Recent Foci on Concrete Technology – from Constituents to Compliance

Ir Jenny F Yeung
Chairperson, Steering Committee on Concrete Technology

https://www.discoverhongkong.com/hk-tc/explore/attractions/best-ways-to-marvel-at-iconic-victoria-harbour.html

Contents

- Constituents
  - SCM - GGBS
  - Aggregates – Volcanic Rock
- Innovative Concrete Mixes
- Testing and Compliance
  - Automated Testing System
  - Maturity Method


https://www.structuralguide.com


https://gcpat.com/

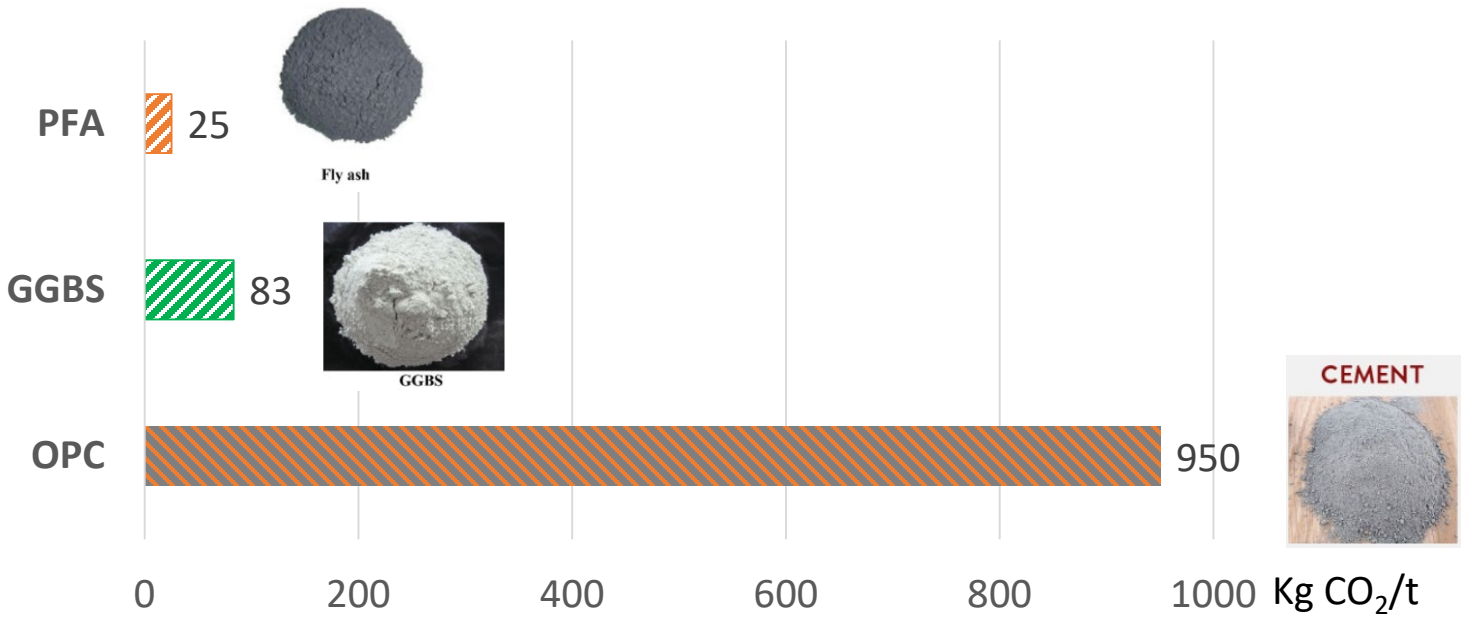

https://unsplash.com/photos/white-concrete-bridge-over-water-lfP2hu6Hpb0

Wider Use of GGBS Concrete

Comparison on Carbon Emission among OPC, PFA and GGBS

Cementitious Materials

(Data from Inventory of Carbon and Energy, Bath University)



Concrete

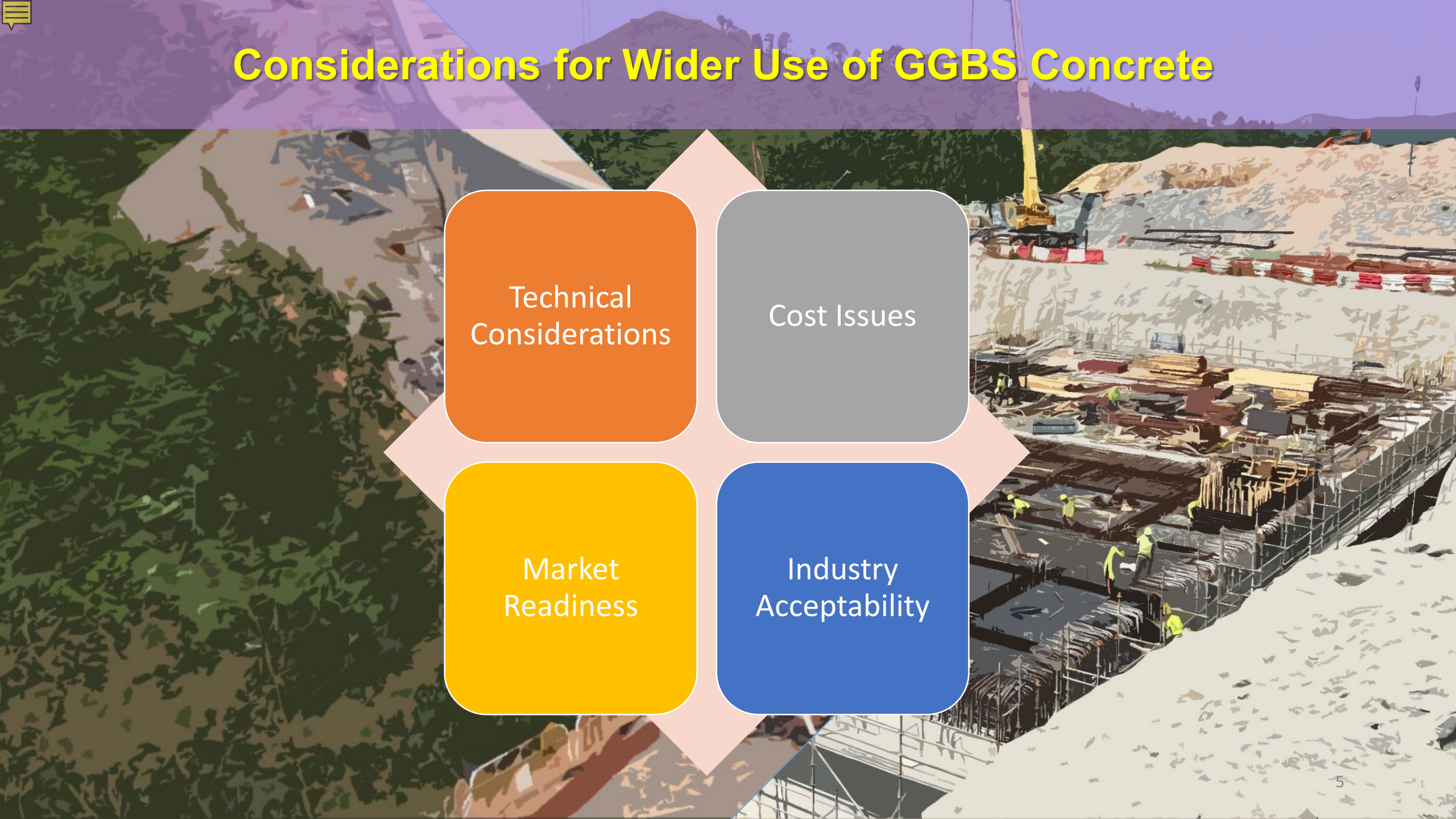
(Cementitious Materials only)

