# Investigation of the Use of GGBS to Mitigate ASR in Concrete using Volcanic Aggregates from Tsing Yi North

Annual Concrete Seminar 2022

LOW-CARBON CONCRETE ON THE MOVE

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# Introduction

Supplementary cementitious material (SCM)

Reduce cement consumption to lower carbon footprint

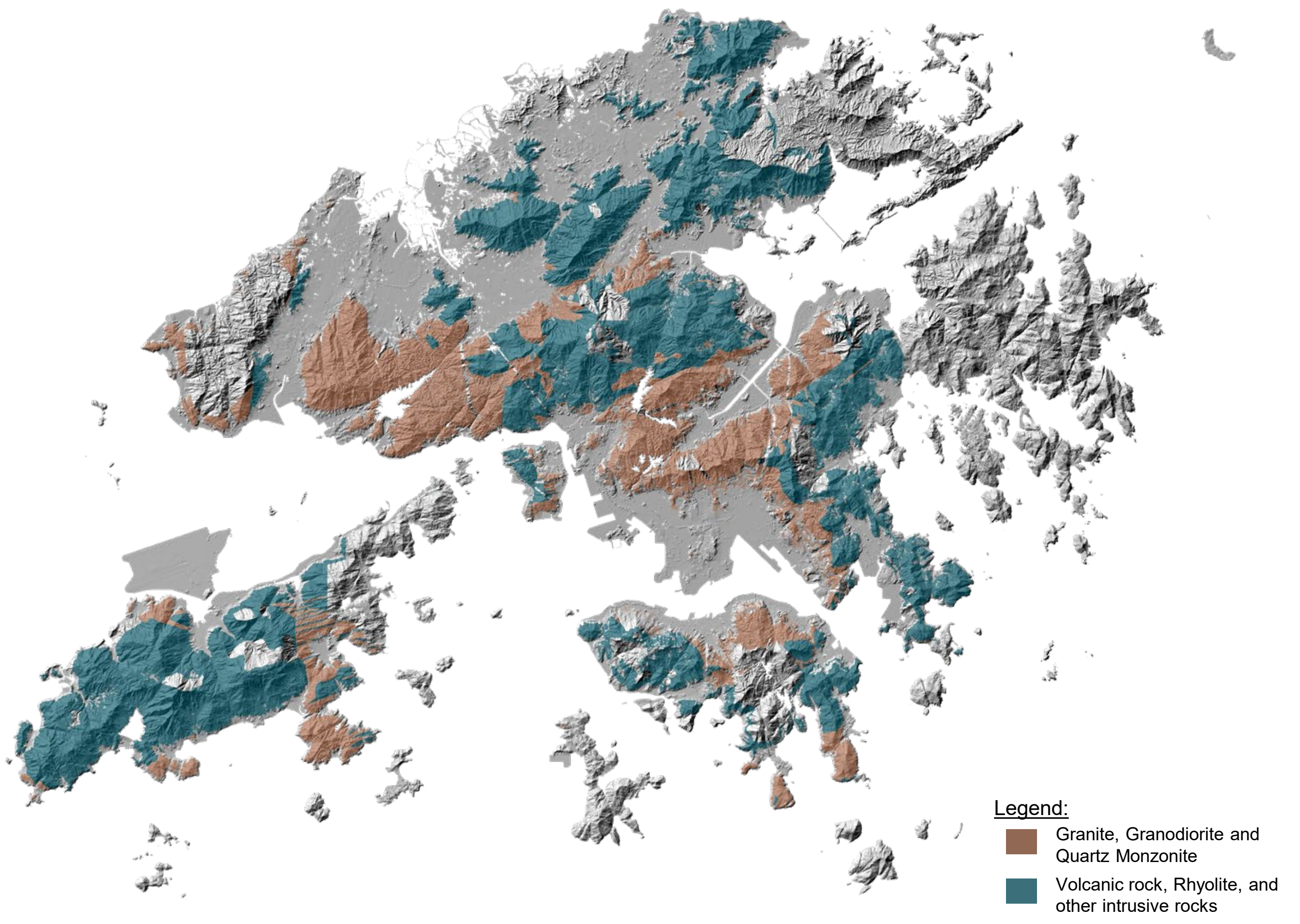
Mitigate the risk of alkali-aggregate reaction in concrete

