Sustainable Marine Infrastructure Enabled by the Innovative Use of Seawater Sea-Sand Concrete and Fibre-Reinforced Polymer Composites

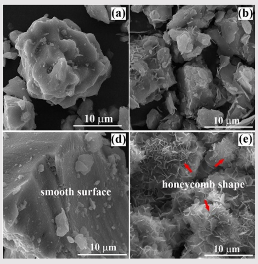
Introduction

Coastal cities like Hong Kong rely heavily on their coastal and marine infrastructure for social-economic development. This project aims to develop a new type of economical and sustainable concrete structures by using durable fibre-reinforced polymer (FRP) composites as replacement of steel and locally available seawater and sea-sand for producing concrete (i.e., seawater sea-sand concrete or SSC). The research programme was implemented as five interconnected tasks.

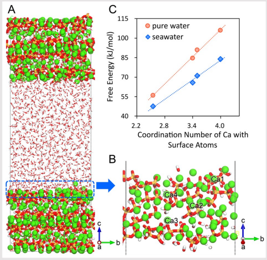
Task 1. Fundamental mechanisms of SSC

For SSC to be widely used in marine infrastructure, its short- and long-term behaviour should be well understood. Furthermore, the properties of SSC may be optimised to suit different needs. Task 1 team has achieved the following objectives: 1) developed the material structure models of SSC at nanometre and micrometre scales; 2) enhanced the properties of SSC through microstructure modification; and 3) related the microstructure to the mechanical and durability properties of SSC.

Mix design and properties of seawater sea-sand concrete



Hydration mechanism and microstructure of SSC

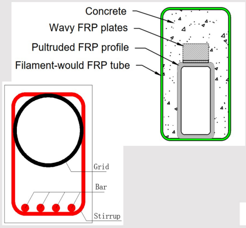


Material structure models at nano- and micrometre scales

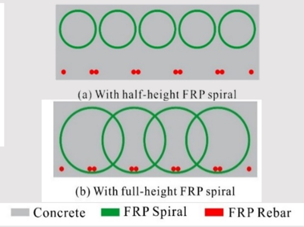
Proportion optimization and plant trial

Task 2. Innovative Forms of FRP-SSC Structures

Task 2 team has developed various novel forms of structural members, bar connectors, and beam-column connections incorporating FRP and SSC. These novel structural elements have been successfully fabricated, and their behaviour and design methods have been investigated through a large number of laboratory tests as well as numerical simulations.

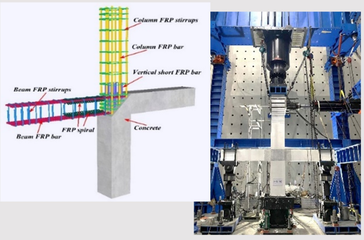


Novel FRP-SSC beams



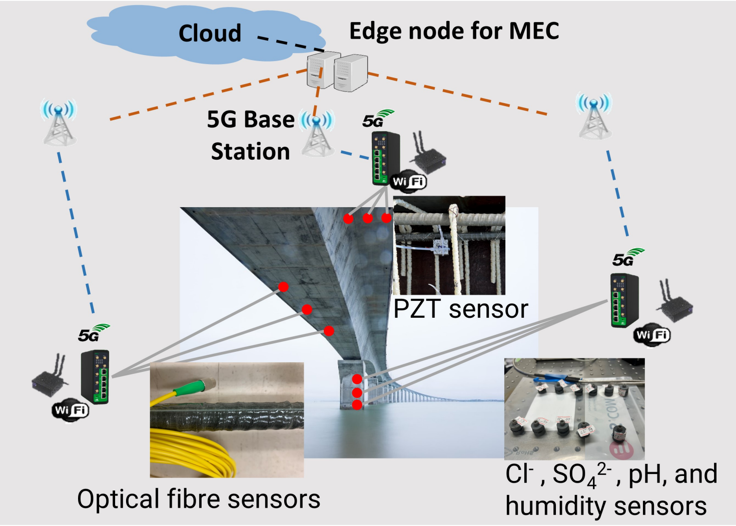
Novel FRP-SSC slabs

Novel bar connector



Novel beam-column connection

Task 3. Performance Evolution Monitoring Technology



Task 3 team has developed an optical fibre-based embeddable sensing system composed of optical fibre-based pH sensors, chloride sensors, sulfate sensors and humidity sensors. The project team has also developed PZT-based smart aggregates, a hybrid FBG and BOTDA sensing system and a wireless data acquisition system for the long-term monitoring of FRP-SSC structures.