Type of Concrete	OPC Concrete	PFA Concrete	GGBS Concrete
SCM Replacement ratio	na	30%	60%
CO_2 Emission (t/m^3 of concrete)	0.380	0.269	0.172

Reduced around 55%

Reduced around 36%

Considerations for Wider Use of GGBS Concrete



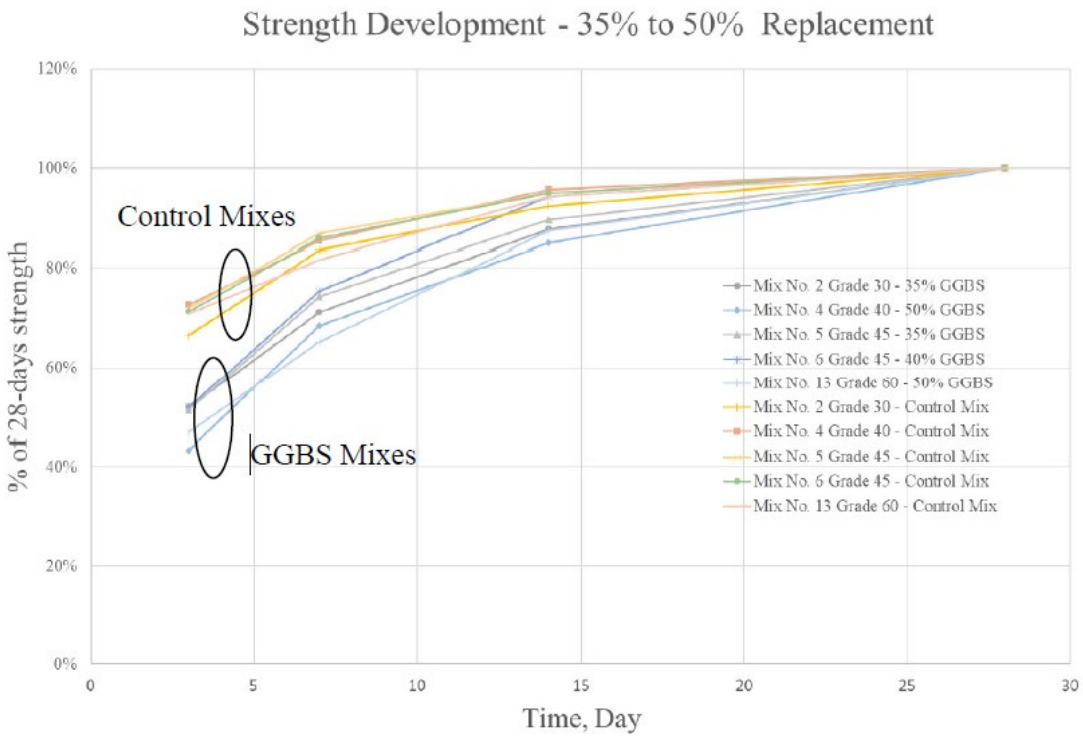
Technical Considerations – Comparison of Strength Development

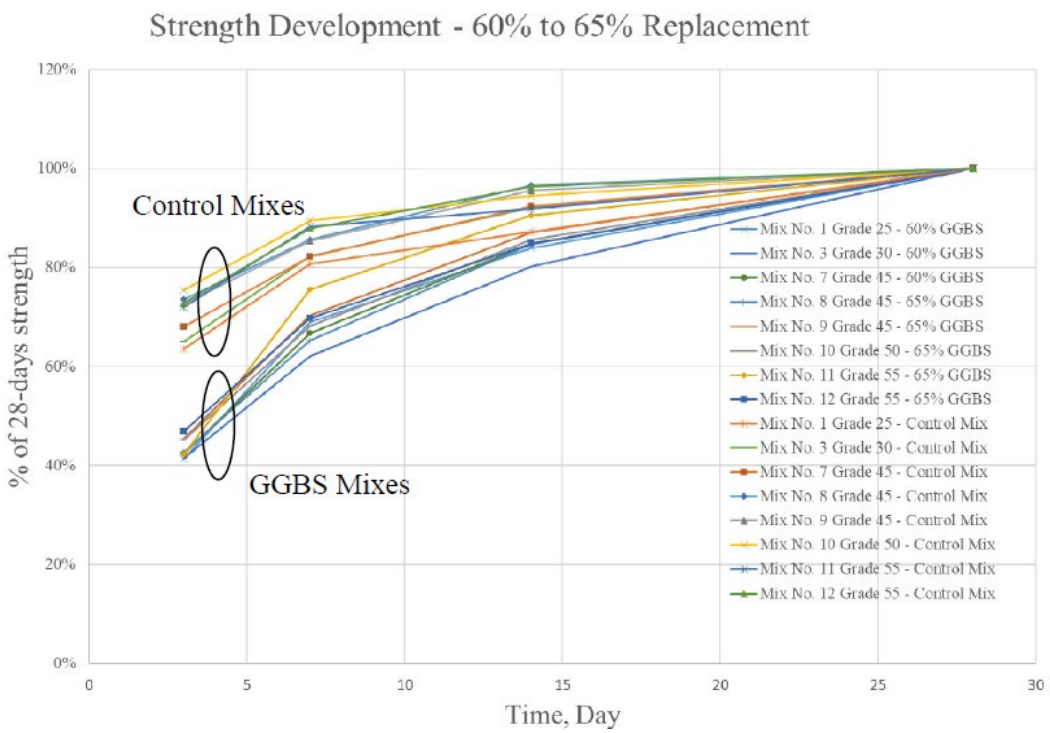
Grade Strength (MPa)	3-Day Strength				7-Day Strength				Average 28-Day Strength, MPa		Average 56-Day Strength, MPa	
	Average, MPa		Average / Grade Strength		Average, MPa		Average / Grade Strength					
	GGBS Mix	OPC Control	GGBS Mix	OPC Control	GGBS Mix	OPC Control	GGBS Mix	OPC Control	GGBS Mix	OPC Control	GGBS Mix	OPC Control
25-30	26.5	37.9	87%	134%	37.2	47.9	131%	169%	55.1	58.2	60.4	61.0
40-50	36.0	52.6	80%	117%	54.6	62.6	122%	139%	78.1	73.2	83.2	77.5
55-60	35.8	56.8	63%	100%	55.3	68.0	98%	120%	79.1	79.0	83.9	85.5