# Choice of 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**



# What is ASR?

**Alkali**
(Portland cement)

↔

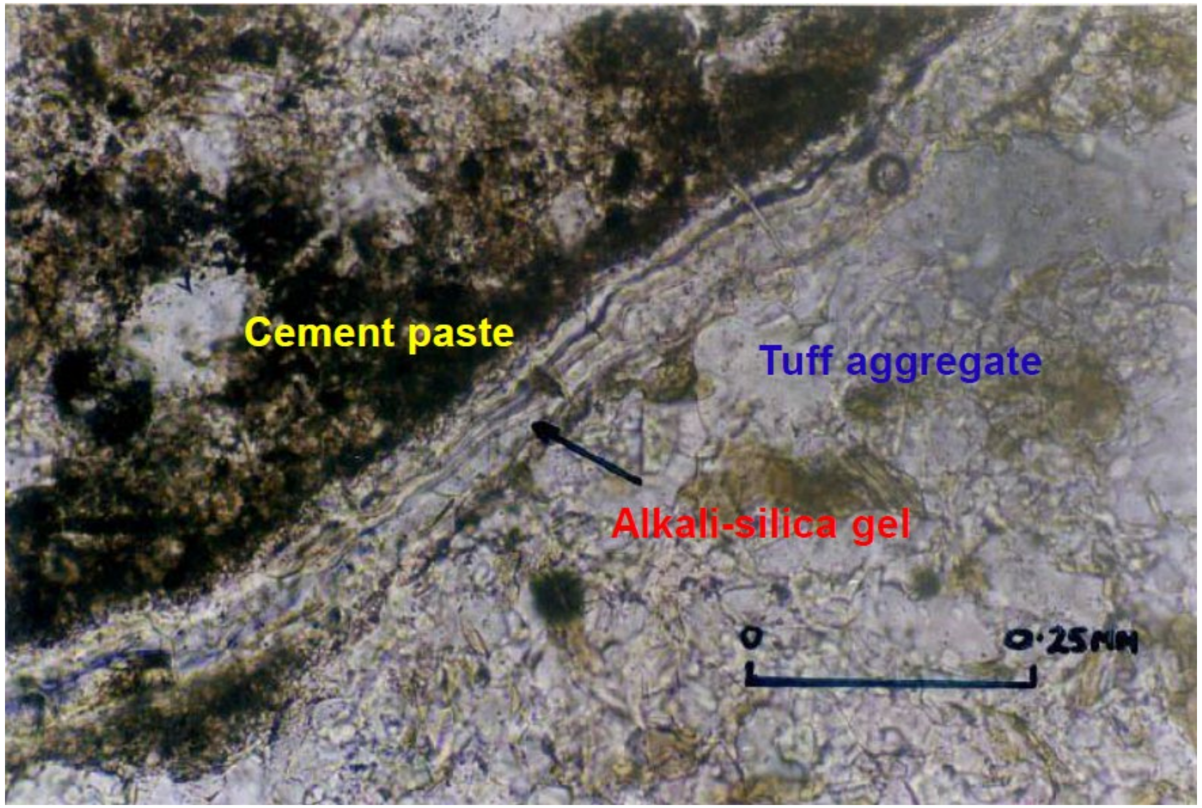
**Reactive silica**
(Aggregate)

**Water**

↓

**Swelling alkali-silica gel**

Cracking in the long term



# Cases of ASR in Hong Kong

| Site | Year Constructed | Year ASR Reported | Approximate Time Lapsed |
|---|---|---|---|
| Shek Wu Hui Treatment Works | 1980 – 1983 | 1991 | 10 years |
| Fanling foot bridge | 1982 | 1998 | 16 years |
| North Point Government School | 1986 – 1988 | 1999 | 12 years |
| Hill Road Flyover | Completed in 1982 | 1997 | 15 years |
| CLP Tseng Tsui Ash Lagoon | 1988 | 1999 | 11 years |

| Projects | Aggregates | | Remedial Works |
|---|---|---|---|
| Shek Wu Hui Sewage Treatment Works (Year Constructed: 1983) | ▪ **Volcanic**<br>▪ Wu Shek Ku Quarry, Shenzhen<br>▪ AMBT 0.309% | Metatuff, foliated, altered abundant finely recrystallized quartz & strained quartz crystal | Surface cleaning, Rendering mortar with latex additive |

