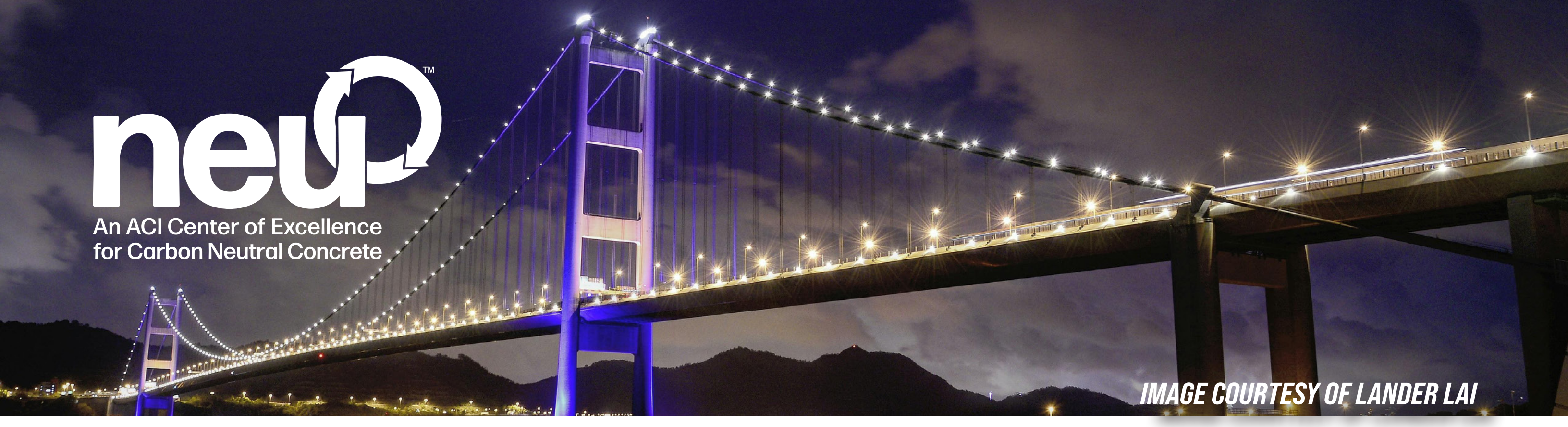

IMAGE COURTESY OF LANDER LAI

CASE STUDY: THE TSING MA BRIDGE

HONG KONG, CHINA

Spanning a distance of 2,167 m (1.35 miles), the Tsing Ma Bridge connects Tsing Yi and Ma Wan islands in Hong Kong. This impressive feat of engineering holds the distinction of being the world's 16th-longest suspension bridge and, at the time of its completion, the second-longest. It also boasts the title of the world's largest suspension bridge designed to carry both cars and trains.

The bridge is a crucial part of the Lantau Fixed Crossing, a vital transportation link between Hong Kong's mainland and the Chek Lap Kok airport. Its construction, costing US $1 billion, marked the government's largest single contract for its ambitious ports and development project.

BUILDING A BRIDGE FOR THE AGES

Completed in 1997, the expected lifetime for the Tsing Ma Bridge is 120 years. The secret behind this bridge's strength and longevity lies in its concrete. Approximately 400,000 m^3 (523,180 yd^3) of high-quality concrete was used, meticulously designed to meet a demanding set of criteria. Not only did the concrete need to achieve a high final hardened strength and resist exposure to harsh chemicals, but its plastic properties during construction were equally important due to the sheer size and unique construction methods employed for some bridge components.

THE NEED FOR PEAK PERFORMANCE

The concrete mix had to meet stringent requirements, including specific minimum and maximum cement content, limitations on placing temperature, and restrictions on heat evolution. Additionally, the concrete needed to be extremely low permeable and resistant to chloride penetration, exceeding typical standards for such large projects. To achieve this exceptional performance, numerous concrete mix designs were evaluated in the lab. The winning formula? A ternary blend cement mixes incorporating fly ash or ground-granulated blast-furnace slag alongside silica fume. The actual design for the tower concrete used 30% ordinary portland cement, 65% ground-granulated blast-furnace slag, and 5% silica fume. This combination delivered the best results in terms of durability and minimized chloride penetration with a lower carbon footprint. While it was not normally a requirement in 1997 to address carbon emissions, the use of this type of formula was innovative and a forerunner to concrete mixes required today.

Over 4,000 tonnes (4,410 tons) of silica fume (Elkem Microsilica), supplied as a densified powder premixed with water before batching, were used in the Tsing Ma Bridge project. The bridge's demanding specifications for both plastic and hardened concrete properties, coupled with a projected lifespan of 120 years, made Elkem Microsilica the perfect choice. It ensured consistent material quality, reliable performance, a secure supply chain, and invaluable technical support throughout the project.

Similar triple-blend cement mixes were also used to produce 1 million m^3 (1.31 million yd^3) of concrete in another renowned project, the Great Belt Link in Denmark, showcasing the effectiveness of this innovative approach.

