NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

RESEARCH
Urban Solutions

School of Civil & Environmental Engineering

Introduction

Professor Wang Rong
Chair of CEE

A leading school for sustainable built environment

The School of Civil and Environmental Engineering (CEE) plays an integral role in spearheading tertiary education, advancing research innovations and providing professional services in a number of key disciplines in Civil and Environmental Engineering and maritime studies fields, with the objective of contributing to the technological and economic advancement of Singapore and beyond. The School's mission in research is to achieve excellence by providing a conducive and intellectually stimulating environment to enable high quality work in strategic directions that are of significant impact to industry, science and technology.

The School comprises strategic research focus groups and together, they form a powerhouse of resources for research development, technology innovation, and research manpower training. Besides these research groups, CEE has 6 research centres, namely:

- Centre for Infrastructure System (CIS)
- Centre for Usable Space (CUS)
- Nanyang Centre for Underground Space (NCUS)
- NTU-JTC Industrial Infrastructure Innovation Centre (I3C)
- Protective Technology Research Centre (PTRC)
- Transport Research Centre (TRC@NTU)

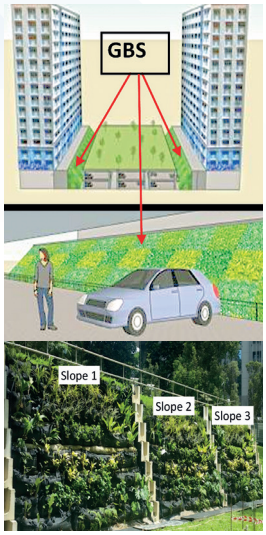
Our faculty has been very competitive in securing research grants to fund their research. Funding for research in the School comes from numerous sources including the local industry and Government Statutory Boards such as National Research Foundation, Ministry of Education (MOE) and the Agency for Science, Technology and Research (A*STAR). Through these means, the School's research infrastructure has continued to grow from strength to strength, in terms of manpower, state-of-the-art facilities, funding, as well as interactions with industry and renowned academic and research institutions.

The building of core competencies is crucial so that the School can lead and develop research programmes, which are of strategic importance for attracting overseas investments to Singapore and creating spin-off technology companies, which adds value to our effort to promote technopreneurship amongst researchers and students. With the excellent research infrastructure and funding, our faculty has been able to deliver good research results, which enable them to file patents, and publish in top international journals and conferences. This research brochure highlights our strategic research areas and recent developments; and it also outlines our research centres. Faced with more challenges in increasing population, space limitation, clean water demand, and sustainable living in the near future, CEE would continue to be the leading school for sustainable built environment.

Geotechnical Engineering
(Soil Mechanics/Rock Mechanics)

Geobarrier System for Use in Underground Structure

Singapore is densely populated where land is scarce. The construction of slopes with steep inclinations will enable the intensification of land use. A new slope protection system, the Geobarrier System (GBS) has been developed and successfully tested in the field. This new cover system comprises a vegetative layer combined with a sophisticated two-layer unsaturated system, which harnesses the distinct differences in hydraulic properties between fine-grained and coarse-grained soils to reduce water ingress. Based on unsaturated soil mechanics theory, the coefficient of permeability of the coarse-grained soil can be much lower than that of the fine-grained soil at high suction values. Under unsaturated conditions, the difference in permeability between the fine-grained layer and the coarse-grained layer limits the downward movement of water through capillary barrier effect. Therefore, GBS can be utilized not only as an earth retaining structure that provides a slope stabilization system against rainfall-induced slope failures; the GBS can also function as vertical greenery as well as a water retention structure to reduce runoff peak flows. GBS can be deployed to add value to underground structures for multi-level basement carparks and in hilly terrain for slope improvement works. GBS uses recycled materials in place of steel or concrete and is hence more cost effective and sustainable. GBS also has a lower carbon footprint and can be considered as green structure when compared to reinforced concrete earth retaining structures. This new system has been test-bedded successfully and it has been implemented in a Housing and Development Board (HDB) basement carpark at Matilda, Punggol. Moving forward, the GBS will be deployed to other HDB development sites e.g. Punggol Northshore District and Bidadari Estate.



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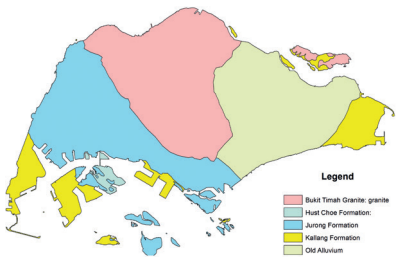
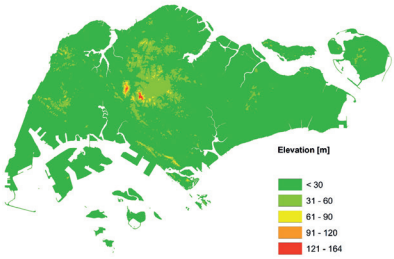
Development of Slope Management and Susceptibility Geographical Information System

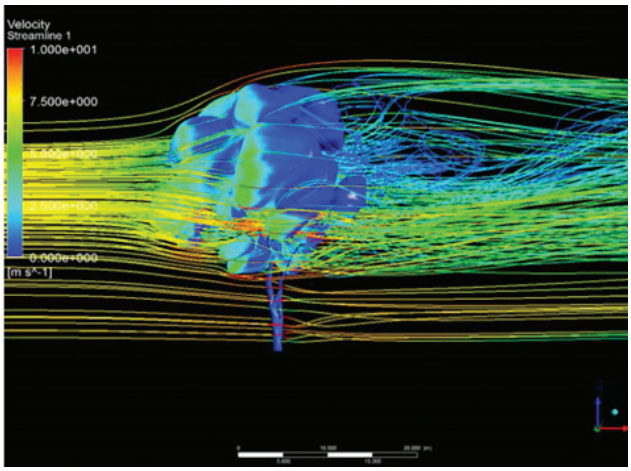


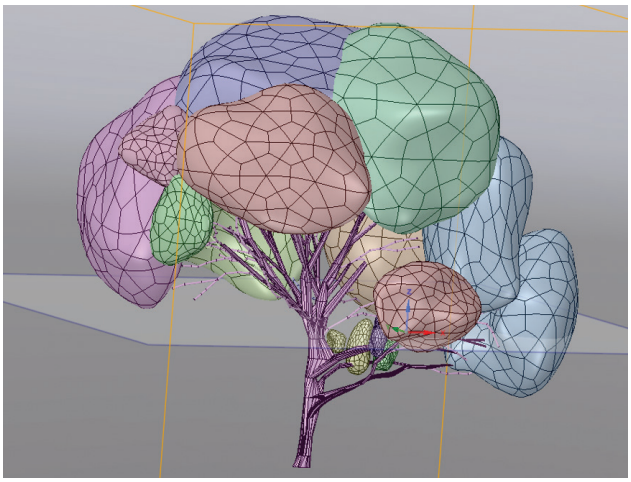


The high precipitation rates associated with tropical regions has often led to the frequent and widespread occurrences of local rainfall-induced slope failures. In Singapore, such slope failures can be observed to occur in normally unsaturated residual soil formations. The engineering behavior of an unsaturated soil is largely influenced by its soil-water characteristic curve (SWCC). The important components of the SWCC are the saturated water content, air-entry value, inflection point, residual water content and residual suction. The coefficient of permeability and the shear strength of an unsaturated soil are both functions of matric suction that reduces significantly during rainfall. The reductions in matric suction affect stability of residual soil slopes. The SWCCs of residual soils vary significantly with different locations, geological formations and degrees of weathering. Therefore, it is important to understand the spatial variation of unsaturated soil properties and antecedent precipitation to grade the vulnerability of slopes to failure. In this project, geostatistical analysis is carried out to establish the unsaturated property map of the residual soils within several zones of different geological formations in Singapore. Then, the unsaturated soil zonation will be combined with the spatial distribution of antecedent rainfall to develop a slope susceptibility map. The developed Slope Susceptibility Map (SSM) can be used to enhance urban planning in Singapore and to provide a database of critical slopes with low factor of safety in Singapore during wet periods. In addition, the SSM will allow targeted preventive measures be carried out to avoid slope failures that will cause damage to infrastructures and endanger public safety. (Prof Harianto Rahardjo; chrahardjo@ntu.edu.sg)

Climate Change Impact on Urban Tree Resilience

Trees are "living structures". They all possess an aboveground superstructure as well as an anchoring sub-structure. As trees mature, the added biomass leads to greater static loadings due to increased self-weight. The increased tree height exposes the upper reaches of the trees' canopies to higher wind speeds, which cause larger bending moments to develop in their rooting systems. An urban tree needs to be able to withstand all the self-weight and climatic loads applied to it for as long a period as possible. With the projected changes in the climate; higher average global temperatures will lead to an increasingly hostile growing environment for the trees. These changes will provide the most persistent challenges to the stability and health of mature urban trees. Extreme swings in climate will mean that wind loads can become ever frequent increasing in magnitudes. The Climate will also swing between extreme dry and wet periods with increasing frequencies. Changes in rainfall patterns and mean sea levels will lead to changes to the inland ground water regime and thus soil water contents within the tree rooting depth. This project purposefully studies the effects of these future changes and determines their impacts on Singapore's mature urban tree population. This research is carried out using field instrumentation and testing, laboratory testing and numerical modelling. The field instrumentation measures the effects of various climatic parameters on tree stability while other field tests on mature trees include static pull tests and greenwood testing. Laboratory tests on soil from the root zone provide engineering properties of the growing medium while scale tree models are tested for uprooting resistance and wind drag. Evapotranspiration, fluid structural interactions and the rooting architecture of trees are also numerically modelled using flux boundary, seepage, static/dynamic structural and computational fluid dynamics simulations. Using the results from the field, laboratory and numerical studies, integrated tree stability models can be created that takes into account the changing growing environment cause by climate change.