Shek Wu Hui Treatment Plant, cracks identified in 1991

# Prevention of Alkali-Silica Reaction (ASR)

## Three basic requirements for ASR to occur in concrete:

- Sufficient quantity of reactive silica (in aggregates)
- Sufficient concentration of alkali (primarily from cement)
- Sufficient supply of water (in hardened concrete, e.g. moisture)

## Guidelines in Australia, Canada, France, Germany, Japan, New Zealand, RILEM, UK

ASR Preventive Method Includes:

- Avoid the use of reactive aggregates
- Use of non-reactive aggregate combination
- Limit alkalis content of concrete
- Use supplementary cementing materials (SCMs), e.g. PFA, GGBS
- Use of suitable chemical admixtures
- No water contract or reducing relative humidity in hardened concrete

# Prevention of Alkali-Silica Reaction (ASR)

**Project Administrative Handbook for Civil Engineering Works and General Specification:**

Reduction of the amount of alkalis present (expressed as equivalent sodium oxide) in the concrete to 3kg/m$^3$.

1. the reduction of amount of cement used in the concrete mix,
2. the use of low alkali cement, or
3. **the use of supplementary cementitious materials (SCM), such as PFA and GGBS**

For structural elements for which ingress of moisture of the concrete is not possible throughout the design life, the 3kg/m$^3$ limit on alkali reactive content need not apply.

**Buildings Department - PNAP APP-74**

1. Equivalent sodium oxide < 3kg/m$^3$
2. Unless concrete element will not be subject to ingress of moisture throughout its design life

# Rare application in Hong Kong

| Projects | Aggregates / Concrete | Measures |
| --- | --- | --- |
| International Commerce Centre (Year Constructed: 2010) | Volcanic aggregates (Anderson Road)<br><br>Grade 90<br>High Elastic Modulus Concrete<br>Test results:<br>100~120MPa,<br>E.M.: 39-50GPa | ▪ Permanent waterproofing plaster for critical locations<br>▪ PFA 35% and Silica Fume (6%)<br>▪ 3kg/m$^3$ alkaline control<br>▪ W/C Ratio 0.28 |

International Commence Centre

# Supplementary Cementitious Materials (SCM)

## Why SCM is useful in mitigating ASR?

PFA – Pulverized Fuel Ash
GGBS – Ground Granulated Blastfurnace Slag
SF – Silica Fume

