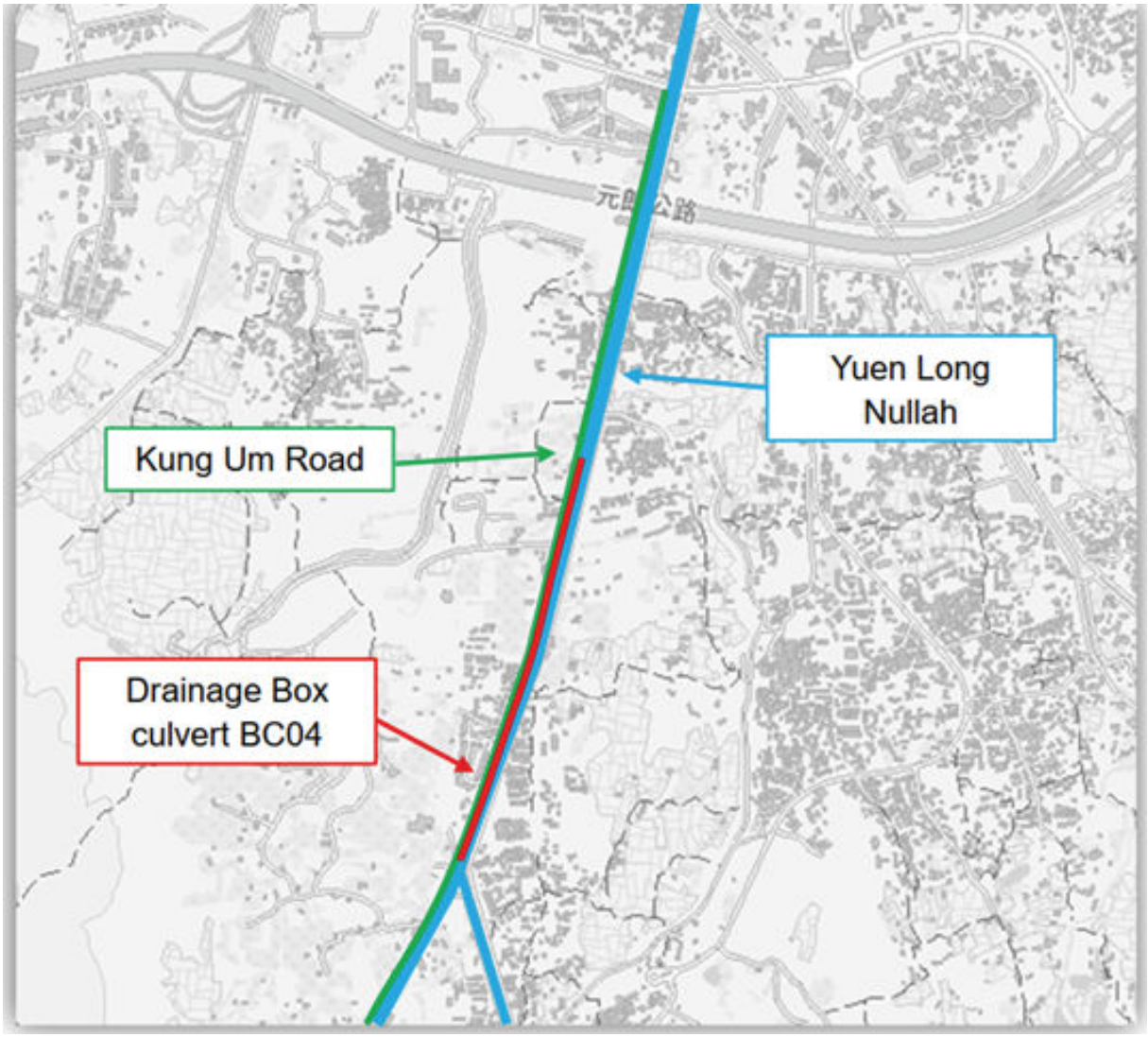

Figure 1: Location of Proposed Drainage Box Culvert at Yuen Long Nullah

The primary objective is to enhance the flood resilience of the Yuen Long District by improving the drainage capacity of Yuen Long Nullah. Concurrently, the Works will upgrade the existing substandard local road into a two-lane two-way carriageway with dedicated footpaths — significantly increasing traffic capacity and improving connectivity and safety for the new population intake and the existing nearby residents.