❖ Compressive strength of 13 GGBS concrete mixes from PWPs tested and compared to OPC concrete mixes

- 3-day strength is already about 63 to 87% of Grade Strength for different GGBS concrete mixes
- The 7-day strength is about 98 to 131% of Grade strength for different GGBS concrete mixes.
- The performance of the GGBS mixes in terms of 28- and 56th day strength are comparable, or even better for some samples than the corresponding OPC control mixes.

Technical Considerations – Comparison of Strength Development





- The early strength development (3-day and 7-day strengths) of the GGBS mixes are slower than the OPC control mixes.
- The actual strengths achieved at such early stages are considered sufficient for general civil and geotechnical engineering works.

Current Technical Requirements and Policies (Public Works)

- Recommended specification for reinforced concrete in marine environment endorsed by SCCT in 2000.

- PWCL Study on GGBS in 2007
  - Durability and strength development
  - Replacement ratio – 30-80%
  - GEO Report 258 (2011)
- General Specifications (GS) for Civil Engineering Works 2006 amended in 2012
  - GGBS as supplementary cementitious material (SCM)
  - Allow replacement ratio 35-75%, otherwise to be approved by the Engineer

- ArchSD GS for Building (2012)
  - Max replacement ratio 40%
- Housing Specification Library
  - Use of GGBS in precast façade (2012) 35% replacement ratio
  - Use of GGBS in precast staircase (2016)
  - Exemption for period from Dec to Mar

SECTION 16 – CONCRETE and JOINTS IN CONCRETE
16.12(6) Either PFA or **GGBS** shall be used in concrete of all pile caps and substructure construction where the concrete member is **thicker than 750 mm**.
16.14 When GGBS is incorporated as a separate cementitious material, its proportion shall be between **35% and 75%** of the total cementitious content for normal concrete.
SECTION 21 – SPECIFICATION FOR REINFORCED CONCRETE IN **MARINE ENVIRONMENT**
21.2.7 (b) … if **GGBS** is used instead of PFA, the proportion of GGBS replacement shall be within **60-75%** range by mass of the cementitious content.

Current Technical Requirements and Policies (Private Works)

4.2.5.5 Use of pulverised-fuel ash (pfa)and ground granulated blastfurnace slag (ggbs)

Where required, either pfa or ggbs should be exclusively combined with Portland cement. If blended cement with pfa or ggbs is used instead of Portland cement, further pfa or ggbs should not be added as a cement replacement. The concrete mix recommendations given in table 4.2 apply also when combinations of Portland cement with pfa or ggbs are used.

The usual range of pfa or ggbs content by mass of the total cementitious content should be:

(a) 25% to 35% for pfa

(b) 35% to 75% for ggbs.

A higher percentage may be used in special applications but will require expert advice and stringent site control.

The durability of the concrete made with these materials can be considered as being equal to that of Portland cement concrete, provided that the pfa or ggbs concrete complies with the same grade as would be achieved by the Portland cement concrete.

Provision in Using the GGBS concrete in COP for Structural Use of Concrete 2013 (2020 Edition)

Recent private jobs using GGBS Concrete

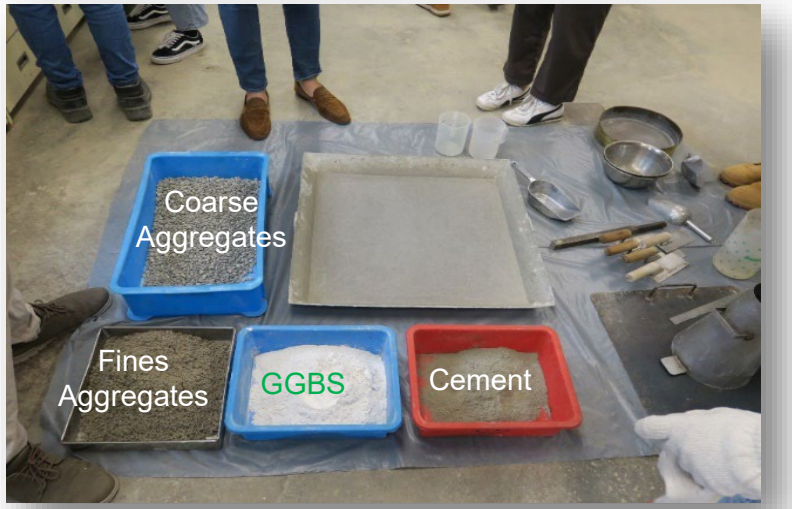
1. Slag Storage Building in Green Island Cement – BD 3/9223/16
2. X-Ray Room in United Christian Hospital – BD 3/4018/13

