CEDD INNOVATION SERIES

Low-density Engineered Cementitious Composites

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.

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Abstract

Low-density engineered cementitious composites (LD-ECC) is an innovative structural material developed through an industry-academia collaboration in Hong Kong. Its primary advantage lies in its customizable density to meet specific project requirements, while maintaining stable and robust mechanical properties even at significantly reduced densities. In a world-first application, the Yuen Long South New Development Area First Phase Development has deployed LD-ECC at the Shap Pat Heung Interchange, replacing a conventional reinforced concrete box structure to form a 110-metre slope embankment for a new slip road. Applied in 400mm layers, LD-ECC was poured directly against precast concrete facing panels, eliminating the need for temporary support during placement. Furthermore, the lightweight panels permitted manual positioning, significantly reducing reliance on heavy-lift equipment. Leveraging the rapid placement, superior tensile ductility and crack-control properties of LD-ECC, the LD-ECC system accelerated construction sequencing, shortening the project timeline by five months and generating estimated cost savings of $5 million through reduced labour, minimized equipment rentals, and diminished site disruption. Recognized for its innovation in sustainable infrastructure, this breakthrough establishes a replicable template for lightweight, high-performance embankment solutions, not only in the Great Bay Area, but also for future One-Belt-One-Road initiatives worldwide.

Contents

1. Introduction to New Slip Road Construction at Shap Pat Heung Interchange

The Shap Pat Heung Interchange (SPHI) is the main access for traffic to the southern part of Yuen Long Town from Yuen Long Highway (YLH) before completion of the proposed improvement works to the Tong Yan San Tsuen Interchange. Apart from serving southern part of Yuen Long Town, traffic from YLH eastbound to Pok Oi Interchange and traffic from Pok Oi Interchange to YLH westbound have to travel through SPHI.