Tree Risk Management: Parameterization of Mechanistic Wind Risk Models in Singapore

Mechanistic wind risk models are commonly used in commercial forestry management. Such models attempt to characterize physical processes involved in tree failure and determine a critical wind speed necessary for failure based on the resistive attributes of the stem, roots, and soil. Generally, empirical estimates of trunk and root system strength are used to determine a critical wind speed at which failure will occur. However, these models have been primarily developed for European sites and associated species, such as Sitka spruce [Picea sitchensis (Bong.) Carriere (Pinaceae)], Norway spruce [Picea abies (L.) Karst. (Pinaceae)], and maritime pine [Pinus pinaster Aiton (Pinaceae)]. Tree pulling and flexural tests have been used to provide some of the parameters needed for these models. However, disparity associated with the testing methods and representation of the tree parts in these tests implies that such parameters cannot be easily extrapolated to tropical trees. Some arborists have attempted to develop a version of these mechanistic models to assess the likelihood of failure for individual open-grown trees but there is a paucity of parameters necessary to compute estimates for similar trees growing in the tropics. Hence, this project seeks to investigate through experiments the important differences between those tree species in the literature and tropical species in order to obtain the relevant parameters for wind risk models applicable to Singapore. The research seeks to characterize the strength of various tree parts and the root-soil system using controlled loading tests for a variety of species commonly planted in Singapore.

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Transforming Singapore's Underground Construction Industry with Biogrout

Recognising that the conventional biogrout was not environmentally friendly and feasible for urban applications, Prof Chu Jian, together with Prof Tan Soon Keat, Prof Zhao Zhiye and their team of researchers made a breakthrough with the development of a new biogrout. Their team's newly developed biogrout will ensure grouting for seepage control in underground construction more effective, efficient and feasible for urban applications. In comparison to existing biogrout, this new biogrout is more cost effective as it consumes less energy during the production process; and can be produced using activated sludge, which in turn reduces the cost of bio cement significantly and the amount of sludge disposed. In addition, no ammonia gas is produced during the biogrouting process, making it feasible for urban applications for the first time. This new biogrout can also flow like water and permeate even the finest cracks. Given this new biogrout's good commercialization potential, two disclosures and further patent applications are currently in progress. Meanwhile, further research is ongoing to strengthen the capabilities of this product, with trials currently being conducted for a Defence Science and Technology Agency (DSTA) project.

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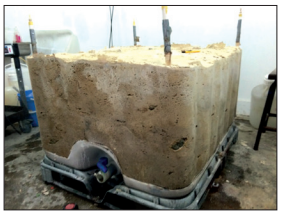

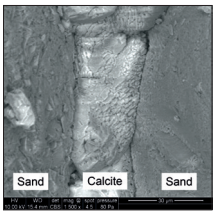

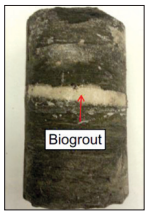

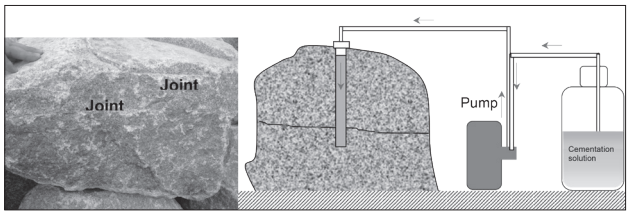

Web-Based 3D GeoData Modelling and Management System (GeM2S)

The main objective of this project is to establish a Web-based three-dimensional (3D) Geological and Geotechnical Data Modelling and Management System (GeM2S) so as to reduce construction cost and increase productivity for future underground construction projects in Singapore. A huge amount of geological and geotechnical data has been collected in the past as shown in Fig.1c. This project is to develop a system to use these data for future underground construction. A 3D geological (Fig. 3) or geotechnical model will be established using the existing borehole data as well as validated in-situ and laboratory data based the interpreted cross-sections (Fig. 1a) and fence diagram (Fig. 2). This model can be updated with new geological or geotechnical data available in the future. By using this system, the geological conditions at a site can be evaluated together with the geological or geotechnical model established. In this way, the uncertainties involved in the design parameters can be reduced, the design can thus be reliable without being too conservative. This application can result in reduction in construction cost. The proposed 3D GeM2S system will be used by both government agencies and industries for either underground master plan or infrastructure developments such as for construction for buildings, roads, MRTs, or underground caverns.

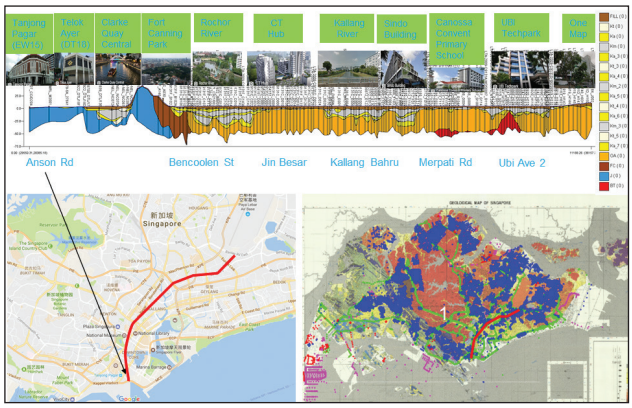

Fig. 1. (a) A cross-section the East coast area of Singapore, (b) Map of Singapore, and (c) The distribution of borehole data of Singapore

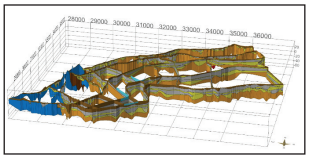

Fig. 2. The fence diagram of the East coast area of Singapore

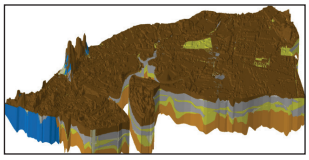

Fig. 3. The 3D geological model of the East coast area of Singapore

Rock Mechanics

CEE has a strong team on rock mechanics research, which includes fundamental rock mechanics (rock property testing, rock failure theory), numerical analysis (probabilistic analysis, simulation of complex failure process and coupled analysis), rock dynamics (dynamic testing, rock blasting field test and numerical simulation). The rock mechanics group has established collaborations with Hyundai Construction on rock cavern preliminary design system, Kajima on rock bolt performance, SINTEF on rock grouting, and Shandong University on grouting lab test.

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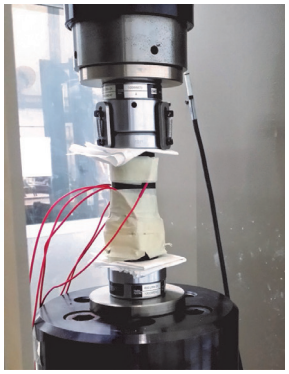

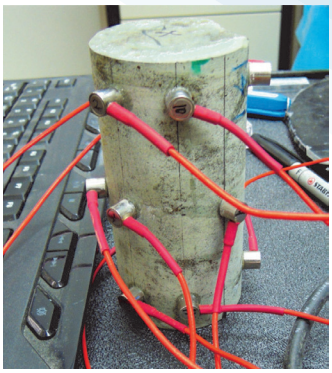

Unconventional Resource Development and Mitigation of Induced Geo-hazards

Harvesting unconventional resources (e.g., geothermal energy and shale gas) trapped in deep rocks offers us a sustainable solution to reduce our dependence on fossil fuels. The development of unconventional energy technologies allows us to enhance energy resilience and reduce carbon emission in Singapore. This study includes two topics. The first topic is to experimentally and numerically evaluate the permeability evolution of unconventional reservoirs, in which hydraulic fracturing not only creates extensive permeable fracture networks but also has the potential to active pre-existing fractures. Our latest results suggest that fracture slip is controllable to enhance reservoir stimulation in unconventional energy extraction. The second topic is to investigate the mechanism of injection-induced seismicity. Fracture activation is likely triggered by fluid injection into a natural fracture at low effective normal stresses. Our work is ongoing to manage strain energy released from critically stressed fractures by controlling water injection strategies. As a result, we expect to transform a remarkable seismic event into millions of imperceptible micro-earthquakes.

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Fig. 1 MTS rock mechanics testing machine with nano-permeability testing system.

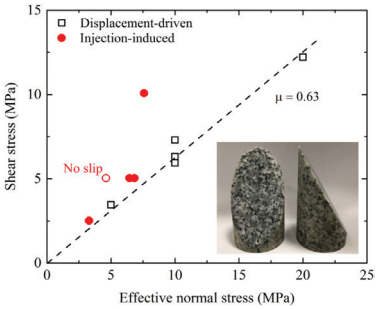


Fig. 2 Effective normal stress and fluid overpressure during the injection-induced failure of a sawcut fracture.

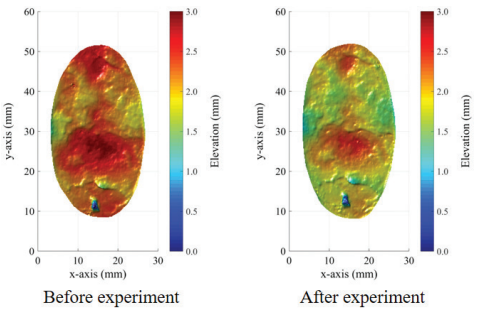
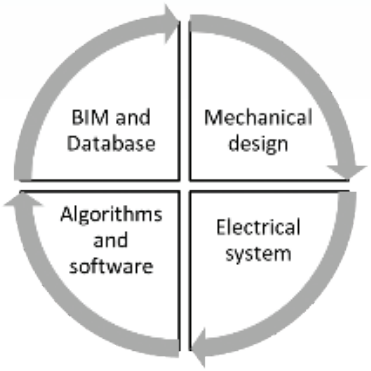


Fig. 3 Topographic contours of natural fracture surfaces before and after the shear-flow experiments.

Construction Productivity & Management

Adaptive Robotic Work Cell for Standard Precast Construction Unit Manufacturing

The aim of this project is to study, develop, and implement a versatile mobile manipulation platform that can be used in precast construction unit manufacturing factory for flexibility, productivity enhancement, and quality in delivering precast units for Singapore's building construction sector. The main project deliverables are Robotic Workcell and computer-aided intelligent system. Some measurable deliverables are: space optimisation, manufacturing capacity, turnaround time, manpower reduction at each workcell.



Building Information Modelling (BIM) based Smart Crane Solution

The Smart Crane System has been developed and utilized at the Yishun Signature construction site, in partnership with BCA and Kimly Construction, for precast elements logistics management, on-site inventory checking and hoisting and installation processes. It has two main functionalities: 1. Semi Auto-detection, track & collection of precast elements. 2. Semi Auto-position and send precast elements to identified locations. Different kind of technologies, such as BIM system, sensors, camera system, positioning system, have been developed and deployed to provide and enable an integration solution that is capable to track precast elements from delivery to installation at site. The construction informatics and componential BIM-based information of the precast element has been used by the system to guide the crane operator to detect, hoist, and locate it at its final designated position in the building. The System was able to address the construction site limitations and constraints such as blind lifting which lead to enhance construction site productivity.