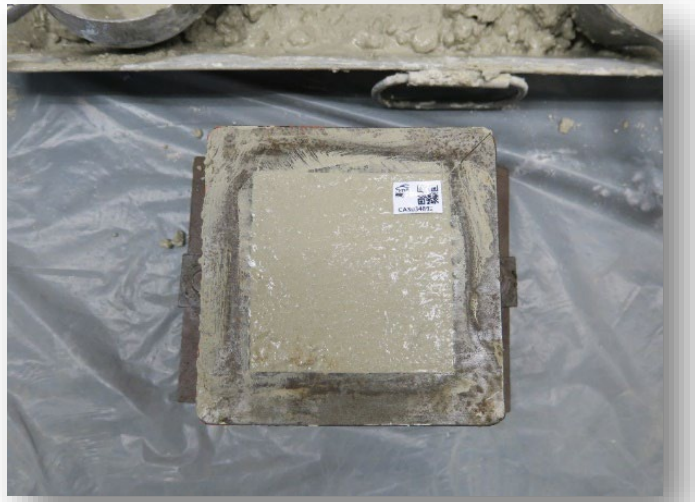
Constructability of GGBS Concrete in Piling Works

@2005 Gammon Construction Ltd.

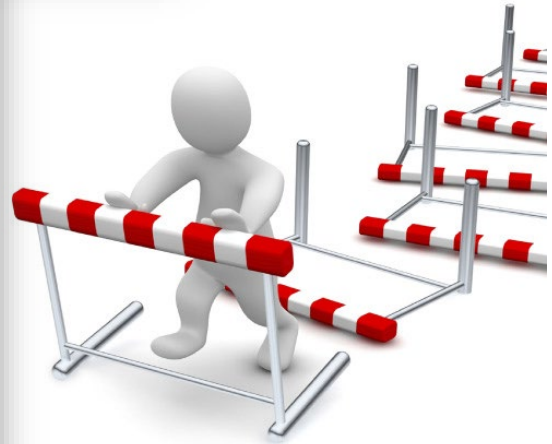
http://www.tremie.co.uk/

https://www.geodynamics.net





Strategies for promoting wider use of GGBS Concrete



Use of Volcanic Rock Aggregates

Feasibility of Adopting Volcanic Rock for Concrete Aggregate

Volcanic rock and rhyolitic dyke rock **50%**

Seldom used as aggregates for concrete production due to the potential of

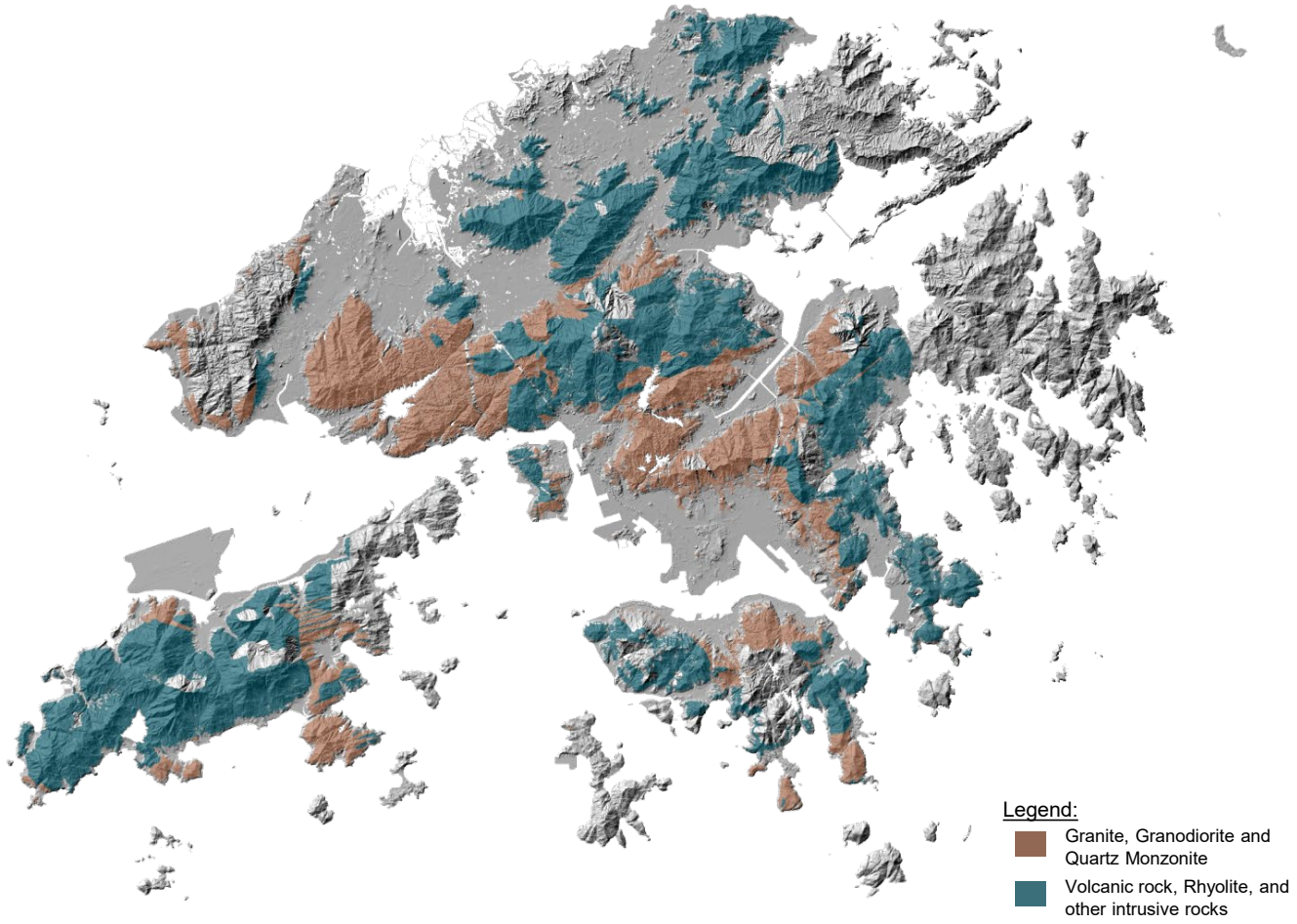
alkali-silica reaction (ASR)

