SS 674 — Providing concrete evidence of better design and better solutions

When construction began on the Mandai Rock Cavern in 1999, the use of steel fibre reinforced concrete (SFRC) was still new to Singapore. Norwegian experts called in to consult on this first-of-its-kind project recommended that steel fibres be used to reinforce the lining of the cavern. Back then, the local representative of Bekaert—a Belgian technology leader in steel wire transformation and solutions provider for sustainable construction—supplied the steel fibres used.

This project provided a good opportunity for the local project teams—which included staff from Defence Science and Technology Agency (DSTA) and JTC Corporation—to witness, first-hand, how steel fibres could be used to distribute stresses and provide more even reinforcement, while demonstrating that the use of SFRC in shotcrete lining required less time and labour when compared to weldmesh lining. JTC then took the learnings from the Mandai Rock Cavern and applied them to the Jurong Rock Caverns and beyond. In industrial developments where SFRC slabs were deployed on ground surfaces, JTC noticed that SFRC slabs were more durable than traditional steel-meshed reinforced slabs, and also required less maintenance.

Above: *FRC precast segmental lining for tunnel in the Thomson East Coast Line.*

In 2008, Land Transport Authority (LTA) used SFRC in temporary tunnels deployed to support the construction of the MRT network, and observed that these tunnels had noticeably fewer cracks. LTA then leveraged the research capabilities of the National University of Singapore (NUS) and Nanyang Technological University (NTU) to improve SFRC formulations for subsequent tunnel projects. Papers documenting their experiences were also published and presented at conferences.

However, without published standards, local design consultants and end-users were still unconvinced, and unfamiliar with the benefits of SFRC. Contracts often specified the amount of steel per cubic metre of concrete , as a way of upholding safety standards. Mr Gan Cheng Chian, the Technical Manager for Bekaert who supplied steel fibres for the Mandai Rock Caverns, recalls a project that called for 180 kg of steel reinforcement bars per cubic metre. He shares that an SFRC solution needed only 35 kg of steel to deliver the same performance required. In order to convince stakeholders to move away from contract specifications that preclude the use of newer, more efficient materials, methods validated by standards bodies were needed.

An industry working group was formed in 2019 under the purview of The Institution of Engineers Singapore's (IES) - Standards Development Organisation (SDO) to look into the use and design of the fibre reinforced concrete structures—since fibres can be made of glass and organic polymers, not just steel. At that point, Sweden was the only country that had published a standard on the design of FRC, even though the European Harmonized Standard for Steel Fibre Reinforced Concrete had been in the works as early as 2012. Despite little variation between methods proposed by

Above: *Construction of hydraulic tunnel linking Tuas Water Reclamation Plant and Jurong Island. Using OPC and steel reinforcement bars would have generated 736 kg of CO_2 per m^3 of concrete. The adopted solution using fly ash cement, OPC, silica fume and steel fibres generated only 328 kg of CO_2 per m^3 of concrete, more than halving the carbon emissions.*

British, German and other European standards development organisations, European Union members were still not ready to agree on a single normative reference.

The working group sought to adopt the Swedish standard as the basis for a local Singapore Standard with a slight deviation. The working group concluded, upon assessing local industry conditions, that doubling the sampling requirements for QA/QC process was necessary to give the local industry the confidence to use these new materials, and that the additional cost incurred due to increased sampling was not significant. Meanwhile, cost-savings derived from the more efficient use of raw materials would far outweigh the costs of testing the additional samples.

Recognising the opportunities that this standard would create, the working group pushed through to get SS 674, the Singapore Standard for ***Fibre concrete—Design of fibre concrete structures*** published within two years. The methods for calculating and deriving design values provided in SS 674 help consultants come up with new compositions of fibre types, customisable to stringent performance requirements. It also gives them more freedom to customise precast concrete elements and manufacture unusual or complex shapes without compromising tensile strength. Engineers can refer to SS 674 to specify the right amount of reinforcement for contract requirements, or to assess the suitability of a proposed solution.

In today's competitive market, where many customers actively seek to lower their carbon footprint, using SFRC enables reductions in steel required for reinforcement. This translates to material cost savings as well as reduced carbon emissions. Some tender documents now stipulate the use of supplementary cementitious materials (SCM) in the concrete mixture, or require the inclusion of post-industrial materials such as fly ash and ground granulated blast furnace slag (GGBFS), since these industrial by-products are considered carbon neutral. However, this type of concrete has lower tensile strength and ductility, thus the need for resource-efficient reinforcement once again comes to the forefront.

When faced with such requirements, design consultants can use SS 674 to determine the exact mix of materials required to meet the customer and building control requirements. "With SS 674 as one of the Building and Construction Authority's (BCA) Approved Documents, consulting engineers now have a much wider range of solutions available to them," shares Mr Gan, who was part of the working group that developed SS 674. "Even if a project has strict requirements for carbon emissions and price, there are so many precision-engineered fibre types optimised for different design requirements to choose from. And products that come with Environmental Protection Declaration (EPD) certificates make calculations for CO_2 emissions levels easy."

Since the publication of SS 674, the Thailand Concrete Association and Hong Kong Institution of Engineers are planning their own journeys towards localised versions of the standard. Mr Gan continues, "Our friends in the region are watching this space with keen interest. They know that a Singapore Standard lends credibility to a product or solution type, and they are using it to convince their local building authorities to adopt these new ideas." The journey towards mainstream adoption for FRC has been a long one. But with the availability of SS 674, the light at the end of the tunnel is now well within sight, and as bright as its future.