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Human Centric Built Environment

Psychological, health and social parameters associated with working in underground spaces

Singapore is a small country coping with the limitation of space. Large-scale integrated underground working environments may be a feasible solution to this constraint. To ensure such developments are successful, it is important to understand human factors associated with underground spaces (UGS). The aim of this research study is to examine and address possible social, psychological and health-related impacts of UGS keeping in mind design and architectural attributes and by using innovative methodologies in an integrated fashion. The research team has collated the largest combined underground-aboveground database of 500 working people in Singapore, which is being used in an ongoing Cohort study. This three stage study includes social and design questionnaires, psychological experiments and health measurement tools and is aimed at identifying the differences, if any, between comparable employees working in above- and underground environments. Year 2017 also saw the creation of Singapore's first ever underground laboratory built in NTU with the intention of exploring psychological, social and design parameters that affect people working underground. The outcomes from the experiments done in the underground 'Human Performance Lab', can be used to generate engineering solutions. The project also uses virtual reality, behavioural techniques and physiological measures such as eye tracking and EEG brain wave recording.

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Structural Engineering & Materials

Smart Sensing Technology for Civil Engineering Applications

This project aims at developing advanced smart sensing systems based on fibre optic sensors (FOS) and piezoelectric sensors for structural health monitoring or geotechnical monitoring so as to enable informed decision making during construction, operation and maintenance of infrastructures. One of the focuses is to develop FOS based transducers such as inclinometer, profilometer, extensometer and water pressure meter for monitoring ground movement and associated parameters. The proposed FOS based devices will be able to monitor ground settlement and related parameters in real time, which would significantly improve current monitoring practices with automated data acquisition, leading to higher productivity by reducing the time and the manpower required. We are also developing another FOS system for monitoring applications of offshore structures such as a floating production storage and offloading (FPSO) unit. The system will be customized and enhanced for harsh offshore environment. Together with an algorithm for hull condition assessment, the proposed FOS system will reduce the reliance on manual inspection and enable condition based maintenance, facilitating effective inspection, repair and maintenance activities for the fixed and floating platforms. The piezoelectric sensors are particularly useful for local damage detection, such as cracks developed on the surface and inside the concrete structures.

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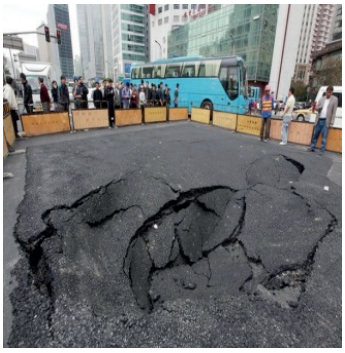

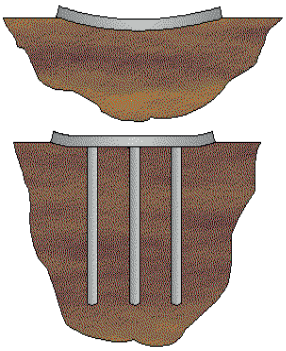

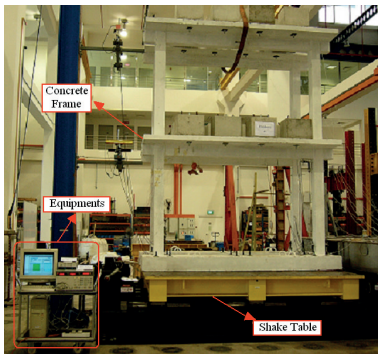

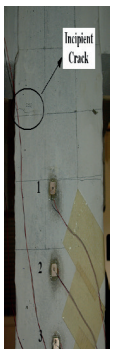

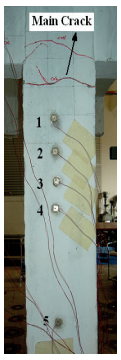

Field Demonstration of Bendable Concrete Precast Pavement

This project is an extension and continuation of the pilot project on Feasibility Study of Bendable Concrete Precast Pavement. Major achievements and conclusions from the pilot project are:

- Bendable concrete (ECC-SG) with high flexural strength and excellent fatigue performance is developed with locally available ingredients;
- ECC-SG can potentially reduce thickness of precast pavement by as much as 50% while doubling the service life;
- Potential to achieve 10-30% saving on construction time of precast ECC pavement;
- While the initial cost of precast ECC pavement is higher, the life cycle cost (agency and user costs) is expected to be much less than the HMA pavement.

Precast ECC pavement, like conventional concrete pavement, will show high stability against plastic deformation but comes with very limited disruption of traffic in case of (asphalt)-pavement rehabilitation or renewal. Based on the results from the pilot project, it is promising to use ECC for precast pavement application. However, some potential technical challenges, such as precast pavement design with ECC (full depth or "white topping" of existing asphalt pavements), quality control of large scale processing of ECC, optimisation of installation procedures with respect to traffic interference and pavement performance verification must be overcome before the wide adoption and application of precast ECC pavement. The project will target these problems, come up with technical solutions, and confirm the design, manufacturing, and performance of precast ECC pavement with a full-scale field demonstration.

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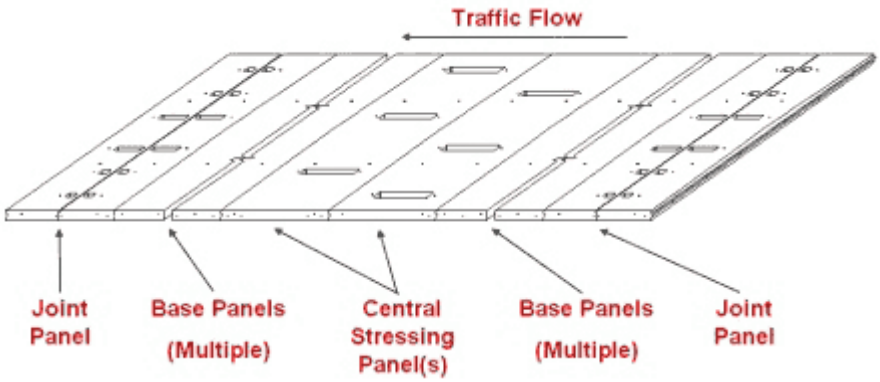

Life Safety and Structural Fire Safety of Mega Underground Caverns in Singapore

Fire safety and its cost-effective design of underground structures depend heavily on early detection systems, evacuation strategies, engineered smoke control, fire modelling, structural fire analysis and design of reinforced concrete members to satisfy relevant parts of structural Eurocode. Unfortunately, to satisfy 4-hour fire rating for deep basements, the code stipulates that reinforced concrete elements must be massive. This poses significant increase in construction cost and potential difficulties in underground construction due to the weight of elements. Besides structural safety, the research addresses safety needs of occupants and fire respondents. This research provides an integrated fire safety assessment of underground developments in Singapore using a performance-based approach which holistically integrates evacuation analysis, fire modelling, structural analysis and fire detection/suppression analysis. Besides the holistic assessment, the kernel of this proposal is to study the most recent advancements in construction materials and methodology worldwide to provide safe and cost-effective solutions for fire safety of underground structures and life safety of occupants. To enhance existing mechanical properties of conventional reinforced concrete including its tensile strength, compressive strength and fire resistance, this project studies the possibility of applying the following novel materials into concrete mix

- Carbon nano-fibres (CNF);
- Ultra-high performance concrete (UHPC) that is fire-resistant;
- High strength concrete that is fire-resistant;
- Polymer fibres;
- Geopolymers to reduce concrete spalling;
- Spray-applied polyurea-based with halogen-free fire retardants as fire- resistant coating.

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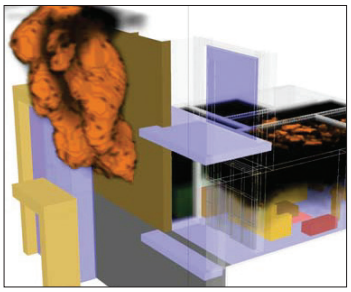

Self-sensing Properties of Engineered Cementitious Composites

Improper design, construction and/or deterioration of concrete structures, e.g. large cracking, may lead to loss of structural stiffness, strength, or even collapse in some extreme cases, such as the tragic 1986 Hotel New World Collapse in Singapore and 2004 Charles de Gaulle Airport Collapse in France, killed 33 and 4 people, respectively. The challenge to maintain the safety of concrete structures will become even greater as Singapore strives to build much higher and deeper to cater for its increasing population, which involves much more complicated designs, constructions, loadings and environments (e.g. underwater/undersea infrastructure/city). To address this long-lasting concern, a more prudent method is to use self-sensing concrete to automatically monitor structural health condition to greatly improve its safety and help save human lives. Proposed in this project is the development of fundamental understanding on the multiple-level mechanical/electrical coupled ehaviour of self-sensing phenomena in bendable concrete material. This is accomplished through systematic redesign of bendable concrete incorporating conductive raw materials via refined micro-level mechanics design tools, multiple-level modelling of the self-sensing behaviour by linking the micro-level of fibre, matrix and their interactions, meso-level of single crack behaviour with macro-level concrete behaviour, followed by experimental studies on the mechanical loadings, physical properties, and environmental exposure conditions that is optimal for self-sensing to occur. Specifically, the proposed work will focus on the following objectives:

1. Design bendable concrete based on micro-level mechanics model;
2. Develop multiple-level model for self-sensing behavior of above material;
3. Investigate mechanical/physical/environmental effects on the self-sensing concrete.

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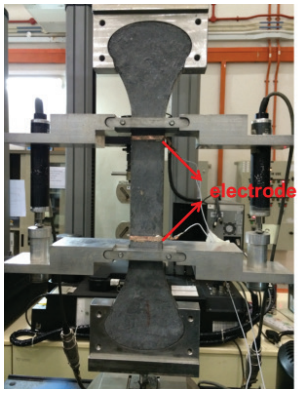

Transportation Engineering & Planning

Rapid Road Transport (RRT)

Rapid Road Transit (RRT) is one of the 6 areas in TUMCREATE (Phase II), which is a 5-year NRF-funded programme on developing the "Ultimate Public Transport System". It involves the participation of Assoc/Prof Wong Yiik Diew, Asst/Prof Zhu Feng and Asst/Prof Yang En-Hua. RRT builds the common blueprint of the programme, bundling the development of all 6 areas as one transport product. The development of concept for the systematic electrification of public and mass transport is also addressed. The RRT group is developing a new Semi-Rapid Transit (SRT) concept as a major milestone in achieving the mission and vision of TUMCREATE. The Semi-Rapid Transit serves the passenger capacity segment between the MRT and the conventional bus system, and complements the current modes of public transport. The new mode consists of different vehicle technologies and operational concepts with state-of-the-art vehicle-to-vehicle and vehicle-to-infrastructure communication, and recent advances in electromobility. To achieve this aim, three main objectives have been defined as illustrated.