Very limited choice of

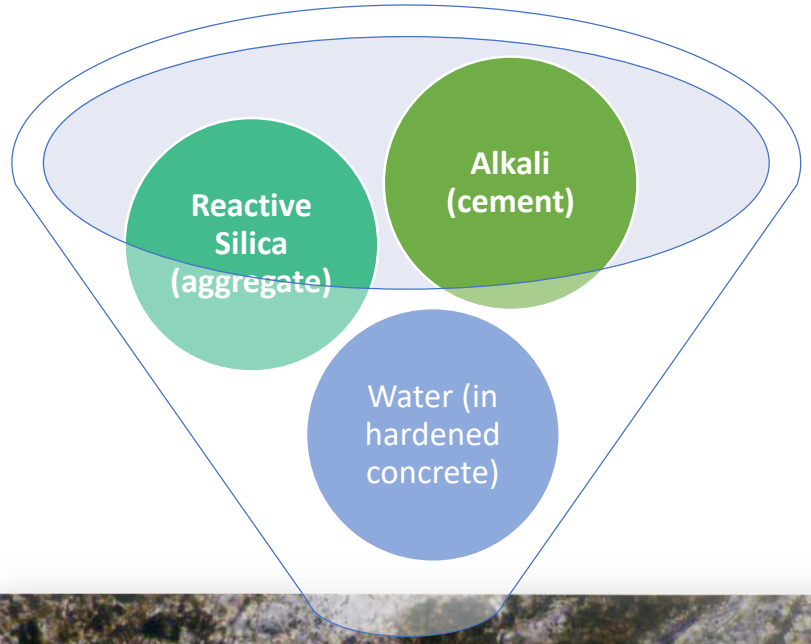
quarrying site

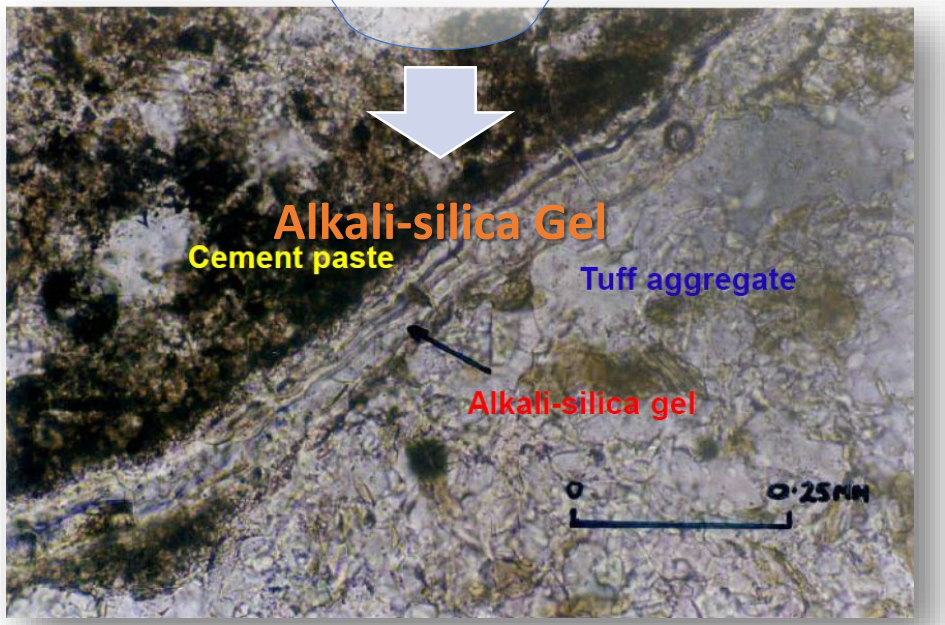
Waste of local

rock resources



Adverse Effect of ASR to Concrete Structures





Shek Wu Hui Treatment Plant,
Map-like cracks identified in 1991

Hill Road Flyover,
Cracks identified in 1998

Technical Requirements for ASR Prevention

Reduce alkalis present

- Reduce cement content
- Use low alkali cement
- Use SCM e.g. not less than 25% PFA, GGBS, silica fume

Avoid reactive silica

- Test for aggregate reactivity
- Disallow reactive aggregate

Prevent water ingress

- Apply water proofing measures
- Reduce humidity in hardened concrete
- Use SCM to reduce permeability

GS for Civil Engineering Works (Edition 2020)

SECTION 16 – CONCRETE and JOINTS IN CONCRETE

16.08 (5) **Aggregates** in the alkali "**Reactive**" category shall **not be used** …

16.12 (8) … **reactive alkali content** …, expressed as the total equivalent sodium oxide (**Na_2O**) …shall **not exceed 3.0 kg/m3** of concrete

Project Administration Handbook for Civil Engineering Works (PAH)

PAH Appendix 5.9 – CONTROL OF ALKALI SILICA REACTIONS IN CONCRETE

Para. 4 … The recommended control framework is given in Appendix H of GEO Report No. 167 …