1.2. The Need for an Enhanced Methodology: Catalysts for Innovation

The conventional approach for constructing a large, reinforced concrete box culvert (Figure 2) adjacent to a live waterway and a busy road usually involves sequential sheet piling works as lateral support for excavation, in-situ casting, and backfilling. This traditional methodology is inherently protracted, involving repetitive cycles of installation and removal of temporary earth lateral support systems. It not only generates significant noise and vibration from sheet piling activities, but also necessitates prolonged partial or full road closures by stages of temporary traffic management for accommodation of necessary plant and materials, machinery movements and concreting works.

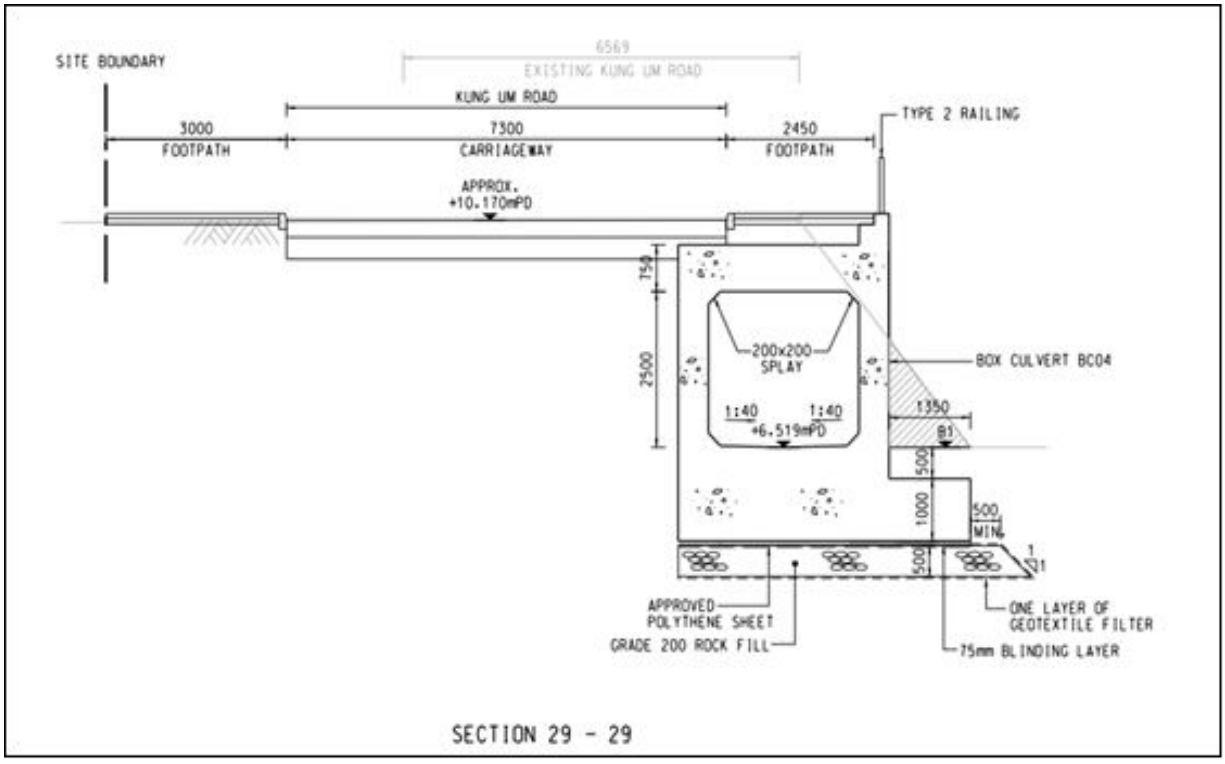

Figure 2: The proposed drainage box culvert

These difficulties presented major risks to both project delivery and local stakeholders. Traditional construction spanning several years would have caused prolonged disruption to road users, residents and businesses along Kung Um Road. Furthermore, the necessity of maintaining the Yuen Long Nullah's drainage capacity further imposes constraints on practical construction methods. Recognizing these limitations, the project team, comprising the Civil Engineering and Development Department ("CEDD"), AECOM and China Railway Engineering Corporation ("CREC") Joint Venture, collaborated to develop an innovative alternative to overcome these challenges.