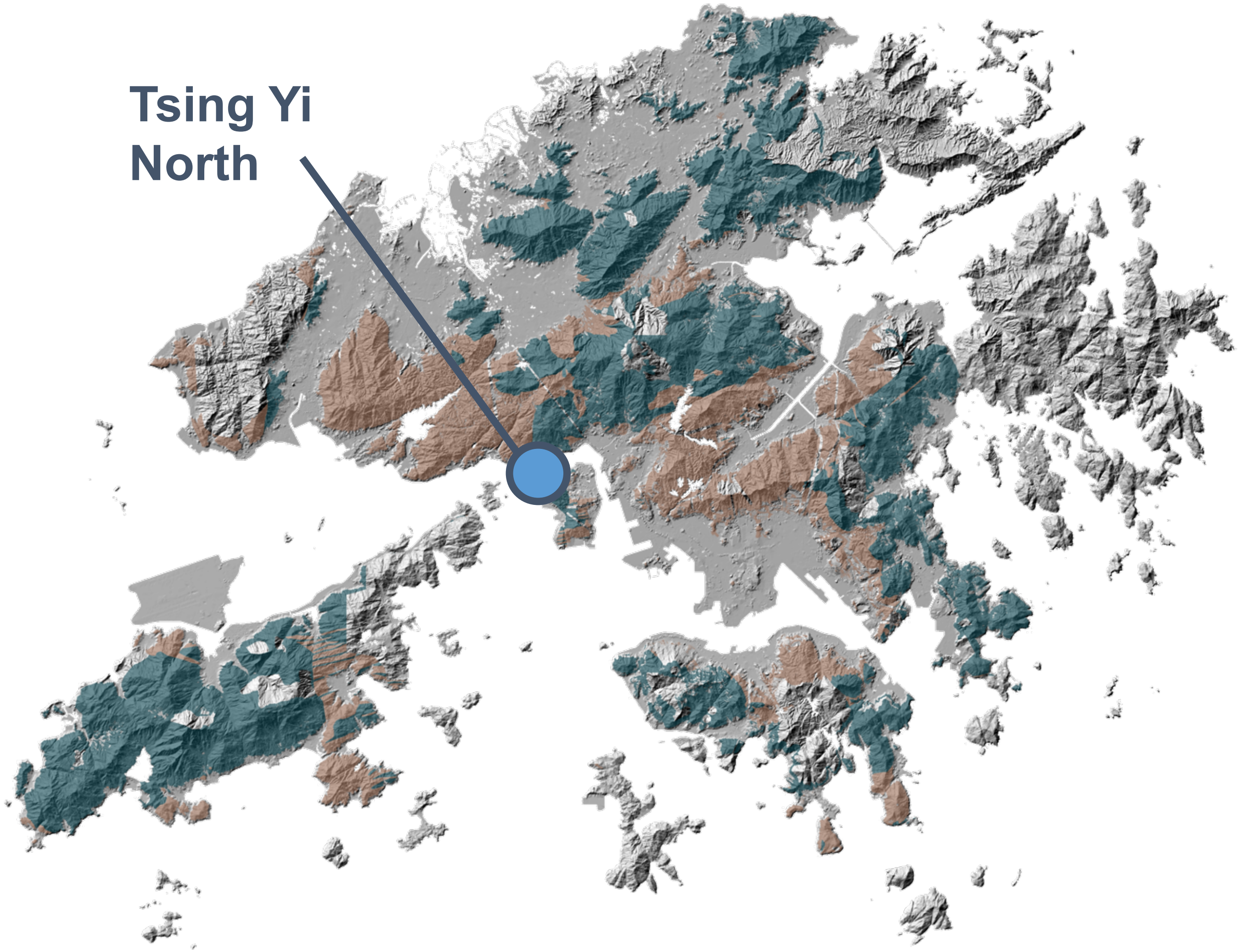
**Alkalis content**
are rapidly consumed

**Reduce permeability**
of concrete

# Site Specific Tests

To verify the use of SCM in local **volcanic and rhyolitic** dyke rock to suppress ASR

To find out **range of mixes** with SCM to suppress ASR for further investigation



# Testing programme

**With reference to RILEM's assessment framework:**

**Petrographic Examination on thin section**

- CS3:2013 Section 9
- Look for aggregates with potential deletrious constituents

**Rapid Screening**

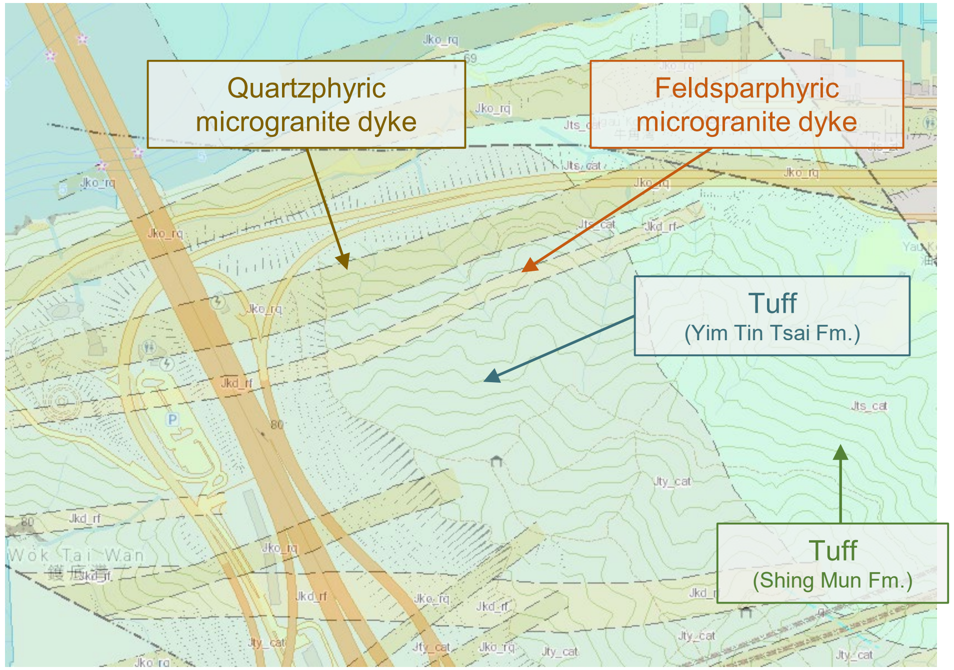
- 14-day Ultra-accelerated Mortar Bar Test (UAMBT)
- CS1:2010 Section 22
- To provide early indication of ASR potential