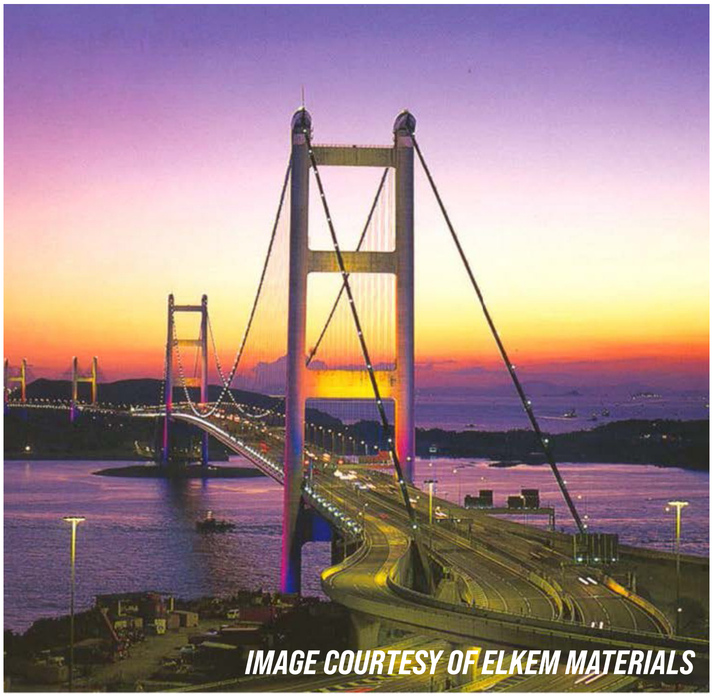
IMAGE COURTESY OF ELKEM MATERIALS

CONSTRUCTION

For the Tsing Ma Bridge, prefabricated composite bridge deck units were constructed off-site, while all other concrete elements were produced at two dedicated batching plants located on Tsing Yi and Ma Wan islands. Each plant boasted a powerful production capacity, capable of churning out 120 m^3 (157 yd^3) of concrete per hour.

The bridge's iconic twin towers were constructed using a continuous slipform technique. This method demanded a unique concrete mix that flowed smoothly yet remained cohesive and prevented segregation. Additionally, the mix needed a long working life to maintain a good surface finish during the continuous pouring process. Adding silica fume to the mix played a crucial role in achieving these properties and contributing to the exceptional strength and longevity of the towers.

The roadway supports were constructed using a standard "cast and climb" method, employing a concrete blend containing 25% fly ash and 5% silica fume. This combination effectively addressed the potential drawbacks of using high percentages of fly ash or ground-granulated blast-furnace slag, such as a slower initial strength gain. Silica fume’s high reactivity counteracted this issue, while also minimizing segregation and bleeding that can occur with highly cementitious mixes.

LASTING STRENGTH AND DURABILITY

The use of silica fume in the ternary blend cement offered a multitude of benefits for the Tsing Ma Bridge's concrete. It enhanced the mix's stability, reduced pumping pressure, accelerated strength gain, and bolstered both early and long-term resistance to chloride ingress. The impressive results speak for themselves: the concrete boasts a compressive strength exceeding 80 MPa (7,250 psi) and remarkably low chloride permeability.

CONCRETE MIX DESIGN FOR THE TOWER

Mix Constituent	Proportions, kg/m^3 (lb/yd^3)
Ordinary Portland Cement (OPC)	135 (230)
Ground-Granulated Blast-furnace Slag (GGBS)	290 (490)
Silica Fume (SF)	25 (40)
20 mm (0.787 in.) Single Sized Aggregate	670 (1,130)
10 mm (0.394 in.) Single Sized Aggregate	310 (520)
Special Crushed Rock Fine Aggregate	710 (1,200)
Free Water Content	175 (290)
Superplasticiser	5.8 (10)
Retarder	0.3-0.6%

TOWER CONCRETE – CEMENTITIOUS CARBON FOOTPRINT

Reference: Elkem Datasheet C4-14.

Specified Strength: 65 MPa (9,430 psi) at 28 days (achieved 80+ MPa (11,600 + psi) at 90 days).

Rapid Chloride Permeability Test (RCPT) equivalent < 100 cmb at 28 days.

OPC	135 x 0.950	= 128.25 **kg/m^3**
GGBS	290 x 0.150	= 43.5 **kg/m^3**
SF	25 x 0.30	= 0.75 **kg/m^3**

Cementitious Carbon Footprint **= 172.50 kg/m^3 (290.8lb/yd^3)***

* *This value is between 'Low Carbon Plus and 'Low Carbon Extreme' on the Norwegian Concrete Association Table 1, from NCA publication number 37, for carbon footprint values.*

If the mix was 100% OPC, cementitious carbon footprint: 450 kg x 0.950 = 427.5 kg/m^3 (720.6 lb/yd^3)

Reduction of carbon using the ternary blend = 255 kg/m^3 (429.9 lb/yd^3)

FACTS

Bridge type: Suspension bridge

Construction started: May 1992

Opened: May 1997

Total length: 2,167 m (7,087 ft)

Clearance below: 53 meters (174 ft) (official shipping height restriction)

Carries: Trains, motor vehicles

Crosses: Ma Wan Channel

Constructed by: Anglo Japanese Construction Joint Venture (comprised of Trafalgar House Construction, Costain Civil Engineering, and Mitsui and Company)

ENVIRONMENTAL IMPACTS

This project replaced a large amount of cement with supplementary cement materials (SCMs), thereby significantly reducing the carbon footprint. Total carbon emissions were reduced by choosing a ternary blend that included Ordinary Portland Cement, ground-granulated blast-furnace slag, and silica fume, resulting in an increased early age and long-term chloride resistance.

PRODUCTS USED

A ternary blend including Ordinary Portland Cement, ground-granulated blast-furnace slag, and silica fume (Elkem Microsilica)

PROJECT TEAM

Constructed by: Anglo Japanese Construction Joint Venture (comprised of Trafalgar House Construction, Costain Civil Engineering, and Mitsui and Company)

Designed by: Mott MacDonald Group

Owner: Hong Kong Government

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Information in this case study was provided by Ferroglobe (originally from Elkem Materials).