2. Challenging Site Constraints and Limitations

2.1. Engineering Constraints

The location of the Works along western bank of the Yuen Long Nullah introduced severe physical and spatial constraints that dictated the engineering requirements:-

- Spatially, the available working corridor was narrow, confined to a 6.5 meters in width between the edge of the Yuen Long Nullah and the carriageway of Kung Um Road.

- Geotechnically, the subsurface predominantly consisted of medium-dense fill material and underlain by interbedded layers of firm to stiff alluvial silt/clay deposits and medium-dense alluvial sand deposits. However, soft, cohesive alluvial clay deposits with low bearing capacity were occasionally encountered, presenting a potential risk in open excavations. The groundwater table was perched at a shallow depth of only 0.7 metres to 2.3 metres below the road surface, necessitating rigorous and continuous dewatering measures for any open-cut method, associated with risks of settlement and environmental impact.

- Hydrologically, the Yuen Long Nullah was a live main drainage channel in Yuen Long District that could not be diverted or substantially obstructed. Any construction activity had to ensure its continuous flow, particularly during the wet season - from April to October each year, when higher risks of intense rainstorm and typhoon events require specific precautions.

- Structurally, the lateral loading profile was highly asymmetric. The excavation would be subject to heavy unilateral earth pressure from the retained riverbank, dynamic live surcharge from the road traffic, and hydrostatic pressure from the high groundwater on one side, while there were no counteracting forces on the opposite side. This severe eccentric loading scenario precluded the use of conventional symmetrical excavation and lateral support (ELS) system.

2.2. Stringent Regulatory Requirements

The Works was also governed by a comprehensive framework of regulatory and performance standards:

- **Drainage Capacity and Flood Prevention:** The new box culvert was designed to increase capacity to mitigate flood risk for the NDA and surrounding catchments with consideration of the climate change effects up to the end of the 21st century. Construction Drainage Impact Assessment for the Yuen Long Nullah during construction stage of the box culvert was required to be conducted in accordance with the Stormwater Drainage Manual.

- **Public Safety and Traffic Management:** Maintaining public safety was paramount. Based on the traffic impact assessment, maintenance of a substantial proportion of normal traffic flow on Kung Um Road was required. This objective clashed directly with traditional methods that require large work zones and lane closures for sheet piling and excavation.

- **Environmental Controls (Noise, Vibration, Dust):** Strict environmental requirements governed the construction activities. Noise mitigation was required for noisy operations such as sheet piling. Vibration limits were in place to protect nearby structures and utilities. Dust suppression measures were mandatory to maintain air quality for the surrounding community.

- **Resilience to Extreme Weather**: Hong Kong›s tropical climate, with its defined wet season and typhoon threats, inherently confines high-risk drainage works to a short dry-season window. A methodology that could extend safe working windows would offer significant programme benefits.

3. Exploration of Potential Innovation and Design Development

3.1. Assessment of Conventional Construction Methods

A thorough evaluation of conventional open-cut methods revealed major structural and operational limitations. To achieve stability in the soft alluvial ground, a cantilevered sheet pile wall would require an embedment depth exceeding 12 metres. This would generate high installation vibrations detrimental to adjacent utilities and cause severe ground disturbance during extraction. Alternatively, while ELS systems provide greater stability, the internal bracing would pose spatial constraints to construction operations. Most importantly, traditional approaches require a multi-year sequence of temporary traffic arrangements, causing prolonged community impact and elevating safety risks for road users.

3.2. Conceptualization of the U-Shaped Tunnel Boring Machine ("UTBM")

Driven by these limitations, the project team looked to adapt the mechanised tunnelling principles for a shallow, open-trench application. The conceptual basis was to integrate the earth-retaining capabilities of a typical shield tunnel boring machine into an open-top configuration capable of laying precast box culvert segments just below the surface. This resulted in the pioneering deployment of the U-shaped Tunnel Boring Machine ("UTBM") in Hong Kong (Figure 3). The vision of it is a self-contained mobile factory; its leading edge would provide immediate, continuous ground support as a "walking shield" behind which all subsequent processes — excavation, bedding preparation, segment installation, and backfilling — could occur in a safe, controlled, and streamlined sequence.

