Topics on Alkali-Silica Reaction

Part 1 – Introduction by Ir. Peter LEUNG

1. **What is Alkali-Silica Reaction (ASR)?**
2. **Cases of ASR Damage in HK**

Part 2 – Control of ASR Damage by Ir. H.D. WONG

1. **Development of Preventive Measures**
2. **ASR Control Requirements in General Specification**
3. **Aggregate Assessments in CS1:2010**

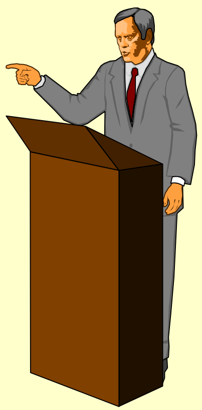
Part 3 – Geological Assessment of ASR by Ir. Phoebe LAU

1. **Geological Assessment of ASR**
2. **Construction Standard on Aggregates for Concrete, CS3:2012 (Draft)**

Introduction

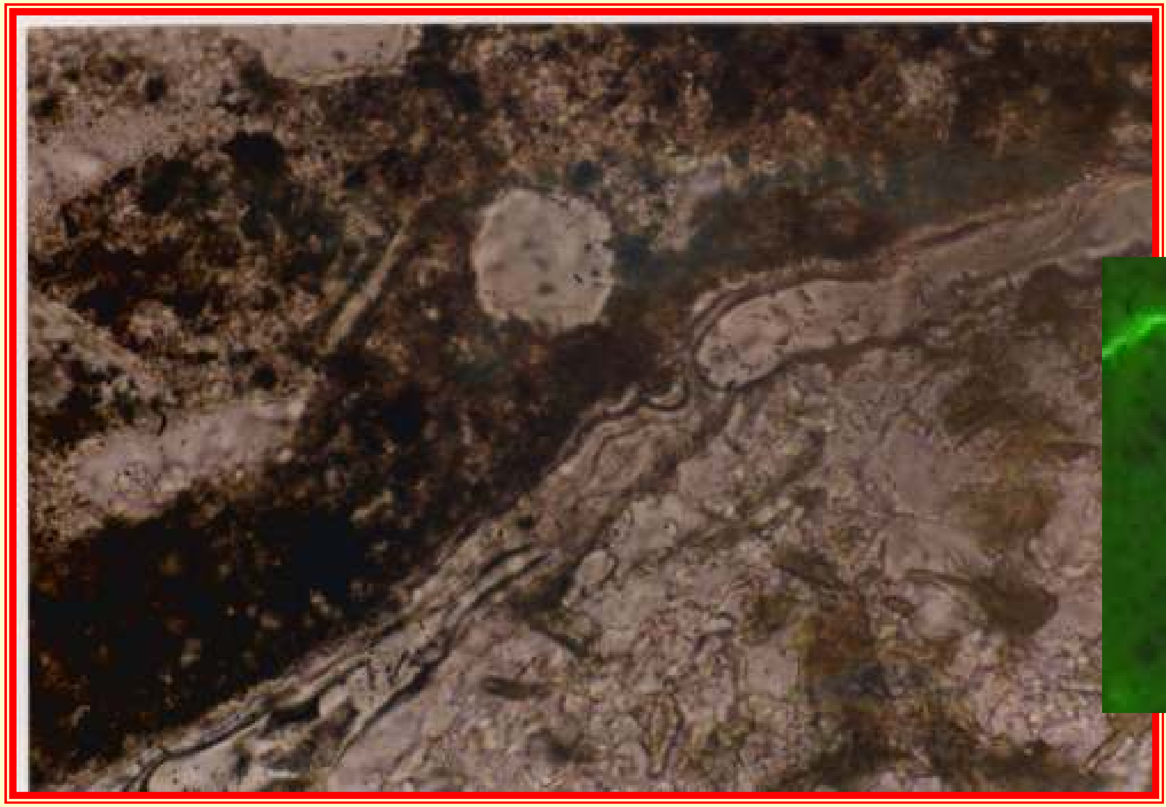
Speaker

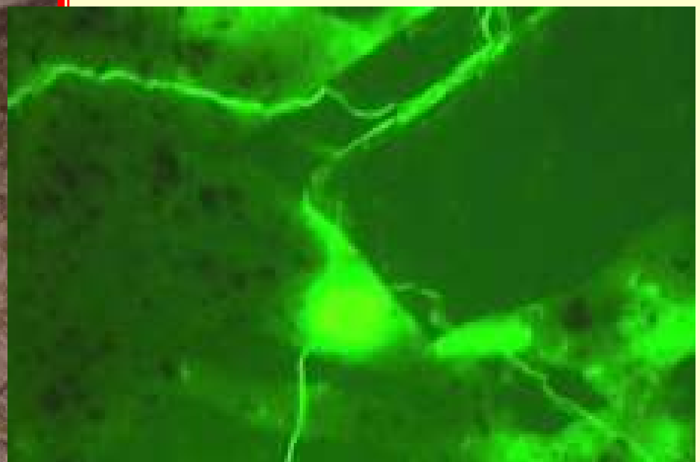
Ir. Peter LEUNG, Senior Engineer, CEDD



Contents

Alkali-Silica Reaction (ASR) is a result of reaction between the alkaline pore solution and reactive silica in the aggregate. The reaction leads to the formation of a gel which absorbs water and expands leading to damaging expansions and cracking in the concrete.