**Concrete Expansion Testing**

- 52-week Concrete Prism Test (CPT)
- CS1:2010 Section 23 with modification to add SCM
- Reference test to give confirmative results on ASR Potential

# Geology at Tsing Yi North

- Tuff (predominant)
- Feldsparphyric microgranite dyke
- Quartzphyric microgranite dyke




**Geology Map (1:20,000)**

**<u>Tuff:</u>**
Strong, dark grey, mottled grey and white, slightly decomposed coarse ask crystal TUFF. No apparent joint.

**<u>Feldsparphyric microgranite dyke:</u>**
Strong, pinkish grey to light pinklish grey, spotted blacked, mottled pink and white, slightly decomposed FELDSPARPHYRIC MICROGRANITE. No apparent joint.

**<u>Quartzphyric microgranite dyke:</u>**
Moderately strong to strong, light brown, spotted grey and white moderately to slightly decomposed QUARTZPHYRIC MICROGRANITE. Joints are medium to closely spaced, smooth planner, extremely narrow, stained with iron and manganese oxide.

Tuff

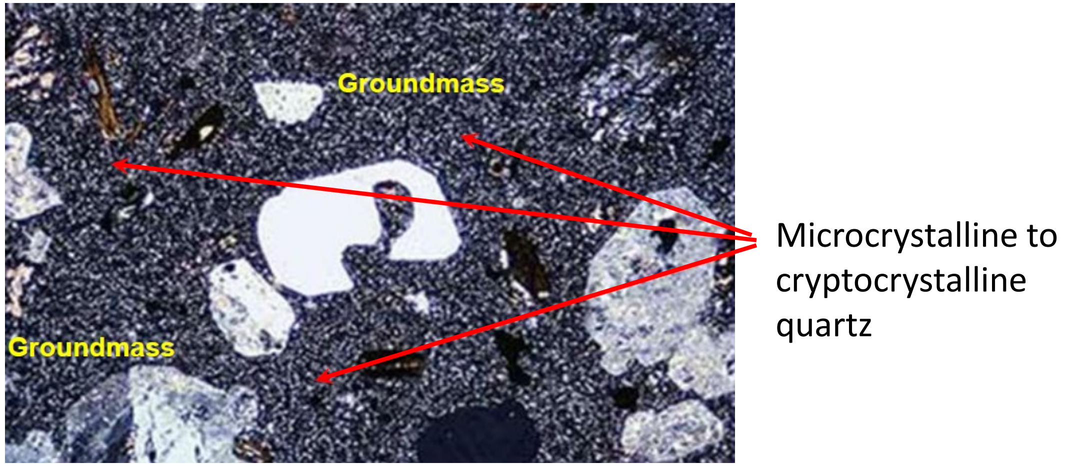
Feldsparphyric Microgranite dyke

Quartzphyric microgranite dyke

# Petrographical examinations

## For aggregates (Section 9 of CS3:2013)

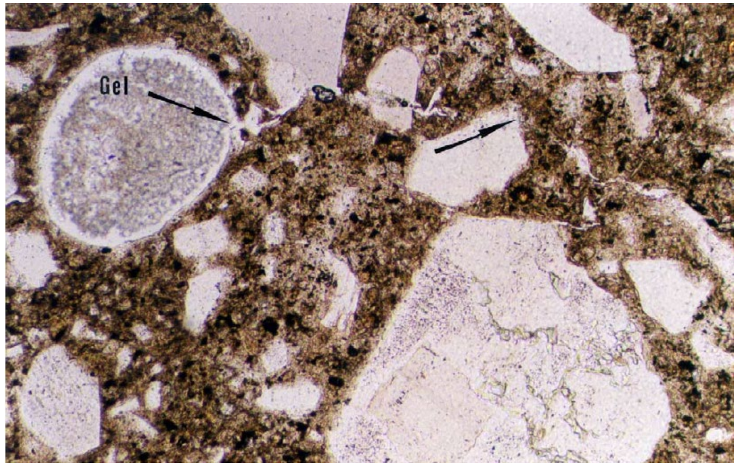
- The groundmass was determined based on point counting analysis by traversing in regular increments over the thin section in the form of a grid pattern.




Thin section of aggregate

## For concrete (CS1:2010)

- Concrete prism of expansion beyond 0.05% in the Concrete Prism Test were taken for further petrographic examination




Thin section of concrete prism

# UAMBT and CPT

## UAMBT - Section 22 of CS1:2010

- Determine rapidly (14 days) the potential alkali-reactivity of aggregates
- Measurement of the expansion of mortar-bars immersed in NaOH solution at elevated temperature.

| Expansion After 14 Days of Immersion in NaOH solution (%) | Potential Reactivity |
|---|---|
| < 0.10 | Non-reactive |
| 0.10 to 0.20 | Potentially reactive |
| > 0.20 | Reactive |