The UTBM technology was originally developed in 2017 for an application in Haikou, where it was configured for a two-cell box culvert structure. The concept was subsequently enhanced in 2023 for a project in Xiong'an, where the machine was re-engineered to accommodate a three-cell box configuration. However, for deployment in Hong Kong, the technical demands of the Works in YLS NDA demanded further site-specific transformation and adaptation. While the previous successful cases demonstrated the system's adaptability across different cross-sectional requirements, the unique environment and asymmetric loading profile of the Works required substantial customization beyond these precedents and engineering refinements to accommodate the peculiar site and weather condition as well as the traffic, environmental and safety standards of Hong Kong.

Figure 3: Overview of the UTBM

3.3. Key Enhancements to the Original UTBM Design

The UTBM concept has been custom-engineered to meet Hong Kong's unique demands:

- **Unilateral Loading:** This patented load-balancing system included an asymmetric shield configuration that matches the ground contours along the nullah bank, enabling effective management of uneven loading conditions. Active pressure redistribution mechanisms were employed to maintain equilibrium, while a friction-optimized shield skin design minimized resistance. Continuous load monitoring was allowing for real-time adjustments based on the prevailing conditions (**Figure 4**), maintaining equilibrium throughout advancement.

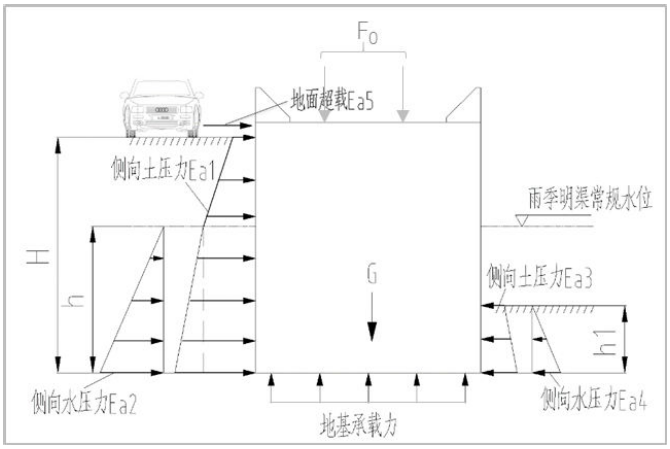

Figure 4: Uneven forces on UTBM from the road and nullah sides

- **Climate-Resilient and All-Weather Design:** To break free from the wet-season constraint, the UTBM's critical components — hydraulic power packs, control cabins, and generators — were mounted at levels above the predicted wet-season water level. The enclosed nature of the excavation within the shield allowed work to proceed during the wet season while the structural stability of the system was verified under the wet-season hydraulic and geotechnical loading conditions. Continuous monitoring of the adjacent water level in the Yuen Long Nullah was implemented throughout construction to provide early warning and validate design assumptions. This enabled a transformative shift from the traditional five-month working window during the dry season from November to March to a year-round construction period.
- **Multi-System Linkage Control System:** A computerized control system (**Figure 5**) was developed to integrate and synchronize the machine's discrete functions. This system linked the shield advancement, bedding layer machinery, and launching girder, ensuring safe coordination between the moving front shield and the delicate precision work happening behind it.