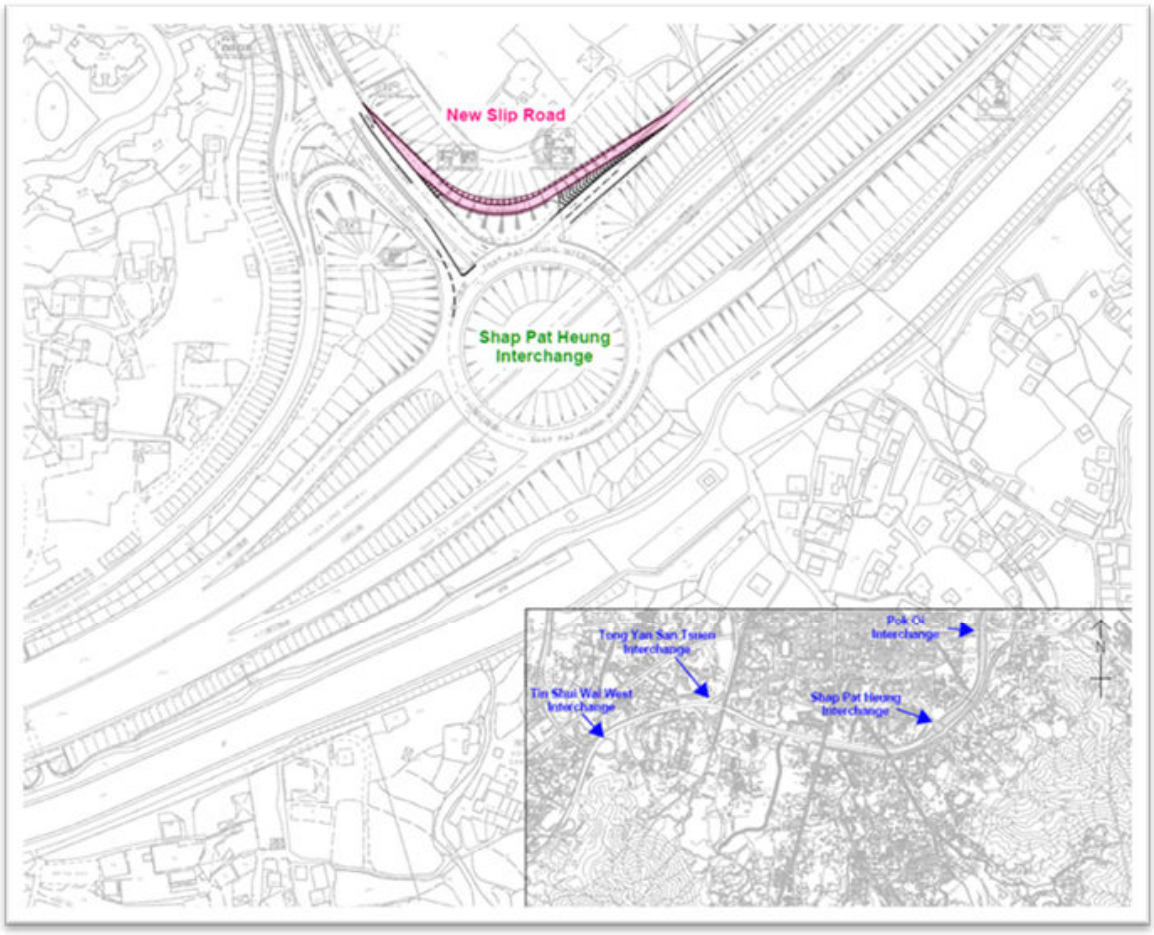

Figure 1 – General Layout Plan

During peak hours, traffic queues frequently form along Shap Pat Heung Road due to bottlenecks at SPHI. To address this issue, the construction of a new slip road, designated as S2, is proposed under the Yuen Long South (YLS) First Phase Development. The slip road will provide an exclusive left turn lane from Shap Pat Heung Road southbound to YLH eastbound slip road. Traffic on this proposed left turn lane would become free flow and bypass the interchange, thereby significantly relieve traffic pressure on Shap Pat Heung Road, and improve overall mobility of vehicles in this area.

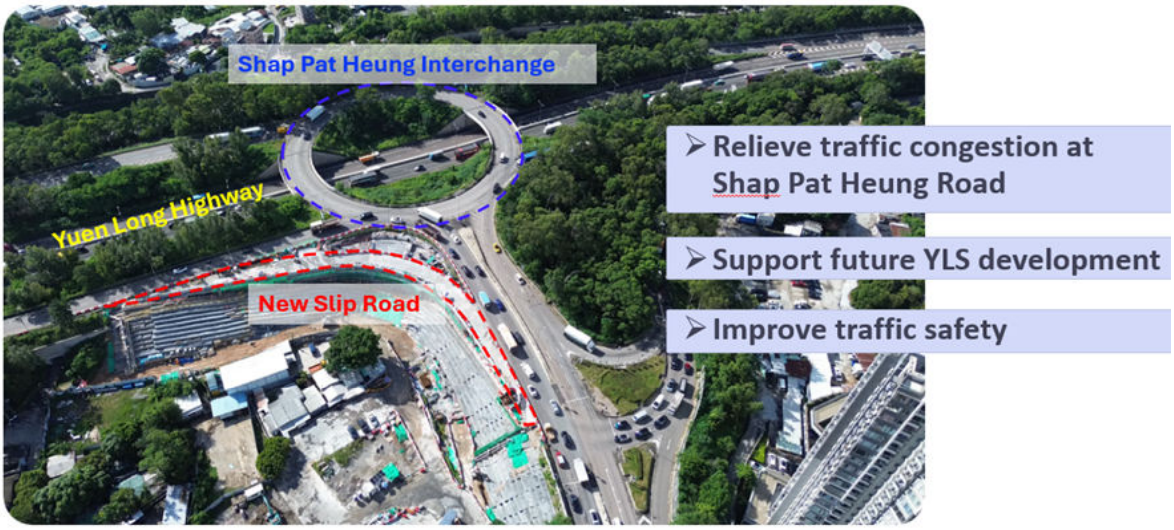

Figure 2 – Benefits of New Slip Road S2

Site Constraints and Limitations in Construction of RC Box Structures on Slopes

During the design stage of this new slip road, different schemes were considered, including a flyover, a retaining wall, and a reinforced concrete (RC) hollow box structure. The RC hollow box structure was ultimately adopted as the most suitable scheme. However, many site constraints as illustrated in the figure below would still lead to difficulties and risks in the construction of the box structure on the slope: -