## CPT - Section 23 of CS1:2010 with modification

- SCM is added in the concrete prism
- Measurement of expansion (52 weeks) of concrete produced by alkali-silica reaction.

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

# Mixes adopted in the tests

**Summary of CPT results in GEO Report No. 354**

| Cement replacement level | Average Expansion in 52-week (%) | |
|---|---|---|
| Aggregate source | ARQ | Lam Tei |
| 0% (Norcem only) | 0.11 (Reactive) | 0.12 (Reactive) |
| 35% PFA | 0.00 | 0.00 |
| 30% PFA + 5% CSF | 0.00 | -0.01 |
| 50% GGBS | 0.01 | 0.00 |
| 70% GGBS | 0.01 | 0.00 |
| 50% GGBS + 5% CSF | 0.00 | 0.00 |

**Mix adopted in this study**

| No. | Cement replacement level |
|---|---|
| 1 | 0% (Norcem only) |
| 2 | 25% PFA |
| 3 | 35% PFA |
| 4 | 30% PFA + 5% CSF |
| 5 | 50% GGBS |
| 6 | 70% GGBS |
| 7 | 50% GGBS + 5% CSF |
| 8 | 0 % (ASR Inhibitor) |

To enable direct comparison, the adopted cement replacement levels are same as that in the GEO Report No. 354 with 2 additional mixes

# Other tests

**Index Test**
**CS3:2013 – Aggregates for Concrete**

Physical tests

- Flakiness Index
- Elongation Index
- Los Angeles Value
- Mean Aggregate Impact Value
- Mean Ten Percent Fines Value
- Oven-dried Particle Density
- Water Absorption
- Magnesium Sulphate Soundness
- Drying Shrinkage

Chemical tests

- Water-soluble Chloride Ion Content
- Acid-soluble Sulphate Content

# Overall testing schedule

**Index Tests, Petrographic Examination (aggregate), UAMBT**

- Tuff
- Feldsparphyric microgranite dyke
- Quartzphyric microgranite dyke

**CPT**

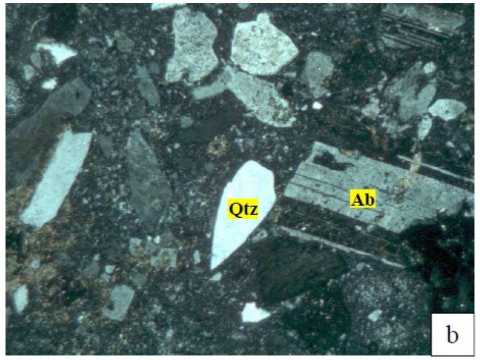
| No. | Cement replacement level | Tuff | Feldsparphyric microgranite dyke | Quartzphyric microgranite dyke |
|---|---|---|---|---|
| 1 | 0% (Norcem only) | ✓ | ✓ | ✓ |
| 2 | 25% PFA | ✓ | ✓ | ✓ |
| 3 | 35% PFA | ✓ | ✓ | ✓ |
| 4 | 30% PFA + 5% CSF | ✓ | ✓ | ✓ |
| 5 | 50% GGBS | ✓ | ✓ | ✓ |
| 6 | 70% GGBS | ✓ | ✓ | ✓ |
| 7 | 50% GGBS + 5% CSF | ✓ | ✓ | ✓ |
| 8 | 0 % (ASR Inhibitor) | ✓ | ✓ | ✓ |