H.2 CONCRETE MIX DESIGN FRAMEWORK

H.3 AGGREGATE SUPPLIES FRAMEWORK

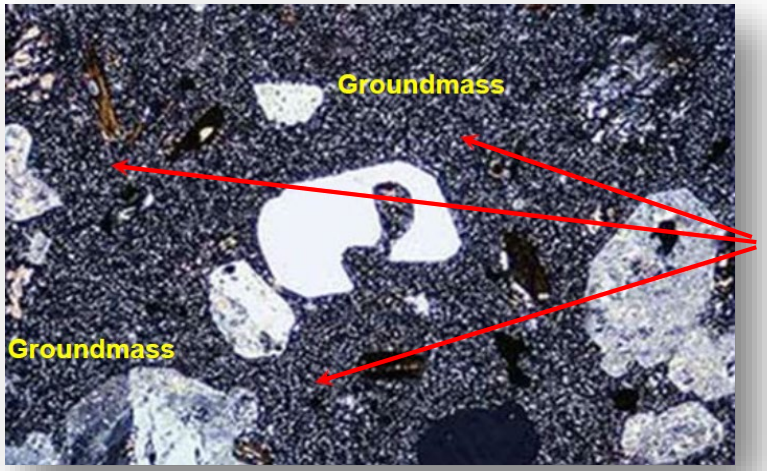
PNAP APP-74

Equivalent sodium oxide < 3kg/m3

https://www.skyscrapercenter.com/building/international-commerce-centre/137

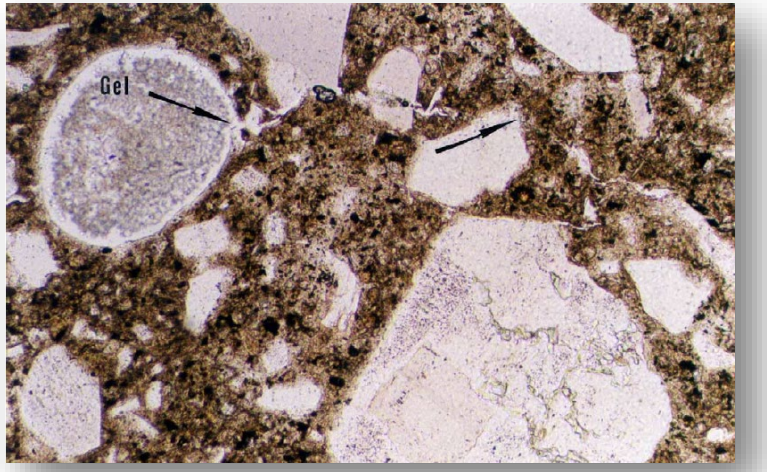
Site Specific Tests on Effects of SCM in Suppressing ASR

Petrographical Examinations



Thin section of aggregate

Microcrystalline to cryptocrystalline quartz



Thin section of concrete prism

UAMBT - Section 22 of CS1:2010

- Measurement of the expansion (14 days) of mortar-bars immersed in NaOH solution at elevated temperature.

CPT - Section 23 of CS1:2010 with modification

- Measurement of expansion (52 weeks) of concrete prism

Comparison of CPT Results of Three Sites

Cement replacement level	Tuff[1] (Anderson Road)	Tuff[1] (Lam Tei)	Tuff (Tsing Yi North)
0% (Norcem only)	**0.11%**	**0.12%**	**0.075%**
25% PFA	-	-	0.005%
35% PFA	0.00%	0.00%	-0.005%
30% PFA + 5% CSF	0.00%	-0.01%	0.000%
50% GGBS	0.01%	0.00%	0.010%
70% GGBS	0.01%	0.00%	0.005%
50% GGBS + 5% CSF	0.00%	0.00%	0.000%
0 % (ASR Inhibitor)	-	-	0.010%

[1] Reference: GEO Report No. 354

Expansion After 52 Weeks (%)	Potential Reactivity
< 0.05	Non-reactive
0.05 to 0.10	Potentially reactive
> 0.10	Reactive

Innovative Concrete Initiatives

Exploration of Innovative Concrete Mix and Production

Light weight concrete mixes

https://www.bd.gov.hk/en/resources/codes-and-references/modular-integrated-construction/index.html

Use of waste glass powder to replace cement

Carbon negative cement

CARBON CURE

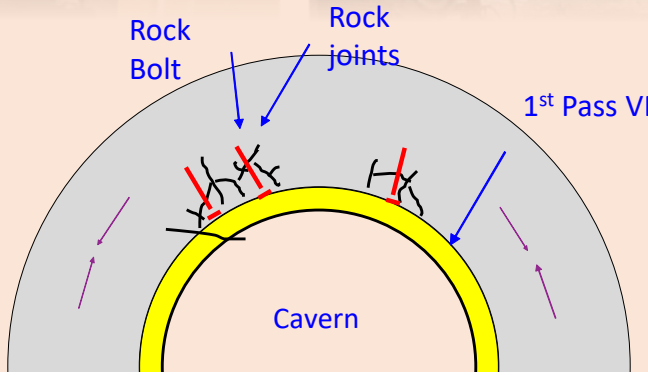
Carboncure technique

Accelerated Carbonisation

Decarbonisation Technologies

Development and Applications of Innovative Sprayed Concrete

Vibration Resistant Sprayed Concrete (VRSC)



Fibre-reinforced Shotcrete

https://shotcrete.org

https://www.avalonstructural.com

https://www.romangunite.com


https://www.giatecscientific.com/

Testing and Compliance of Concrete

Compressive Strength Tests for Concrete Compliance

Construction Standard CS1:2010	• Guidelines for sampling and testing methods • Concrete cubes of 100 or 150 mm
GS for Civil Engineering Works GS2020	• Acceptance criteria for public works • Pairs of cubes tested at 28 days for compressive strength
CoP for Structural Use of Concrete	• Acceptance criteria for private works • Pairs of cubes tested at 28 days for compressive strength