- RRT1: Definition of the SRT layer and integration into the overall network of Singapore. The objective is to define the features and requirements of the proposed public transport concepts and their integration into the existing public transport network for Singapore and other cities.
- RRT2: Technologies for holistic traffic management and control. The objective is to define innovative vehicle and operational approaches for the proposed public transport concepts.
- RRT3: Electrified public transport system – from concept to infrastructure. The objective is to identify the optimal road and energy infrastructure for the proposed public transport concepts for their implementation in Singapore and other cities.

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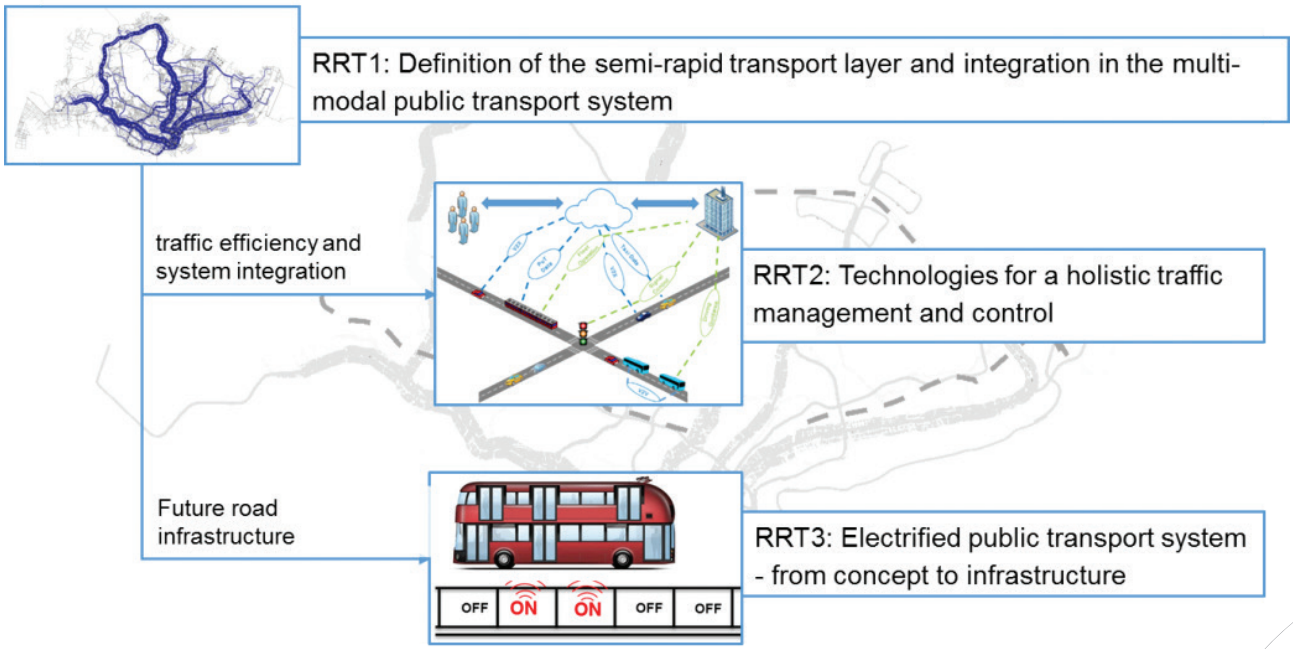

Sustainable Urban Waterways / Waterbodies

Microbiological, Chemical and Physical Interactions in Rock Cavern Water Storage

Waterways and waterbodies in urban areas play an ever increasing role towards meeting quality of life expectations of urban communities. Prime examples of such communities are readily found in Southeast Asia which is home to about 350 million people, with sprawling coastal megacities such as Bangkok, Jakarta, and Manila, each with population exceeding 10 million. These cities are also located along the coast for which the coastal seas also play similar key roles. Waterways and waterbodies traditionally play roles of water conveyance which for urban communities, are in associated with stormwater management and flood avoidance. Increasingly, these waterways and waterbodies are being redeveloped or rehabilitated for positive societal impacts, being folded as part of the urban green space for recreation, social cohesion and aesthetics with further positive impacts on biodiversity. Research at CEE on urban waterways and waterbodies seeks to address various challenges relating the preservation and improvement of the functions of such waterways and waterbodies, and mainly involve the study of: (i) field monitoring and analysis of flow and water quality, (ii) dynamic rainfall - runoff and quality modelling for urbanized catchments, (iii) reservoir hydrodynamic and water quality modelling, (iv) fluvial hydraulics and sediment transport, (v) coastal hydraulics and management, and (vi) impact of long-term climatic changes and adaptation planning.

A project funded by MND focused on exploration of the feasibility of using an underground cavern as a reservoir to augment the overall yield of fresh water supply in the country. The reservoir is envisaged to function as a long term storage facility, with frequent recharge from excess storm runoff from the surface drainage system and withdrawals, at less regular intervals, to augment surface water supplies. The study involves modules of laboratory test, mathematical modelling, and pilot cavern design. The project is the first ever study on physical, geochemical and microbiological interactions in cavern storage conditions and their impacts on water quality in Singapore. The research outcome not only will enhance water security for the nation but also mitigate land scarcity issues, facilitating long-term sustainable development of Singapore.

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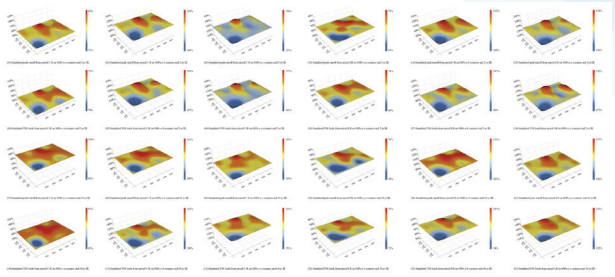
Future scenarios modeling of urban stormwater management in response to anticipated impacts of urbanization and climate change

Future scenario modelling is now being used investigate the effectiveness of urban stormwater infrastructure and catering to potential future changes. The changes of urban stormwater, both in flow quantity and water quality, attributable to climate change and urbanization, are examined herein. Different degrees of performance to 2-year and 10-year design storms are discernible. The peak runoff and water quality are impacted more significantly by urbanization factors than that due to climatic change. The influence from urban intensification (land use and population density) is more significant than that from land-use changes alone. Low impact developments as key adaptation practices could be potentially effective in mitigating adverse impacts of future changes on urban stormwater system. The methodology developed is useful for urban stormwater planning and testing the development plan against future change scenarios associated with urbanization and climate change.



Simulated peak runoff and total suspended sediment (TSS) loads from downtown commercial area (C-R) and industrial area (I-R) based on future development and climate change scenarios. Red contours refer to relative high values and blue contours refer to low values of runoff and TSS, respectively.

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Sustainable Management of Navigation Waterways

Sustainable management of navigation waterways by dredging is a critical element in global urbanization, and open water disposal of dredged sediments at designated coastal locations is the most common practice around the world. To carry out the disposal operations, preapproval from regulatory agencies is generally required with predictions of the fate and transport of the disposed sediments in the water column for impact assessment. However, the predictions from existing numerical models can be substantially inaccurate due to the complexity of the hydrodynamics invovled. In this project, a new model, BSDM, is developed based on a tree-search classification approach. The model takes into account the various physical factors including the sediment characteristics and release conditions, and the model predications have been validated through comparison with experimental and field studies. The commercial software, which is available for download upon request, can be applied for the related engineering analysis and assessment.

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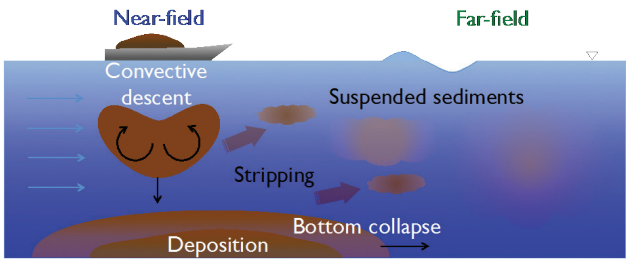

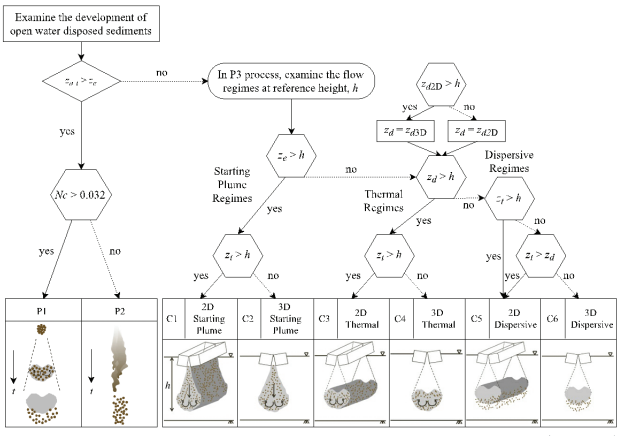

Hydrodynamic characteristics of propeller jet and its associated scour hole around an open-type quay

In the past decade, the shipping industry development was based on an increase in vessel capacities, which inevitably was accompanied by the increase of engine power. As a result, higher flow velocities generated by larger and more powerful ship propellers have caused more scour-related damages to the bed and banks of harbor basins and navigation channels, particularly when the under-keel clearance is small and the seabed and banks are not designed for such velocities. This project aims at achieving a quantitative understanding of the flow behaviors of both confined (open-type) and unconfined propeller jets and the associated scour hole through an extensive experimental program. In additional to the traditional use of the Acoustic Doppler Velocimetry (ADV) approach, the study develops an innovative application technique of the use of high-speed Particle Image Velocimtry (PIV) in oblique rather than the customary normal PIV measurement. The latter pioneering method was successfully employed in this project. In this way, the interaction between turbulent flow and a developing 3-dimensional scour hole has been revealed. In particular, the detailed measurement of the flow field at the fluid-boundary interface is achieved at a micro level, which is of great importance to researchers and engineers in both laboratory and field applications. Results of this project provide reliable data for the prediction of the maximum scour depth that forms in the absence and presence of quay structures and optimization of ports and navigational channels design, thereby reducing maintenance cost through the design and construction of more cost-effective scour countermeasures.