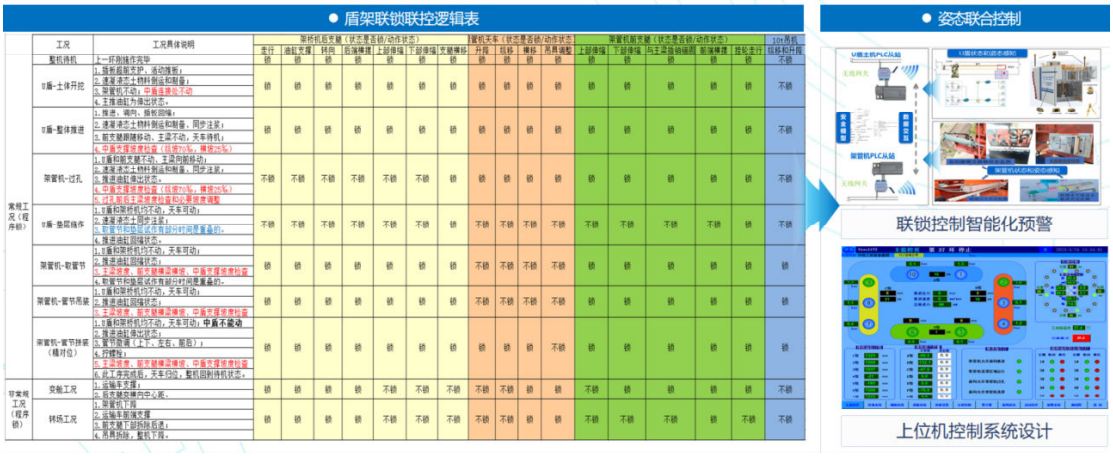

Figure 5: The UTBM linkage control system

- **Typhoon-Resistant Launching Girder:** For segment installation in the narrow corridor, a bespoke dual-main-beam launching girder was equipped. It featured a 6-degree-of-freedom ("6-DOF") hydraulic adjustment system (**Figure 6**) for micron-level precision placement of 75-tonne segments. To mitigate the risk posed by extreme wind conditions, a defined typhoon resilience protocol was integrated into the system design. As a safety measure, the girder was lowered to a storm-secure position in advance of the anticipated issuance of Typhoon Signal No. 8 or 10. This pre-planned operational protocol ensured the structural safety of the equipment and enabled the rapid resumption of erection works upon the signal downgrade, thereby safeguarding overall programme adherence.

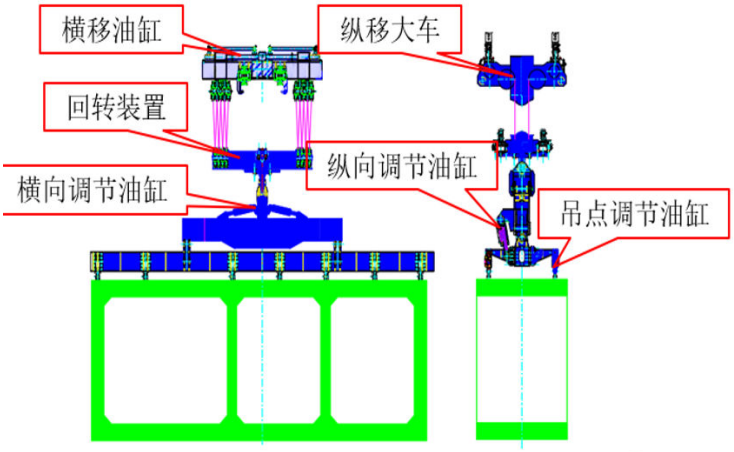

Figure 6: The six-degree-of-freedom hydraulic adjustment system

4. First Application: UTBM for Unilateral Excavation

4.1. Construction Process

The UTBM in YLS NDA, named “Bauhinia” – the floral emblem of Hong Kong, was assembled on site in modular units, thereby facilitating convenient mobilization. Its operation embodied a seamless, integrated cycle:

- **Shield Advancement:** The U-shaped front shield, employing the «support-before-excavation» principle (**Figure 7**), was incrementally jacked forward into the soil, instantly creating a stabilised working chamber behind.

Figure 7: The front and side views of the UTBM

- **Automated Bedding Preparation:** Immediately behind the excavation face, an automated system using laser-guided screeding arms laid a granular bedding layer to a tolerance of ±7mm, creating a level foundation for the culvert segments.
- **Precision Segment Installation:** Precast concrete box segments, manufactured off-site, were delivered to the machine›s rear. The overhead launching girder, using its 6-DOF adjustment system, lifted each segment and positioned it with millimetre accuracy (±5mm).

4.2. Adapting the UTBM to Site-Specific Demands

Similar to conventional tunnel boring machine, the machine’s operation was dynamic and responsive. The control system constantly monitored shield jack pressures and the positioning of the UTBM, allowing operators to make real-time adjustments to counteract variable soil conditions. The synchronization between the shield’s forward movement and the segment installation cycle was managed to optimise progress. Critically, this entire process occurred within the machine’s footprint, allowing minimum disturbance to the traffic on Kung Um Road.