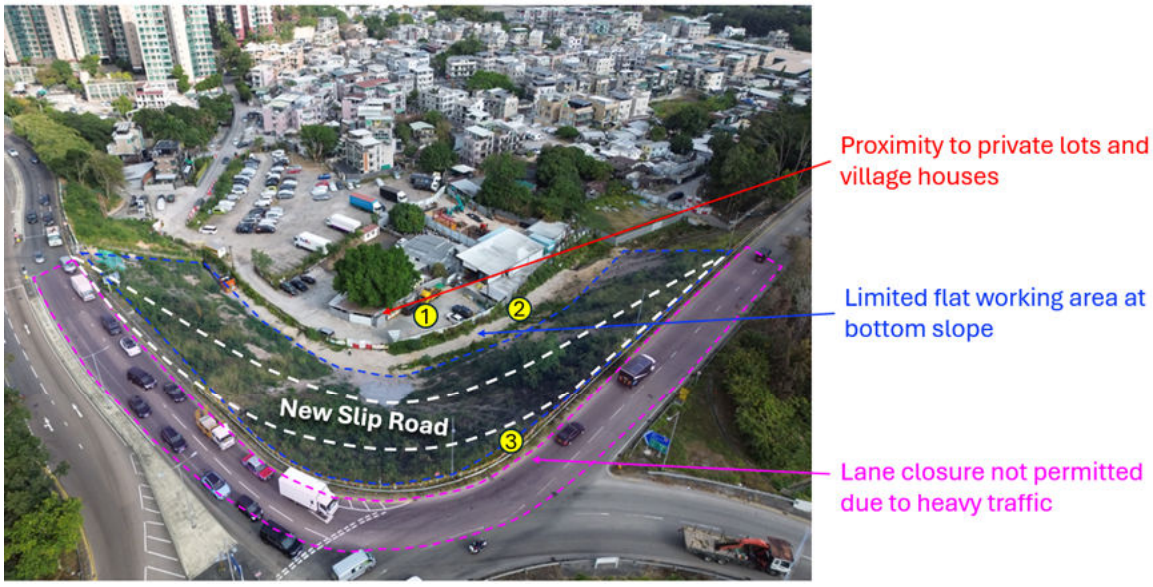

Figure 3 – Site Constraints in New Slip Road Construction

The construction of the RC hollow box structure on the steep slope faces significant challenges, including:

- Installation of extensive falsework;
- Labour-intensive on-site activities—formwork erection, rebar placement, and concrete pouring/vibration —on slopes and with limited access;
- Frequent use of heavy-lifting equipment for material transportation on congested site;
- Working at height, posing extra safety risk.

As a result, the construction process would be slow due to low productivity. The estimated construction time is 10 months.

2. Inspiration to Develop an Innovative Cementitious Material

In view of the significant safety and programme concerns due to the severe site constraints outlined above, an alternative scheme of forming a road embankment was considered based on " 气泡混合轻质土填筑工程技术规程 "(CJJ/T177-2012)" in the Chinese Mainland to replace the original RC box structure design.