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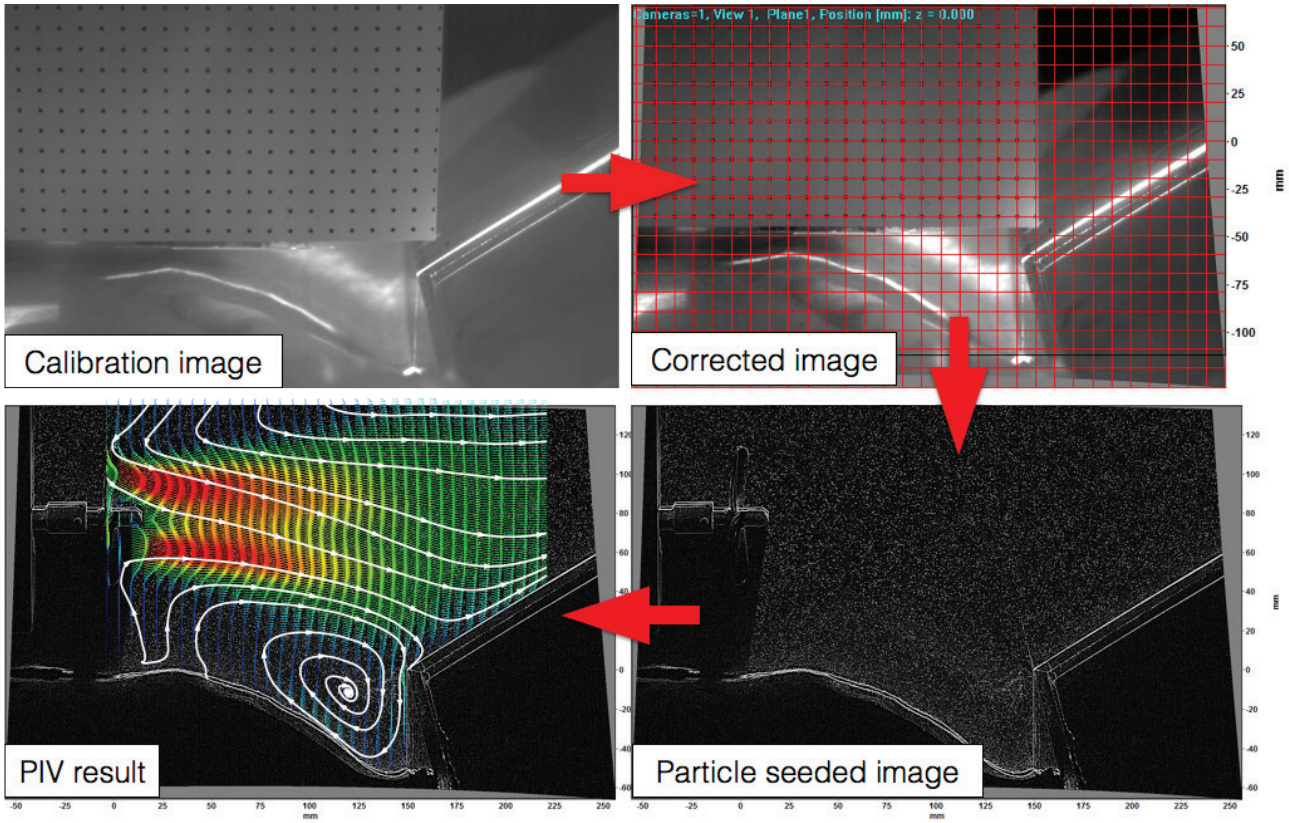
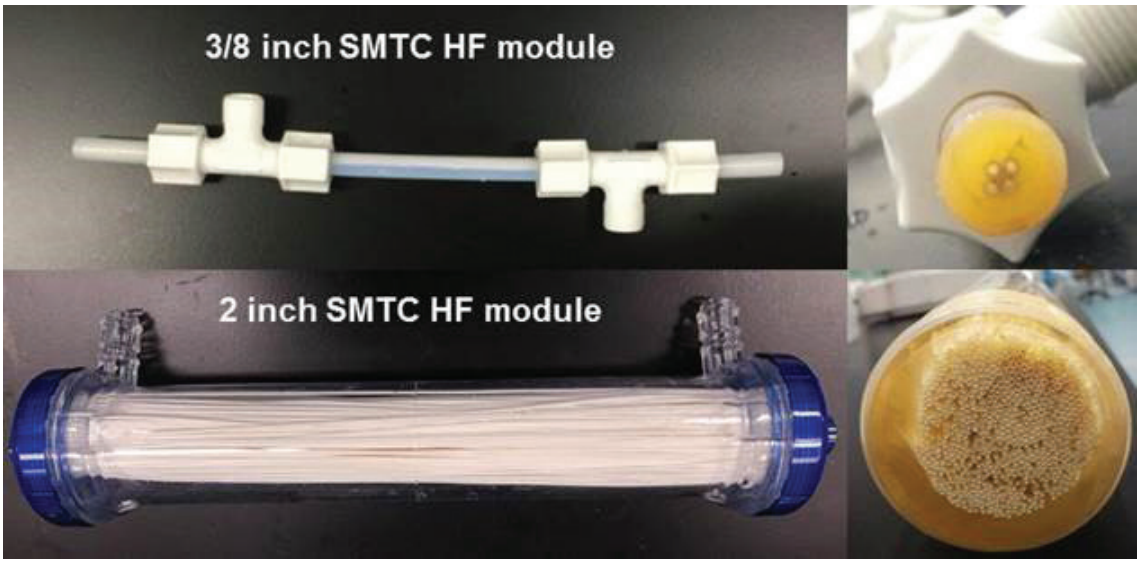


Membrane Science & Technology

Developments of Novel Membranes and Membrane Processes for Water Reuse and Desalination

Membrane technology is increasingly playing an essential role in our life, for example, in the water production and desalination, wastewater treatment and reclamation, gas and liquid separations & purifications, energy and environmental applications, etc. The membrane research is led by Profs. Wang Rong and Chong Tzyy Haur at the Singapore Membrane Technology Centre (SMTC), a member of the Nanyang Environment and Water Research Institute (NEWRI) at NTU, in collaborating with multidisciplinary talents at NTU and international organizations, and industry partners. The SMTC is supported by the National Research Foundation (NRF) and Economic Development Board (EDB) of Singapore. The SMTC has a world-class research laboratory of 1200 m2 equipped with state of- the-art membrane facilities and advanced analytical instruments. The fundamental and applied research topics include novel membranes, enhanced module & system design, fouling control, characterization, energy from brines, novel membrane bioreactors & energy, CO2 separation, and cleaner production. Highlights of projects include following:

(1) Biomimetic Membrane – Nature has developed a most efficient way for water transport across an osmotic pressure gradient via aquaporin (AQP) proteins. An artificial membrane can be developed to mimic the natural cellular membranes by incorporating the aquaporins into the thin film composite structure. The AQP membrane has been demonstrated for water reuse application and able to achieve lower cost of water production due to reduction in energy requirement. A new IAF-PP project funded by NRF with a budget of S$8.5 millions has been awarded to Prof. Wang's team to scale-up the fabrication of high performance AQP-based biomimetic hollow fiber membranes in April 2018. This innovation will bring benefits not just to Singapore but also to the international community by solving one of the world's most challenging issues – clean water production at an affordable cost.



(2) Low Pressure Nanofiltration (NF) Membrane – NF membrane technology is an attractive option for water softening to remove divalent cations (such as calcium and magnesium ions), groundwater treatment, cooling tower water recycling, wastewater treatment and seawater pretreatment. The novel low pressure hollow fiber NF membrane only requires operating pressure of 2 bars, compared to typical commercial membranes that require 5 – 10 bars, thus reducing the energy consumption. The membrane is now being commercialized through a local company, De.mem.

(3) Improved Recovery and Energy- Efficient Reverse Osmosis (EERO) Process – The challenge of current reverse osmosis (RO) technology for seawater desalination or water reclamation is the requirement of high pressure and high energy at high water recovery, so typical recovery of SWRO is limited to 50%. The EERO process is based on multi-stage processing and optimization via countercurrent flow, retentate recycling, combination of NF and RO stages, and operation without entropy-ofmixing effect. The EERO process allows higher recovery at lower energy consumption compared to existing RO technology at the same recovery level. A pilot trial with a 25 m3/d EERO system at Tuas R&D site has shown the improvement of SWRO recovery from 45 to 65% at operating pressure of 50 bars.

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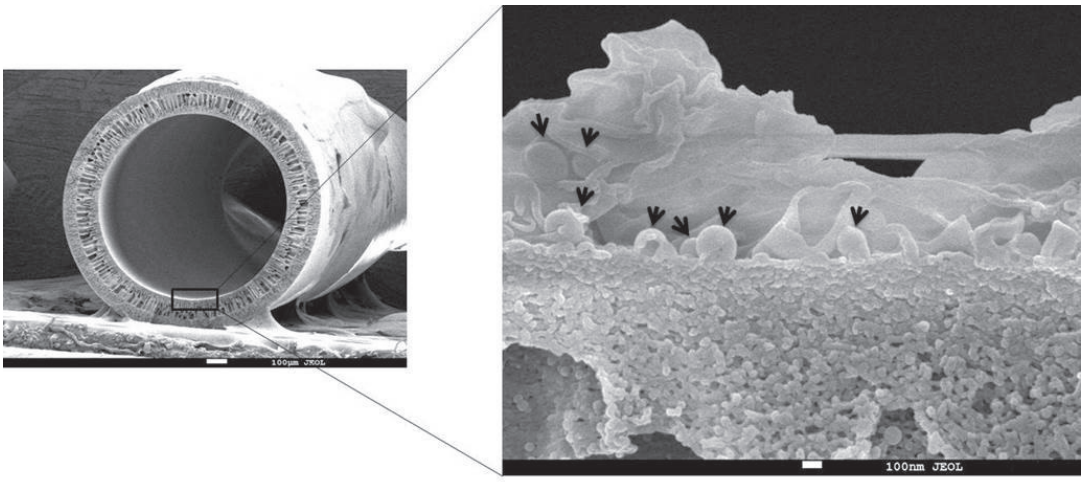