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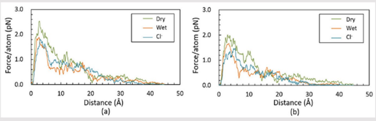
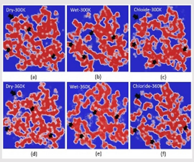
Task 4. Material Deterioration and Constitutive Modelling

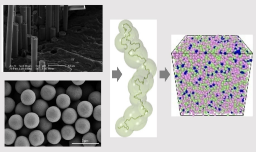
Task 4 focuses on deterioration at the material level. Saline corrosion tests, carbonation tests and associated mechanical tests have been conducted for seawater sea-sand concrete, while the deterioration of FRP in an alkaline environment has been examined using lab exposure tests, diffusion tests as well as molecular dynamics simulations. The project team has also developed constitutive models for the long-term deterioration of FRP, SSC and their interfaces.



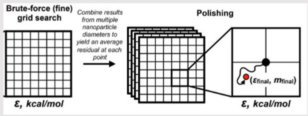
Stress curves from normal separation simulations of the interfaces under dry and wet environment.



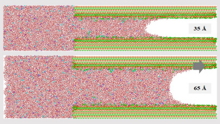
Free volume analysis of the vinylester matrix at interface



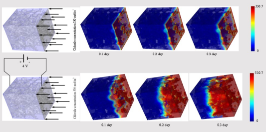
Construction of coarse-grained model of GFRP



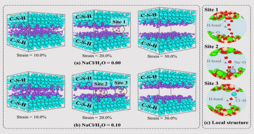
Optimization process of forcefield of coarse-grained models including two brute-force optimization steps and one polishing stage for CG beads sizes



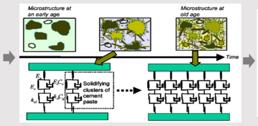
Seawater transport in C-S-H gel at nanoscale



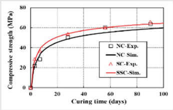
Chloride penetration in concrete at mesoscale



Mechanical characteristic of C-S-H at nanoscale



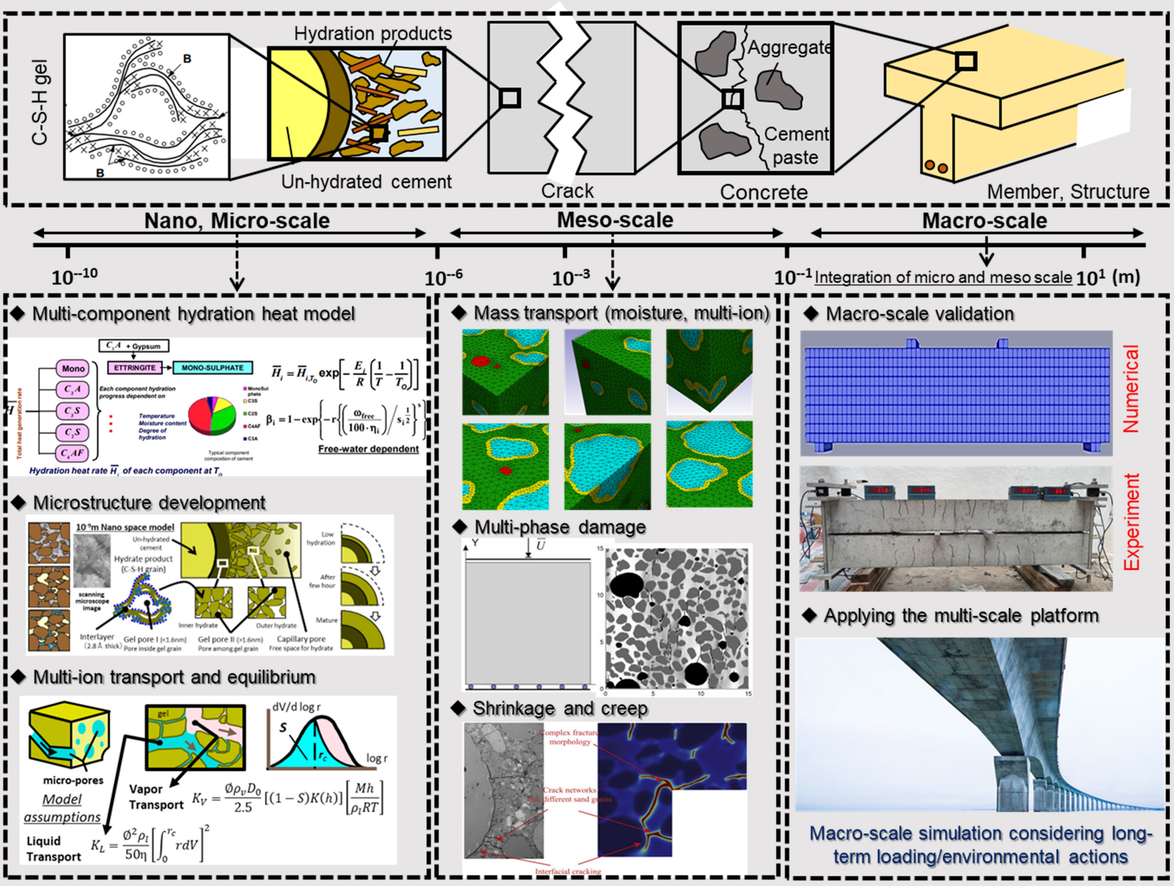
Mechanical characteristic of cement paste at microscale