Conventional Manual Testing Procedures

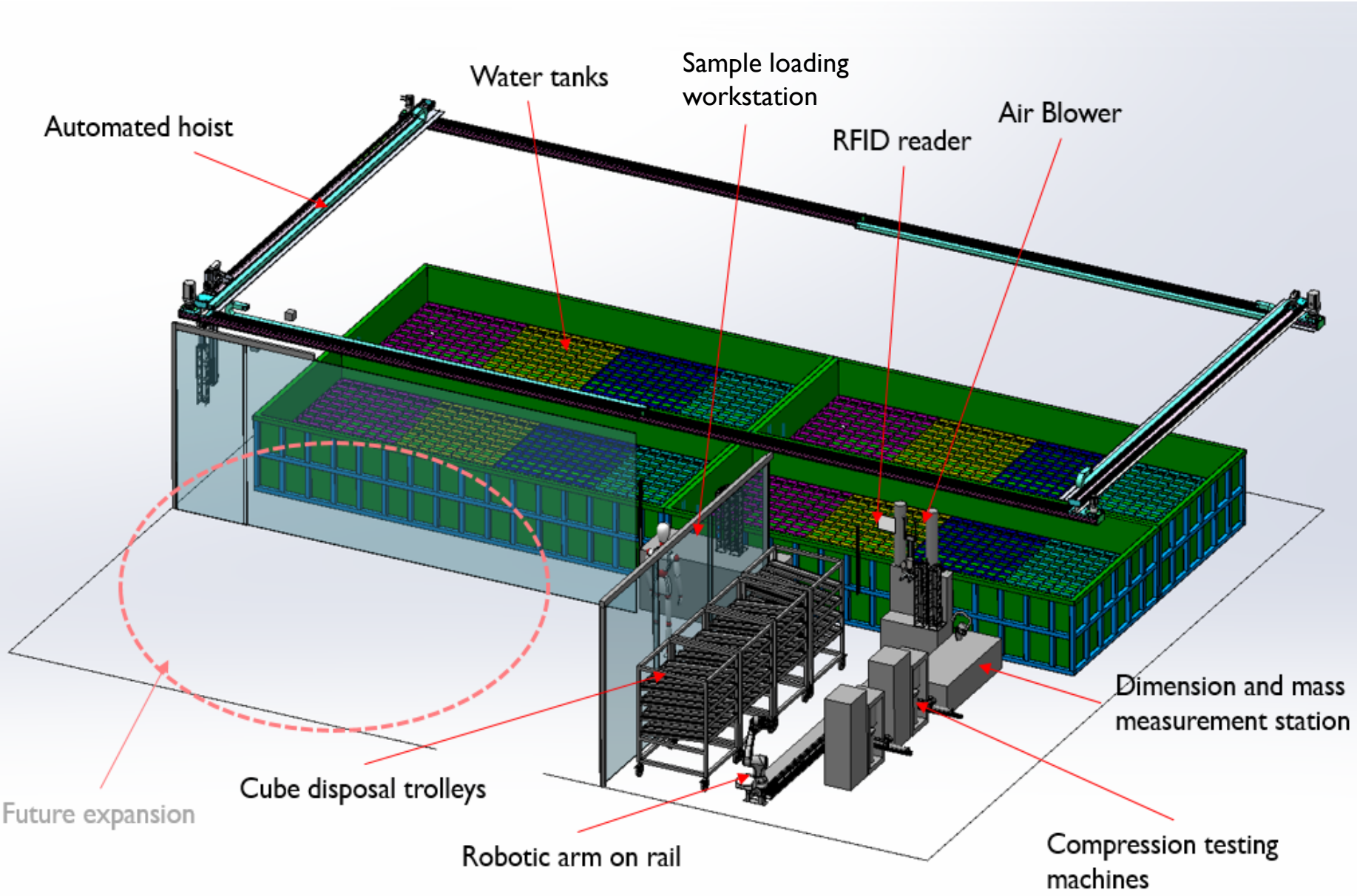
Measuring sample mass

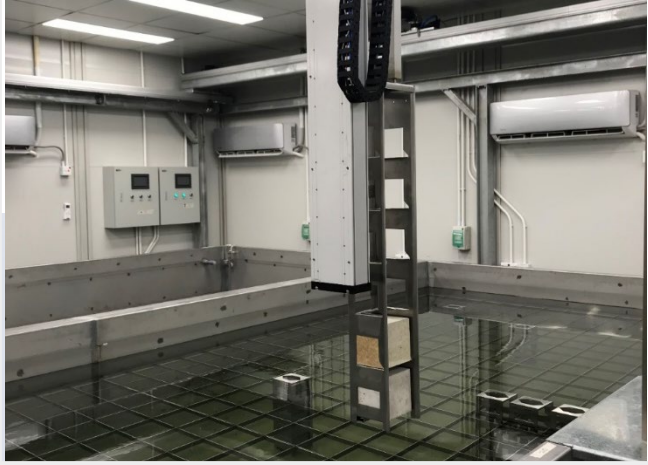

Placing test samples into curing tank


Measuring dimension using caliper


Placing samples onto compression test machine

Automated System for Concrete Cube Testing

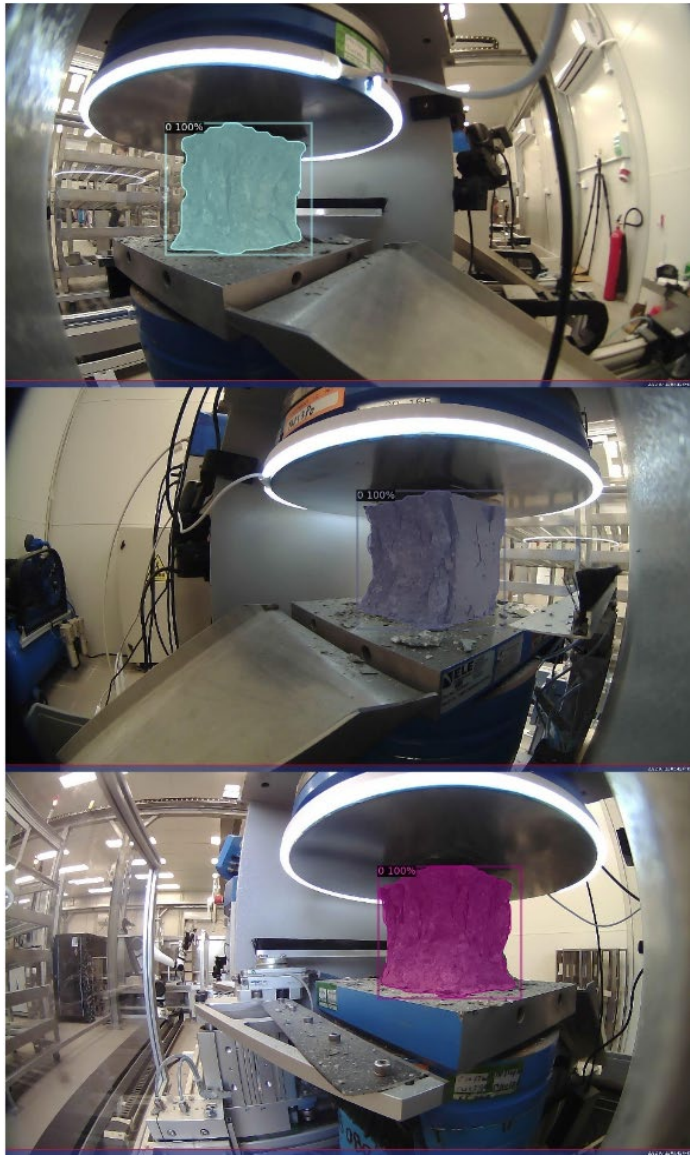




Applications of Advanced Technologies

- Radio Frequency Identification, Custom-made telescopic hoist, 6-axis robotic arm with movement accurate to 0.05mm
- Newly developed computer vision algorithm to identify the fracture mode of a tested concrete cube by the Artificial Intelligence