AQP Membrane: Arrows indicate the locations of proteoliposomes

Environmental Bioprocesses & Biotechnology

Pretreatment Processes and Enhanced Anaerobic Digestion

Anaerobic digestion is applied on feeds with high organic solids content such as sewage sludge, MSW, animal wastes, and other agricultural residues. The purpose of such digestion is to reduce the mass of solids requiring subsequent disposal. A by-product of the digestion process is biogas which has value as a source of energy. The typical shortcoming of anaerobic digestion is it is "slow" and breakdown of the solids is far from complete. The consequence of this is the solids reduction can range from 35 to 45% only. Unlike in wastewater treatment where methanogenesis can become rate limiting in a primarily acidogenesis-methanogenesis process, in digestion hydrolysis can become rate limiting in a hydrolysis-acidogenesis-methanogenesis arrangement. This means rapid solubilising of the organic solids is important to the "speed" of the overall process. The project undertaken has spread over a number of years and is a cluster of sub-projects which investigated pretreatment processes such as ultrasonication, alkaline and enzymatic action on the solids to enhance hydrolysis. The latter released cellular contents which could then undergo acidogenesis followed by methanogenesis. The latter then converts the organic acids into methane. Following these investigations, the engineered system can be either a 2 or 3 cascading reactors system. These approaches allowed for solids reduction of 55 to 70% - ie a significant increase over the conventional approach. While the investigation had initially focussed on development of a system for sewage sludge management, modifications in process control parameters and engineering would allow its application in the agri-industry. The interest there would then not only be on pollution management but also on resource recovery such as bioenergy via the methane generated. However, an added benefit of enhanced hydrolysis is the increased release of phosphorus and potassium – important nutrients in agriculture in addition to nitrogen. The system would therefore allow for better recovery and utilization of nutrients in agriculture as in NPK and reduce need for inorganic fertilizers. The project has generated IPs covering devices such as a mixer and sensor, processes such as enhanced "hyper-rate" digestion process, and engineering such as the system design protocol. The system shall be trialled at NEWRI's WW-ART located at UPWRP at demonstration scale. This would allow for better appreciation of engineering and operating issues, and capex and opex. The facilities shall be ready for operation by the end of 2018.

Demonstration scale anaerobic digesters at NEWRI's WW-ART facility

A Total Solution for Food Waste Management Toward Zero-Solid Disposal and Energy/Resource Recovery

Food waste is produced from various sources including food processing, vegetable market, restaurants etc. According to Food and Agriculture Organization nearly 1.6 billion tonnes of foods including fresh vegetables, fruits, meat, bakery and dairy products are wasted annually, which is about 27% of the total global agricultural productivity for both food and non-food uses. For example, the amount of food waste generated in Singapore has increased by almost 50% in the past 10 years and is expected to increase with the growing population and economic activity, but only about 13% of the food waste is recycled, and the rest is disposed of at the waste-to-energy plants for incineration. It is obvious that food waste if not managed properly would also cause many problems, e.g. contamination of recyclables, odour nuisance and vermin proliferation, thus the food waste management is becoming a pressing challenge worldwide. Although incineration can substantially reduce the food waste volume by 80–90%, it has the drawbacks of high operation cost, generation of hazardous gases and ashes, suggesting that incineration is not an eco-friendly and sustainable approach of future food waste management. On the other hand, in many highly urbanized countries, landfill is no longer a viable option due to the scarcity of usable land. This study developed a holistic approach which was based on the ultra-fast hydrolysis of food waste with the fungal mash rich in various hydrolytic enzymes produced in situ from food waste as well. After the 8-h hydrolytic treatment, the solid residue and liquor were separated. It was found that the produced solid residue can meet all the requirements for biofertilizer in terms of NPK and heavy metal contents, while the separated liquor with high soluble organics concentration was further subject to anaerobic digestion for enhanced biomethane production. About 0.41 kg of biofertilizer with a moisture content of 76.9% and 54.4 L of biomethane could be produced from 1 kg of food waste. This study may lead to the paradigm shift in food waste management with the ultimate target of zero-solid discharge.

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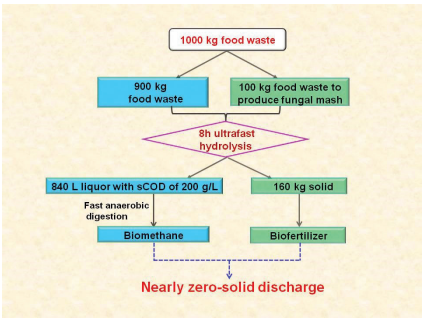

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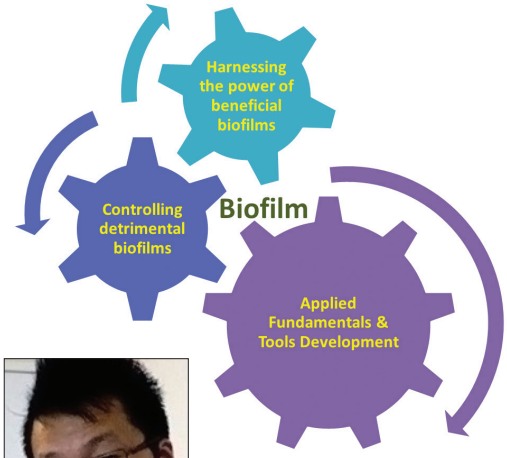
Biofilm Biology-Informed Biofilm Engineering for Environmental Biotechnology

In natural and engineered environments, microbial processes mediated by microbial communities that are associated with surfaces or interfaces (known as biofilms) are ubiquitous. Some biofilms are beneficial and some others are detrimental to the environmental health and engineering applications. My research at NTU (www.bcaolab.org) focuses on biofilm engineering - a highly interdisciplinary research topic at the interface between engineering and microbiology with the goals of mechanistically understanding biofilm-mediated processes and applying insights from biofilm biology to develop environmental biotechnologies for harnessing the power of beneficial biofilms and combating detrimental biofilms.

Here are several examples of my ongoing research work:

(i) Mechanistic studies of the biofilm lifestyle of environmental bacteria and implications
(ii) Engineering biofilms for water purification and chemical synthesis
(iii) Development of novel tools for biofilm studies



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Environmental Chemistry & Materials

Materials for environmental protection and monitoring

Protection and monitoring of natural waters for toxic components is essential for human well-being. Since the content of pollutants occurring in natural ecosystems should be kept as low as possible, there is an ongoing search for analytical methods with ever lower detection limits for detection of pollutants as well as constant search for new technologies for removal of toxins from the environment. Nowadays, environmental analysis is realized by costly and sophisticated instrumentation which requires high maintenance. The routine measurements in most environmental, clinical, and foodstuff samples are not straightforward. Thus, the project will be devoted to exploration of novel materials for environmental protection and monitoring in order to develop more efficient and more sensitive environmental sensors and pollutant removal platforms. In this project, various materials will be developed and studied for the use in chemical sensors or pollutant removal platforms. Those materials, among many, will involve, e.g. different papers and textiles, conducting and non-conducting polymers and nano particles. Primarily use of the material will be towards water based analysis and removal of pollutants, however, gas sensors and air pollutant removal platforms will be also considered. The project is foreseen to establish novel materials and novel application of these materials in sensors and pollutant removal platforms for more efficient and more sensitive environmental protection and monitoring. This interdisciplinary project will promote scientific breakthroughs in the area of material engineering research by development of novel materials as well as breakthroughs in the area of environmental engineering in form of development of novel protection and monitoring environmental systems.

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Sustainable Urban Waste Management: Waste-to-Energy

In Singapore, approximately 3 million tonnes of municipal solid waste (MSW) are annually incinerated in the waste-to-energy facilities, or commonly known as waste incineration plants. The electricity output of a waste incineration plant is only 20-23%. There is high potential to increase this value by utilizing more efficient electricity generation processes. Besides incineration, gasification is another strategy to generate electricity from wastes through a thermochemical conversion process. Gasification can convert the combustible fraction of MSW into gaseous fuel such as syngas. The major economic barriers to adoption of gasification as a sustainable MSW management are the low calorific value of syngas and its high cleaning cost for its suitable use as fuel in gas turbine powered electric generators (with higher efficiency of electricity generation) or as a chemical feedstock. The School of CEE and NEWRI-R3C (Residues and Resource Reclamation Centre) are developing a MSW gasification and syngas cleaning technology that can convert MSW into syngas which can be used to power gas turbines. The project is funded by the National Environment Agency, Singapore. This project aims to develop a cost-effective technology for production and purification of the syngas fuel so that it is suitable for application in combined cycle gas turbine (CCGT). Laboratory studies have shown that the technology can achieve up to 27% net electrical efficiency. This is achieved through increasing the calorific value of the syngas via MSW pre-treatment and optimization of gasification conditions (e.g., enriched air, consistent operation). The produced syngas are treated in an innovative multi-stage purification system to remove impurities such as particles, tar, HCl, and sulphur compounds (H2S and COS) that otherwise will compromise gas turbine robustness. To improve cost efficiency of the syngas purification, a novel catalytic tar removal process have been developed that can convert tar into syngas and other valuable products. The removal of sulphur gases are carried out using metal oxide sorbents at temperatures above 200 °C that can reduce the capital expenses by 15% per kW compared to conventional syngas purification technologies operating below 40°C. A pilot scale syngas purification system will be constructed and attached to a MSW gasification plant for fuel grade syngas production to evaluate the commercial viability of the waste-to-energy gasification process.

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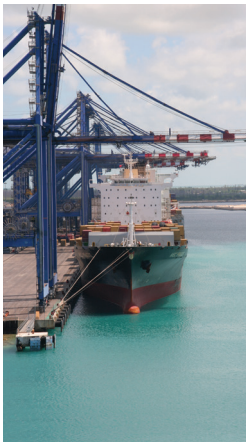
Maritime Logistics, Port Economics and Management

Smart cargo handling equipment and battery management system for port sustainable energy management

The research in Maritime Logistics focuses on methodological and application issues relating to the process of planning the efficient, cost effective flow of freight with an emphasis on sea-freight transport. The research addresses the issues related to the role of ocean carriers in the global supply chain as well as the intermodal interactions between sea-freight and other transport modes. Since about 90% of world trade volume is carried by maritime transport, research in maritime logistics contributes to trade flows and connectivity. On Port Economics and Management, a wide variety of perspectives are drawn from economics, management, technology, strategy and policy. Port studies are closely related to trade, in particular international trade, economic performance and maritime transport. Hence, the research area is very significant for most countries and regions. Singapore is the largest trans-shipment hub in the world. In line with the development of the next generation mega terminal in Tuas, port studies will play a key role contributing to the port's innovation and growth. A key project is "Smart cargo handling equipment and battery management system for port sustainable energy management". The industry collaborator is PSA Singapore – the largest container terminal operator in the world. This project addresses an important research topic of port sustainable Smart cargo handling equipment and battery management system for port sustainable energy management energy management. As a world-class hub port, Singapore is expected to demonstrate its capability in sustainability. Therefore, there is a strong demand for developing a new and effective solution to achieve green port operations and enhance the productivity/growth simultaneously. The major aim of the project is to design and develop a full featured and generic battery management system (BMS) for cargo handling equipment. This generic BMS is able to perform predictive health monitoring and management of installed energy storage system, which is independent of energy storage suppliers. The concept of this project is based on the state-of-the-art supercapacitor technologies which will allow a 24/7 fully electric solution. The final prototype that is envisioned will be able to outperform the existing competing technologies in terms of functionalities. The new concepts and methods used in this project will drive future research and be widely applicable in various seaport terminals in Singapore and beyond. The research and the knowledge created contribute to maintain Singapore's competitive advantage and its status as a hub port. The project deliverables will also raise the R&D capability profile of Singapore as a maritime knowledge hub.