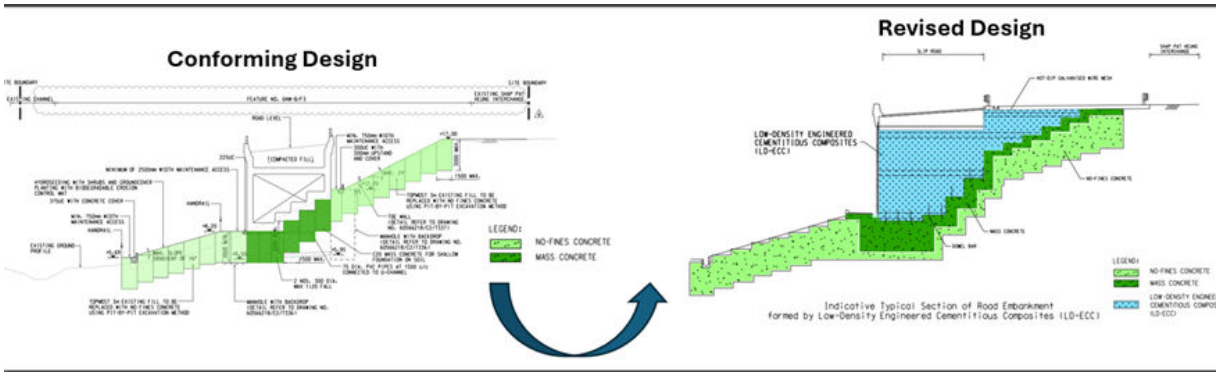

Figure 4 – Comparative Illustration of Conforming Design and Revised Design

Following site visits and examination of the lightweight soil material, it was observed that the material requires further improvement to ensure the formation of a durable road embankment under the site conditions at the S2 slip road. The key areas requiring enhancement are summarized below:

1. **Compressive Strength**

   The current compressive strength, ranging from approximately 0.3 to 1.0 MPa, is considered inadequate and should be increased to meet performance requirements.

2. **Ductility**

   Improved ductility is required to enhance the material's ability to accommodate deformation without cracking or failure.

3. **Water Resistance**

   The resistance to water absorption and softening character should be enhanced to ensure long-term durability, particularly under wet site conditions.

4. **Resistance to Vibration and Settlement**

   The material should exhibit higher resistance to traffic induced vibration and long-term ground settlement.

5. **Quality Control**

   More simple and straightforward quality control measures are necessary to minimize variability in foam characteristics during production.

In contrast, Engineered Cementitious Composite (ECC) materials have been widely applied worldwide due to their superior mechanical performance. ECC typically achieves compressive strengths of approximately 40 MPa or higher, with densities generally ranging from 2100 to 2400 kg/m³.

However, in applications where ultra-low-density fill materials (around 700 kg/m³) are required, conventional ECC becomes unsuitable due to its relatively high density. In such cases, alternative materials such as foamed concrete, which typically exhibits compressive strengths of 0.8 to 2.5 MPa, or lightweight soil materials, with compressive strengths ranging from 0.3 to 1.0 MPa, are commonly employed, but both materials are relatively brittle due to their low ductility.

To bridge this critical gap between low density and high performance, an innovative Low-density Engineered Cementitious Composite (LD-ECC) was adopted for the construction of the road embankment. This "World-First" material was wholly developed and produced through the joint efforts of local professionals, academicians, and a concrete supplier in Hong Kong. The key properties of this new LD-ECC material are summarised below.

Table 1 – LD-ECC Prosperities

No.	Testing item	Testing method	Testing results (Controlled & Patent Pending)
1	Workability	In-house test method	Slump flow spread ≥140 mm
2	Wet density	CSI:2010 Section 5	650 kg/m^3
3	Compressive strength	CSI:2010 Section 12	3.0 MPa
4	Elastic Modulus	CSI:2010 Section 17	3.0 GPa
5	Poisson's Ratio	ASTM C469	0.23
6	Ductility	Interim Guidelines on Testing of Unconfined Compressive Strength of Cement Stabilized Soil Cores in Hong Kong (October 2017)	8.8% (post-peak strain)
7	Flexural Strength	ASTM C1609	1.36 MPa
8	Toughness index	ASTM C1609	14.5 Joule
9	Shear	GEOSPEC 3, 2001 Clause 15.3	Sample do not have any signs of shear when reach the capacity force (2.0kN) of the test machine
10	Splitting Tensile Strength	CSI:2010 Section 13	0.43
11	Adiabatic Temperature Rise	In-house test method	60.0 °C
12	Water Absorption	In-house test method	≤10%
13	Max Water Penetration Depth	CSI:2010 Section 18	47 mm (Range: Moderate Impermeability)
14	Chloride Ion Penetrability	CSI:2010 Section 19	Class: Very low
15	Chemical Analysis of Harden Concrete	CSI:2010 Section 21	Chloride ions <0.01% (m/m) Sulphate: 2.21% (m/m)