5. Outcomes and Benefits

5.1. Labour, Time, and Cost Savings

The productivity gains were transformative. By integrating multiple processes, the UTBM method reduced overall labour requirements on the front line by approximately 30%. The mechanised, integrated operation enabled the installation of three 2-meter-long box culvert segments per day seamlessly, representing a 45% productivity increase over conventional sectional construction. The programme for constructing the approximately 900-meter long precast box culvert was condensed into just two dry seasons. This dramatic acceleration led to substantial overall cost savings, offsetting the initial capital investment in the innovative technology, and delivered the public benefit of advancing the new infrastructure years earlier.

5.2. Enhanced Safety and Minimal Community Disruption

Safety performance set a new benchmark. Unlike conventional trenching methods that rely on temporary earth-retaining structures such as long sheet piles which introduce significant safety risks during installation and removal, the UTBM's robust design eliminated the need for such supports by sustaining unilateral loading independently. This innovation not only enhanced structural safety but also removed hazards associated with handling and transporting bulky sheet piles, reducing risks for both workers and the public. All high-risk activities were either automated or performed within the protected environment of the shield. This resulted in an exemplary safety record with zero incidents related to the box culvert construction.

Community disruption was minimised to an unprecedented degree. Noise impacts were drastically reduced; the acoustic barriers lowered noise levels compared to those of a traditional work site. Vibration and dust emissions were negligible due to the absence of percussive piling. The visual impact was also contained, with the site appearing as an enclosed factory rather than open excavations.

6. Recognition

6.1. Local and International Awards

The successful deployment of the UTBM in the FPD of YLS NDA has attracted significant local and international recognition. At the New Civil Engineer Tunnelling Awards 2025, the project was shortlisted as a finalist in four award categories: Project Legacy & Social Value, Carbon & Sustainability Initiative of the Year, Technical Innovation of the Year, and Tunnelling Project Team of the Year. Ultimately, it won the Award of Innovation in Tunnel Design & Construction. The judges highlighted the system's originality, smart engineering, and measurable impact—faster delivery, safer working conditions, and a significant reduction in carbon emissions.

Within Hong Kong, the UTBM has been widely praised as a landmark achievement in smart construction. The Hong Kong Institution of Engineers ("HKIE") organised dedicated site visits, showcasing the UTBM as a pioneering model for the local industry, while Construction Industry Council (CIC) honoured the project with a Merit Award for Productivity at the Construction Innovation Award 2025.

The industry has extensively acknowledged the UTBM's achievements in advancing construction safety. During the Construction Safety Week 2025, the UTBM project received the Excellence Award in the CIC's "Construction Safety - Innovative Technologies" Competition. This was followed by the winning of the prestigious Gold Prize in Category 2 (Major Project below HKD 3 billion) of the HKIE's Design for Safety Excellence Award 2026, where the UTBM was cited as a key innovation. UTBM also received an Honourable Mention at the Lighthouse Club's 7th International Design for Safety Award. These consecutive accolades highlighted its transformative contribution to construction safety management.

6.2. Recommendations for Future Applications

The deployment of UTBM in YLS NDA has successfully established a proven, replicable delivery model for linear underground infrastructure in congested urban environments. The methodology is recommended for future drainage, river revitalisation, underpass, and utility tunnel projects in Hong Kong, particularly where the following site characteristics are present:

- Tight spatial constraints adjacent to nullahs, river corridors, roads and railway.
- Challenging soft ground conditions with high groundwater.
- A paramount requirement to maintain existing traffic flow and minimise public disruption.
- Sensitive environmental or community settings with low tolerance for noise, vibration, and dust.

Furthermore, this project exemplifies Hong Kong's distinctive role as a "super-connector" and "super value-adder." It involved adapting a technology concept sprouted in Chinese Mainland, fostering it through world-class local engineering and project management expertise, and blossoming a successful template suited for exporting to other high-density coastal cities globally that struggle with analogous geotechnical and environmental challenges. The UTBM at YLS NDA extends beyond the introduction of a new construction machine; it serves as a testament to how innovation, collaboration, and a commitment to the community can redefine the boundaries of modern civil engineering.


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