Another key project is "Greenhouse gas emission from international shipping: strategies and impacts". Recent climate changes have had widespread impacts on human and nature systems. International Maritime Organization (IMO), as the United Nations (UN) specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships, has addressed the importance of GHG emissions by international shipping. Singapore, being a large flag state, global hub port, large bunkering port, international maritime centre and active participant at IMO, has vested interests in the development of GHG emission control and monitoring efforts at IMO and other forums. Such efforts will have implications on stakeholders in the maritime industry, other businesses and consumers, who primarily use shipping as their main mode of transportation to move or receive materials and products around the world. This project aims to study the implication on the various approaches and pace our strategy accordingly to allow the Singapore shipping community, businesses and also consumers to adapt to the new changes since shipping will remain the main mode of transport for world trade.

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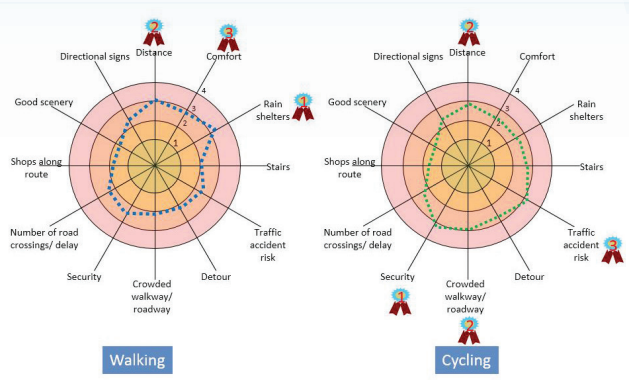
Research Centres/ Institutes

Centre for Infrastructure Systems (CIS)

The Centre for Infrastructure Systems (CIS) was established within the School on 1 June 2006. It is the merger of the Centre for Advanced Construction Studies (CACS), Centre for Transportation Studies (CTS) and Geotechnical Research Centre (GRC). The aim of the merger is to allow a wide range of expertise in infrastructure development to be available within one Centre as well as to achieve synergies among the various specialized fields. The mains areas of focus of CIS are (a) Construction Productivity and Management and (b) Transportation and Infrastructure. The Centre developed applications in Building Information Modelling (BIM), developed traffic management tools, calibrated design parameters for transport infrastructure, established walk-ability and cycle-ability indices, characterized road user's adaption; assessed environmental impact of transport. CIS has undertaken projects in the areas of:

Factors affecting choice of walking/cycling



1-Not important, 2-Somewhat important, 3- Important, 4-Very important

1) Building Information Modelling (BIM);
2) Automation in Construction;
3) Lean manufacturing and production of precast concrete components;
4) Transport demand management: road pricing tools; parking studies;
5) Active mobility, by walking: infrastructure design parameters; walk-ability index; by cycling: impact of cycling facilities; cycle-ability index; cycling demand;
6) Motorist's adaption to road infrastructure: driving in long tunnels; impaired driving (e.g. elderly drivers); vehicular emissions and energy efficiency.

Centre for Usable Space (CUS)

The Centre for Usable Space (CUS) was established in March 2015. The mission of CUS is to provide leadership in developing innovative solutions and technologies for space creation and management and for liveable urban centres and mega-cities. CUS strives to host research programmes that focus on: (i) coalition of research centres and groups to carry out upstream scientific research, and (ii) collaboration with local and international partners to conduct applied R&D work.

The CUS's research focuses include:

1) New construction materials including biocement made using wastewater sludge and other waste materials, biogrout, watertight sheet piles, and new fill materials for land reclamation;
2) New measuring and monitoring systems. These include invention of system-on-chip system, underground wireless system, new ground investigation methods and technologies using GEM3 as a platform;
3) Establishment of a Data driven, 3D visualization based underground construction management system. Comprehensive ground investigation data and geotechnical monitoring data will be processed together to allow 3D visualization in a way similar to the BIM system.
4) Space creation technologies. These include waterfront city and waterfront living, new land reclamation methods, monitoring and remediation of aging infrastructures, underground resource mapping and utilization, and combined chemical and mechanical blasting methods for tunnels.

CUS is also actively in establishing research collaboration and reaching out to industries. We have ongoing research collaborations with MIT, UC Berkeley, Hong Kong University, Chongqing University, and British Geological Survey. We have been organizing seminars and public lectures including the COE Distinguished Lectures on Urban Solution in 2015 and 2016 and a 2-day Symposium on New Technologies for Urban Geotechnical Constructions at NTU@One-North from 26-27 July 2017.

Nanyang Centre for Underground Space (NCUS)

Space is one of the key constraints to Singapore's economic and social development. The establishment of the Nanyang Centre for Underground Space (NCUS) in Dec 2011 aims to lead scientifically Singapore's deep underground space development. The major research focus of NCUS includes:

a) conceptualize, plan and undertake feasibility studies for large scale deep underground space utilization in Singapore;
b) lead technology development and innovation for underground space development;
c) support world-class researchers to perform high impact research for underground development;
d) become the leading centre for technology solutions in its domain of deep underground space utilization.

NCUS is very active in interdisciplinary research and industry driven project. NCUS's project teams include faculties on water/environment area within CEE as well as NBS/SSS faculties on social/psychological area, and our agency/industry partners include JTC, PUB, Hyundai construction, SINTEF (Norway), and Kajima (Japan). Besides the NTU campus underground concept study for a showcase of underground usage on NTU Yunnan campus, the centre has currently the following research projects:

- Structural and Social Impact of Rock Blasting on Nearby Environment
- Microbiological, Chemical and Physical Interactions in Rock Cavern Water Storage
- Biogrouting for underground construction
- Joint SINTEF(Norway)/I3C/NCUS project on grouting technology
- Joint Hyundai/NCUS project on Development of a Construction Management and Preliminary Design System for Rock Caverns
- Joint NCUS/Kajima collaboration on rock bolt modelling

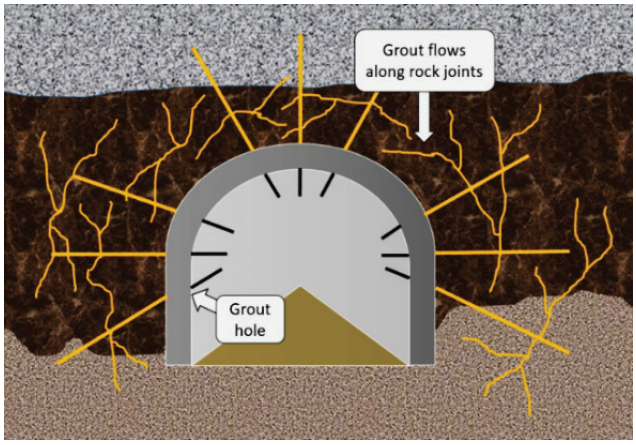


Fig. 1 Grout flow model for rock grouting

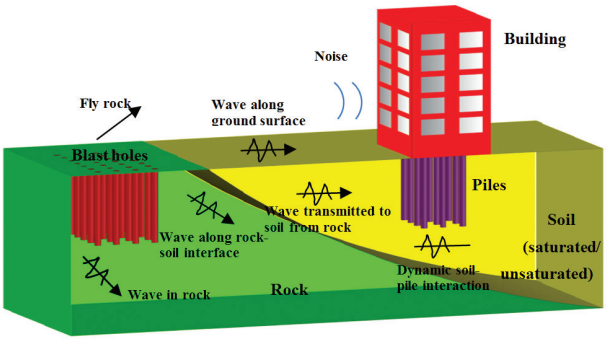


Fig. 2 Rock blasting field test (Gali Batu)

NTU-JTC Industrial Infrastructure Innovation Centre (I3C)

The NTU-JTC I3 Centre was jointly established by JTC Corporation (JTC) and NTU in August 2011 to promote the growth and development of economically viable and sustainable industrial infrastructure solutions in Singapore. In alignment with the general objective of developing ideas and solutions to create a vibrant industrial infrastructure research ecosystem, the centre's activities are focused on the following key areas:

- Conduct Research, Development and Demonstration (RD&D) projects
- Strengthen technical bench strength
- Tap on talent pool of NTU students
- Manage research, outreach & building relations