Its lightweight feature (650 kg/m3) significantly reduces bearing pressure (by approximately 50%) on slope, while its superior properties such as high ductility, high fatigue resistance, crack self-healing, etc., assure long-term durability and operation reliability under varying weather conditions and severe external loading.

After several full-scale trials of LD-ECC pouring for road embankment construction, it was concluded that a pouring layer thickness of 400 mm was determined to be optimal for both quality control and on-site construction efficiency. When the pouring thickness does not exceed 400 mm, no additional temporary support is required for the precast concrete panels. Furthermore, the weight of each 400-mm-high precast concrete panel allows for manual handing and installation, thereby significantly reducing the number of lifting operations required on the slope.

Thus, the LD-ECC was placed in successive 400-mm layers in slip road S2, using precast concrete panels that possess an aesthetically pleasing appearance and serve as permanent formwork. This approach eliminates the need for conventional temporary formwork, thereby saving construction time, enhancing overall construction efficiency, and significantly improving site safety.

In terms of occupational health, the self-compacting nature of LD-ECC eliminates the need for mechanical vibration during placement, thereby reducing noise exposure for workers and contributing to hearing protection. Consequently, LD-ECC can be classified as low-noise concrete, minimizing impact on the environmental and surrounding community.

3. First Application of LD-ECC for Road Embankment Construction

The availability of this advanced material represents a game-changer in the construction of road embankments, as well as in land formation on sloping ground. The stability and structural integrity of the road embankment formed by the LD-ECC are in full compliance with all relevant design standards and guidelines promulgated by the Highways Department and the Geotechnical Engineering Office of the HKSAR. The good quality and performance of the LD-ECC achieved in this pilot project have received wide recognition in Hong Kong construction industry.

This innovative LD-ECC is the world-first material offering the following outstanding physical characteristics:

- Very low weight but attaining high compressive strength (650 kg/m³ attaining ≥3 MPa; 950 kg/m³ attaining ≥7 MPa);
- High ductility to accommodate deformation and settlement;
- Very high fatigue resistance to cope with traffic-induced vibration;
- Self-healing of cracks.

Compared with conventional reinforced concrete box culvert or retaining wall systems, the implementation of the LD-ECC road embankment methodology achieves comparable overall construction costs while delivering significant efficiency gains. By leveraging this advanced material's superior tensile ductility, crack-control properties, and rapid placement characteristics, the project achieved a dramatic acceleration in construction sequencing, reducing the overall programme duration by approximately five months. Preliminary cost analyses indicate an estimated project saving of approximately $5 million, driven by reduced labour requirements, shortened equipment rental periods, minimized site disruption, and accelerated project handover. The LD-ECC solution is not merely a material replacement, but a strategic innovation that enhances both schedule reliability and long-term economic value in infrastructure projects.

4. Recommendations for Future Applications

The successful construction of the Slip Road on the steep slope at SPHI demonstrates the advantages of LD-ECC as a robust material for land formation conveniently even in constrained environment such as limited access and restricted working space.

With the completion of the new road embankment at SPHI using LD-ECC under the First Phase Development of the Yuen Long South New Development Area, Building Technology Research Institute is engaged to leverage the experience gained in this project to develop standards and specifications for wider application of LD-ECC.

Due to its simplified construction methodology and shorter construction duration, LD-ECC road embankment technology demonstrates strong potential for wider implementation in the Great Bay Area and future One-Belt-One-Road projects.

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