Mechanical characteristic of SSC at macroscale

Task 5. Deterioration and Modelling of FRP-SSC Structures

In Task 5, both accelerated laboratory and field exposure tests have been conducted to investigate the deterioration of FRP-SSC structures. The project team has also developed a predictive method based on a multiscale multi-physics approach for the long-term performance of FRP-SSC structures, and have verified the method using test results.



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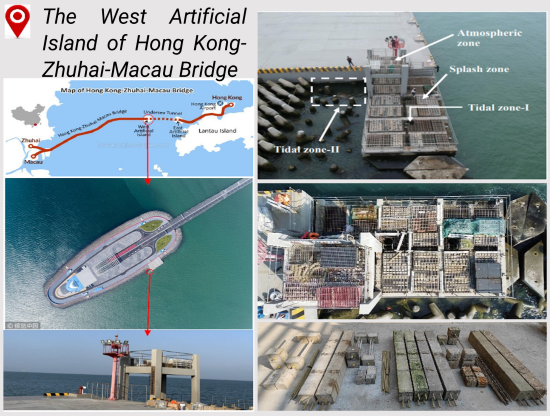
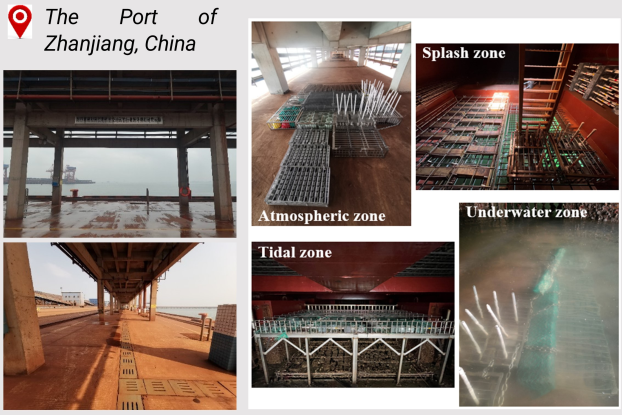
Exposure Tests in Real Marine Environments

Over five thousands of specimens were placed in two field exposure stations, and mechanical tests of the specimens have been conducted after they were subjected to up to over four years' exposure.

The West Artificial Island of Hong Kong-Zhuhai-Macau Bridge



The Port of Zhanjiang, China



Demonstration Projects

Two demonstration projects have been constructed, and another one is in the construction process. The first project is for the structural components (i.e., a slab and a beam) of a field exposure station at the Lvsi Port, Nantong, China; the second project is for the paving slabs of a road in Shatin Sewage Treatment Works, Hong Kong, China; and the third project in the construction process is for the wave wall at Lei Yue Mun, Hong Kong, China.

FRP-Seawater Concrete Slab,
Lvsi Port, Nantong, China

FRP-SSC Paving Slabs,
Ma Liu Shui, Sha Tin, Hong Kong

FRP-SSC Wave Wall
(Construction in progress),
Lei Yue Mun, Hong Kong

FRP-SSC Mock-up Frame

A three-storey FRP-SSC mock-up frame has been constructed, and it is placed at the Guishan Island in Zhuhai, Guangdong. The frame is 7.8 metres high and contains many innovative structural members and sensors developed in this project, including FRP tube-confined reinforced concrete columns, concrete columns reinforced with hybrid bars, concrete beams reinforced with FRP-coated bars, ductile concrete beams and slabs reinforced with FRP bars.

Fabrication of the developed innovative
structural materials and sensors

Construction of the
mock-up frame

Installation of the
mock-up frame