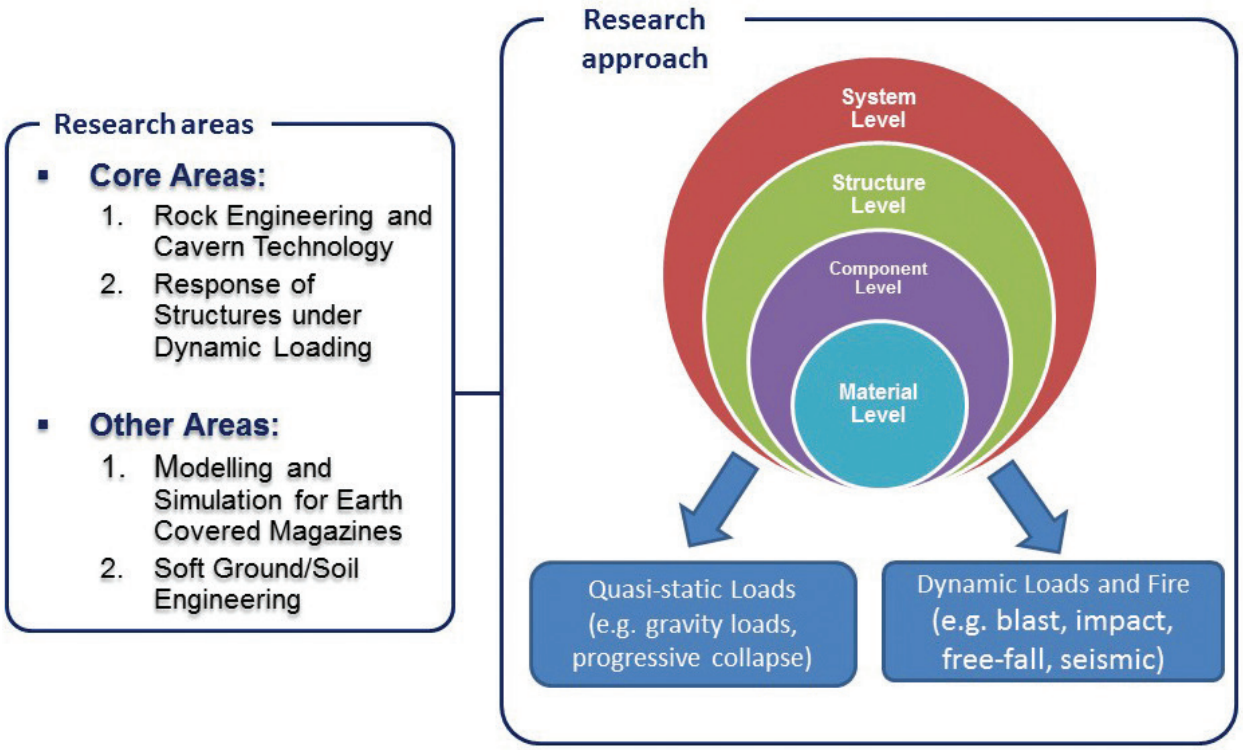
In particular, the centre's research thrusts are in four areas, namely reclamation & marine infrastructure, sustainable infrastructure, underground infrastructure, and infrastructure systems & materials.

Protective Technology Research Centre (PTRC)

The MINDEF-NTU Protective Technology Research Centre (PTRC) is an inter-disciplinary research centre, which was established on 29 September 1998 with an MoU signed between MINDEF and NTU. Hosted in CEE, PTRC provides the necessary focus for joint R&D efforts in dynamics and protective engineering involving Faculty and researchers from CEE and MAE. The R&D capabilities of PTRC are listed as follows:-

- **Core Areas**
  - Rock Engineering and Cavern Technology
  - Response of Structures to Dynamic Loading
- **Other Areas**
  - Soft Ground / Soil Engineering
  - Modelling and Simulation for Earth Covered Magazines

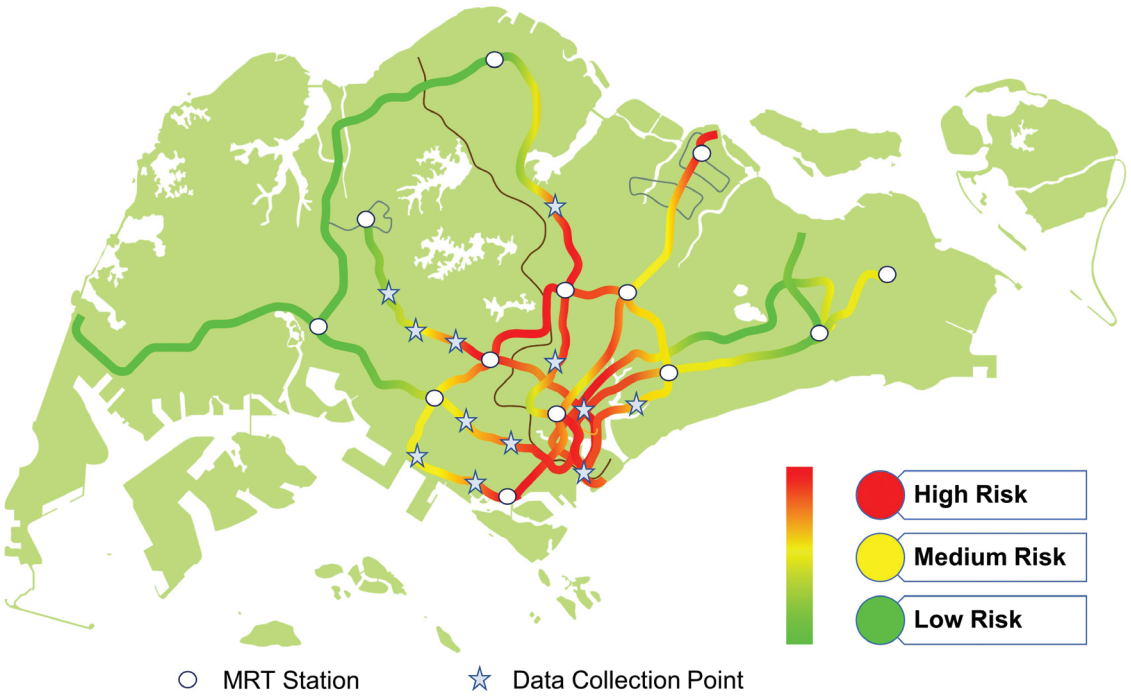
Some of the projects were on the effects of dynamic, explosion or blast loading on blast doors, foundations of civil defence shelters, underground facilities and aboveground structures. These research projects involved both numerical simulations and experimental investigations on the effects of high-intensity transient dynamic loading on soil and rock media, as well as on structural components and systems. Recently PTRC has been awarded a research project by HDB (~$4.8 million). The objective of the project is to develop a smart integrated construction system for the construction industry. PTRC is also working on a project with DSTA on Fibre Reinforced Polymer (FRP), with the objective of developing numerical models to simulate the behaviour of FRP-strengthened RC walls subject to near-field blast effects.



Transport Research Centre @NTU (TRC@NTU) – LTA

With the collaboration between Land Transport Authority of Singapore (LTA) and Nanyang Technological University (NTU), Transport Research Centre @ NTU (TRC@NTU) was set up in November 2015 as an initiative to further mobility research for paving the way for Singapore's future land transport system.

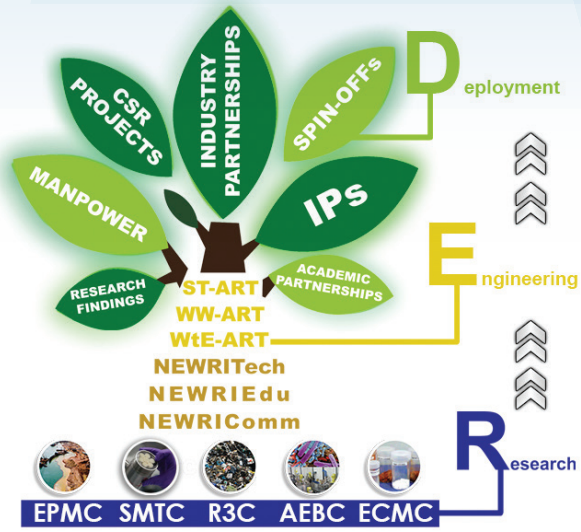
It is the Centre whereby LTA will fund projects to enhance knowledge and drive innovation into specific focus areas, such as, active mobility; electro-mobility; geotechnical and tunnelling engineering; and MRT system and condition monitoring. To realise this vision, LTA has signed a number of agreements with NTU to mobilise series of transport research projects. As expected by LTA, TRC@NTU is actively establishing its R&D road-maps and working on research to help LTA to create a well-connected land transport system with less reliance on cars, which meets diverse needs of commuters while pushing the boundaries of Singapore's research efforts in the areas of future mobility. The Centre has in fact provided a multidisciplinary platform to 'glue' all the NTU professionals of variety backgrounds to work together with LTA to conduct research and technical trials for innovative technologies in the transport industry. The Centre involves principal investigators nd researchers from all over the university such as School of Civil and Environmental Engineering, School of Mechanical and Aerospace Engineering, School of Electrical and Electronic Engineering, School of Social Sciences, and School of Art, Design and Media.



GIS-based Lifecycle Durability Assessment of Underground Infrastructures Project at TRC@NTU

Nanyang Environment & Water Research Institute (NEWRI)

NEWRI develops environmental solutions, based on transdisciplinary scientific knowhow and application experiences. We are globally ranked among the top research organisations in the environment & water domain. NEWRI has teamed with industries worldwide as a solutions provider. We are at the forefront of fundamental scientific research which provides the basis for our innovations. Our 400-strong scientific research and engineering team is led by globally ranked thought leaders in the domain. NEWRI does not stop at research but continues into de-risking its technologies, guided by our Research-Engineering-Development (RED) philosophy. NEWRI's engineering cluster (ST-ART, WW-ART and WtE-ART) has the capacity to engineer at full-scale. NEWRI is structured to create solutions for community and industry. As cities grow, emerging challenges include aged waste treatment infrastructure, space constraints for waste management, changing wastes load and characteristics, and the need for tailored solutions. NEWRI's know-how have been deployed in the real setting and at full-scale, through NEWRI's commercial and CSR projects. (Carried out by NEWRITech and NEWRIComm respectively).



Institute of Catastrophe Risk Management (ICRM)

The Institute of Catastrophe Risk Management (ICRM) was officially launched on 21 January 2010 and will be the first multi-disciplinary and leading catastrophe risk management research institute of its kind in Asia. ICRM has its focus on Asia because Asia has traditionally suffered the most in terms of human fatalities and economic loss from natural catastrophes, while being the least prepared region of the world to mitigate such risks. The Institute aims to help the regional and international communities better understand the characteristics of risks related to natural disasters such as earthquakes, tsunamis, volcanic eruptions, typhoons, floods, droughts, as well as non-traditional risks which include infectious diseases and terrorism.

Through ICRM, NTU faculty and researchers will work on integrated risk assessment and management of natural hazards as well as man-made threats. Such work will be conducted in collaboration with research organisations worldwide in the risk management domain as well as insurers, reinsurers and risk modellers of the finance industry, and insurance/reinsurance industry and associations. ICRM aims to develop Asian catastrophe risk models and build up industry benchmarks and indices to reflect the uniqueness of Asian catastrophe risks.

ICRM is envisioned to be a key player in Singapore's effort to further strengthen its position as a major international finance hub, especially in the insurance and re-insurance areas. The models and tools developed by ICRM will allow governments, public organisations and the industry to analyse potential losses, and thus develop risk-management strategies.

Decision makers in Asia in particular will be able to utilise such tools to identify vulnerabilities, prepare for a range of possibilities and allocate resources. ICRM will undertake the state-of-the-art multi-disciplinary research work which leads to better understanding, communicating and managing of major disasters, both natural and non-traditional, and thereby provides major positive impacts on the society.

NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

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Information is correct at time of printing (Dec 2018)
For updates, please refer to school website.