**Petrographic Examination (concrete prism)**

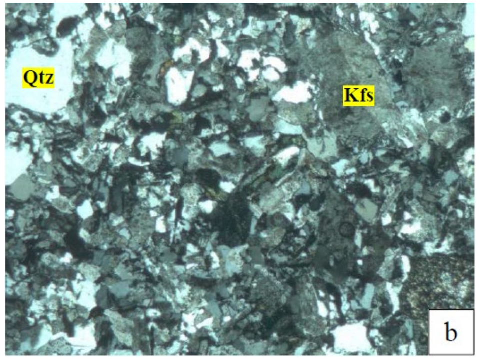
- Specimens with expansion >0.05%

# Petrographic Examination on Aggregate

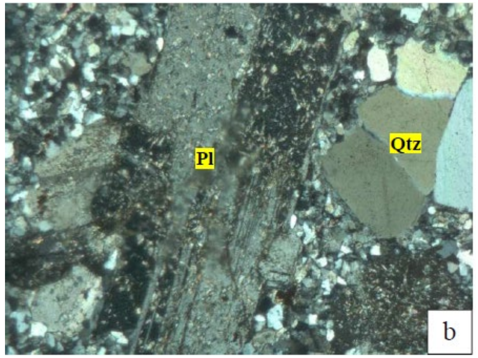
| Petrographic examination | Tuff | Feldsparphyric microgranite dyke | Quartzphyric microgranite dyke |
|---|---|---|---|
| Classification of samples | **Potentially reactive** attributed to strained quartz crystal fragments and cryptocrystalline to microcrystalline quartz | **Potentially reactive** attributed to strained quartz phenocrysts and quartz of the fine-grained groundmass | **Potentially reactive** attributed to strained quartz phenocrysts and quartz of the fine-grained groundmass |



Tuff



Feldsparphyric Microgranite Dyke



Quartzphyric Microgranite Dyke

# UAMBT and CPT result (without SCM)

| Aggregate | UAMBT | | CPT | |
|---|---|---|---|---|
| | 14-Day Expansion (%) | ASR Potential | 52-Week Expansion (%) | ASR Potential |
| Tuff | 0.24 | Reactive | 0.075 | Potentially reactive |
| Feldsparphyric microgranite dyke | 0.14 | Potentially reactive | 0.1 | Potentially reactive |
| Quartzphyric microgranite dyke | 0.15 | Potentially reactive | 0.03 | Non-reactive |

| Expansion After 14 Days of Immersion in NaOH solution (%) | Potential Reactivity |
|---|---|
| < 0.10 | Non-reactive |
| 0.10 to 0.20 | Potentially reactive |
| > 0.20 | Reactive |

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

# Summary of CPT Results (52 weeks)

| Cement replacement level | Tuff | Feldsparphyric microgranite dyke | Quartzphyric microgranite dyke |
|---|---|---|---|
| 0% (Norcem only) | 0.075% | 0.1% | 0.030% |
| 25% PFA | 0.005% | 0.025% | 0.025% |
| 35% PFA | -0.005% | 0.025% | 0.025% |
| 30% PFA + 5% CSF | 0.000% | 0.025% | 0.025% |
| 50% GGBS | 0.010% | 0.035% | 0.035% |
| 70% GGBS | 0.005% | 0.030% | 0.035% |
| 50% GGBS + 5% CSF | 0.000% | 0.030% | 0.035% |
| 0 % (ASR Inhibitor) | 0.010% | 0.045% | 0.035% |