Identification of fracture pattern



Benefits of Automation

自動化系統檢石屎磚壓力鋼筋拉力

工務試驗所測試效率提高60%

記者：蔡思宇

土力工程處轄下的工務試驗所，今年開始使用兩套自動化測試系統，測試石屎磚壓力和鋼筋拉力。處長張偉文表示，系統投入運作後，不但可以即日得出測試結果，提高試驗所生產率和效率六成，而且測試的精準度也更獲保證。

兩套系統包括由該部門自行研發出的「自動混凝土磚測試系統」，可覆蓋整個石屎磚測試程序，另一套則是土力處引入的全港首套「自動鋼筋測試系統」。

張偉文接受專訪時指出，傳統的石屎磚和鋼筋測試，需要使用人手搬運相當重的石屎磚和鋼筋樣本，到不同的儀器進行測試，以及以人手進行很多的樣本準備及測試步驟，涉及大量體力處理操作。由於自動化測試系統能夠以起重臂和機械臂，取代人手進行所需步驟，可以減少人手體力處理操作，提高工作人員職業安全和健康。

減少人力提高安全

他指出，工務試驗所每年進行約六十萬項測試，當中石屎磚壓力測試及鋼筋拉力測試已佔近半。由於石屎磚的測試量龐大，每年催政府工務工程的測試量已超過二十萬次。他說，「自動混凝土磚測試系統」，是透過電腦控制整個測試程序。每一項測試完成後，所有測試數據會自動即時上傳電腦。同樣，鋼筋的測試需求亦十分龐大，每年催政府工務工程的鋼筋拉伸測試量已超過三萬次。

保證測試精準程度

張偉文強調，使用該兩套系統主要目的，不是為了壓縮時間，因為工程規劃在某些步驟中，有固定的時間需求，所以測試時間並不是整個工程時間的決定因素。自動化測試系統可以最大程度上，保證測試的精準程度，並且記錄所有的測試過程。他表示，自動化測試是客觀測試的結果，可以降低人為出錯的機率。他指出，兩套系統今年開始運作，目標是「自動混凝土磚測試系統」的運用，估試驗所邇測試的兩成，「自動鋼筋測試系統」的運用，則接近一半。

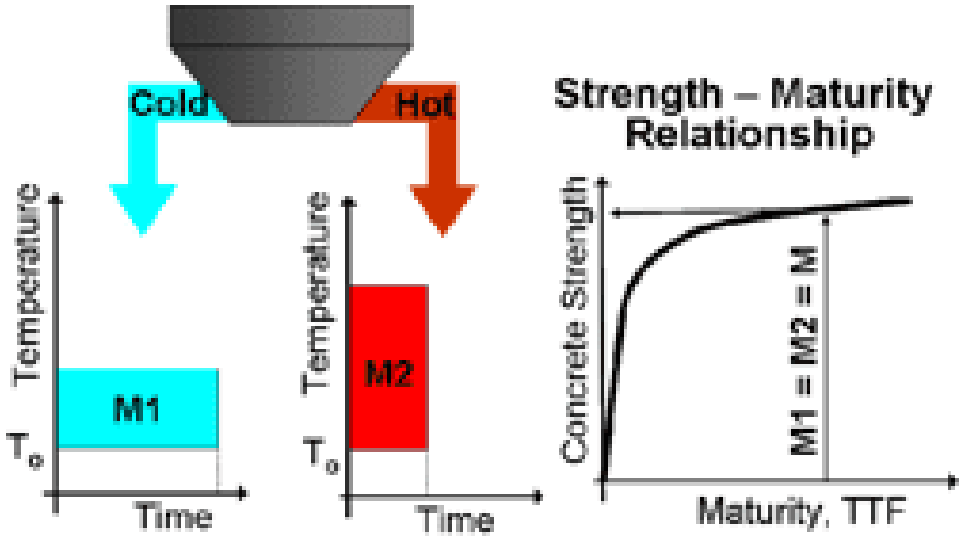
至於未來會否全面使用自動系統代替人力，張偉文表示將視乎情況而定，但最終仍希望保留小量人力。他透露，「自動混凝土磚測試系統」成本約九百七十萬元，「自動鋼筋測試系統」成本約六百多萬元，兩套系統每年的保養維修費合共約一百萬元。兩套系統均採用太陽能發電，減少碳排放。

土力工程處處長張偉文指，自動化測試系統即日得出測試結果，測試精準度獲保證。左圖：系統會把測試數據即時上傳電腦。 梁文輝攝

Maturity Method for estimating concrete early strength

Construction Industry Council

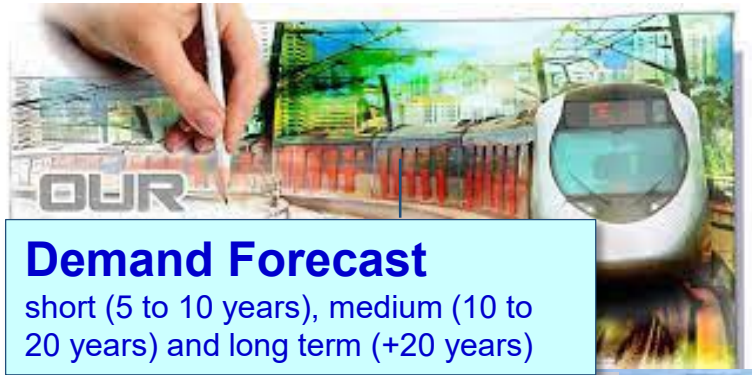
Construction Industry Council



https://eng.auburn.edu/files/centers/hrc/930-590-2.pdf

Concrete Demand and Supply Study

Supply Chain Review
concrete batching plants, products delivery, other elements in supply chain



Demand Forecast
short (5 to 10 years), medium (10 to 20 years) and long term (+20 years)

Assessment of Supply Adequacy
various territory-wide supply-demand scenarios

Formulation of Strategy for Concrete Supply
holistic multi-pronged approach and recommendations

https://www.peri.com.au/projects/cultural-buildings/hongkong-zhuhai-macao-bridge-hzmb-operation-buildings-east-and-west.html