**Observations**

1. With SCMs, all expansion is less than 0.05%
2. No significant benefit for higher dosage of 35% PFA than 25% PFA.
3. Higher dosage of 70% GGBS shows slightly better results than 50% GGBS
4. Reactiveness of feldsparphyric microgranite is higher than tuff before and after treated
5. CSF has no significant effect in general
6. ASR inhibitor is less effective compared to SCMs

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

# Summary of CPT Results (52 weeks)

| 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% |

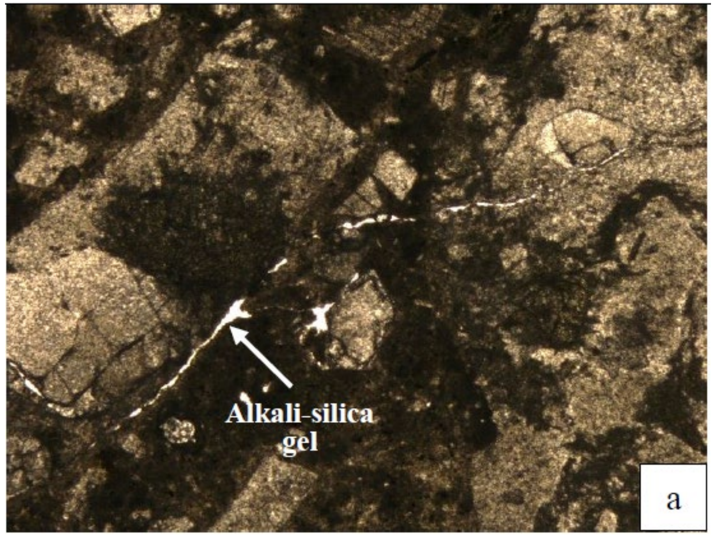
[1] Reference: GEO Report No. 354

**Observations**

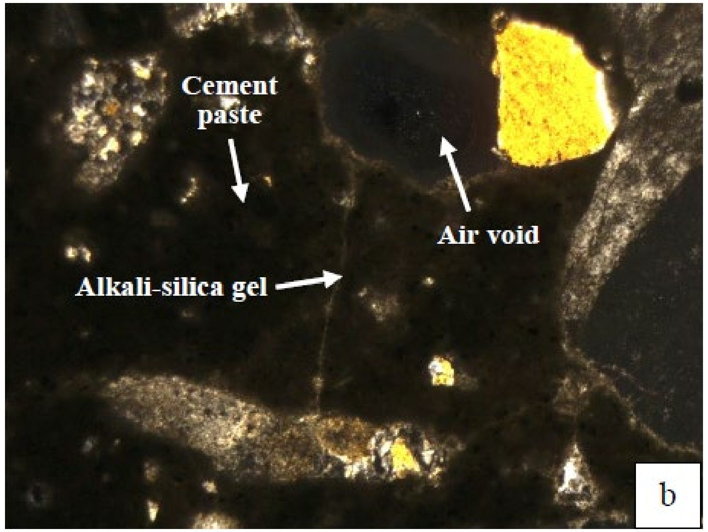
1. The tuff at Tsing Yi is less reactive than those in Anderson Road and Lam Tei
2. With SCMs, all expansion is less than 0.05%
3. The increase of effectiveness of SCM is not significant when it is beyond certain replacement level
4. CSF has no significant effect in general
5. The result is very consistent

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

# Petrographical examination on concrete prism




Concrete prism using
Tuff as aggregate




Concrete prism using
Feldsparphyric Microgranite
dyke as aggregate

- Concrete prisms with expansion beyond 0.05% in the CPT were cut into thin section

- Alkali-silica reaction is the likely cause of the expansion

# Conclusion

a) A complete set of tests, include index tests, petrographical examination, UAMBT and CPT according to RILEM's assessment framework and CS1 : 2020 were carried out.

b) The test results indicate that the application of the SCMs is effective in suppressing the potential deleterious effect for volcanic tuff and rhyolitic dyke rock in the Tsing Yi North.

c) The increase of effectiveness of SCM is not significant when it is beyond certain replacement level.
   - No significant benefit for higher dosage of 35% PFA than 25% PFA.
   - Higher dosage of 70% GGBS shows slightly better results than 50% GGBS.

d) CSF has no significant effect in general.