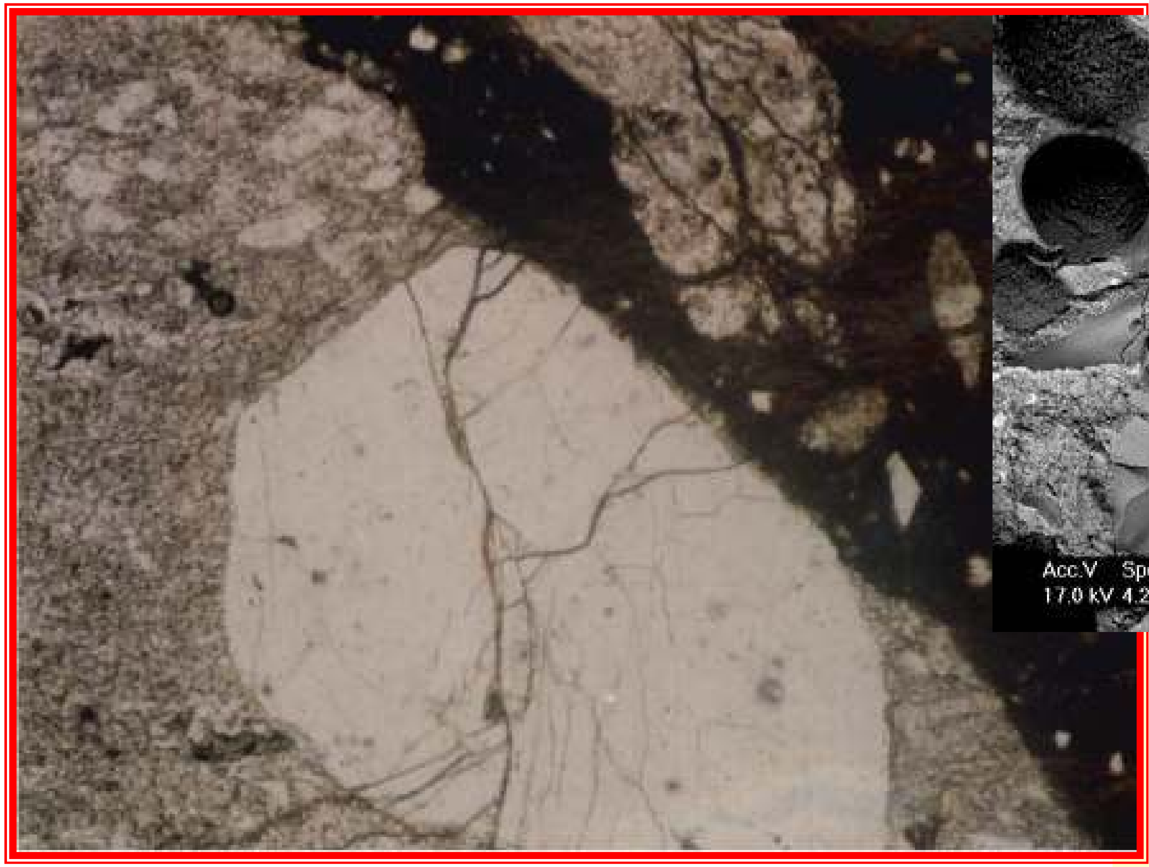


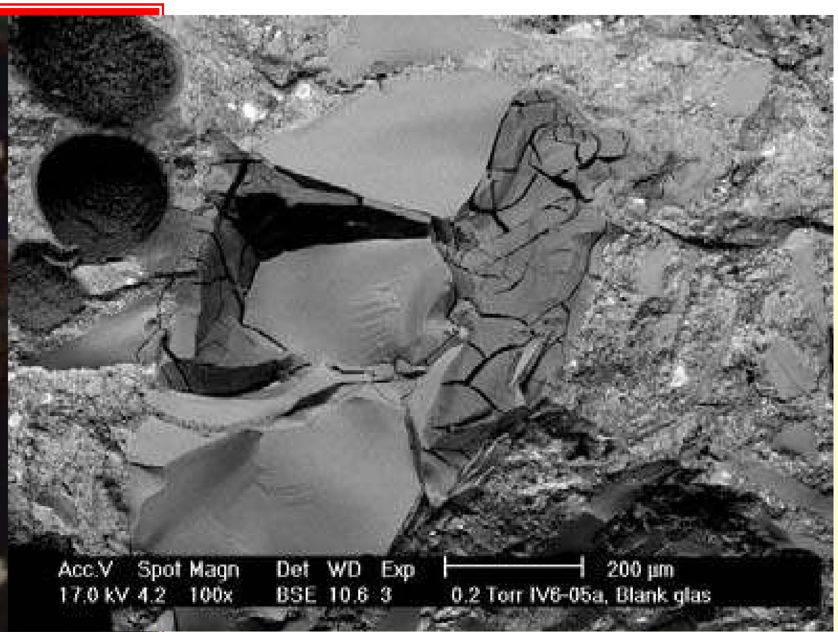


Fluorescence microscopy image

- Source: Mircolab

Alkali-silica gel:





Electron microscope image

- Source: Microlab

Consequence of ASR damage:

- Reduce concrete strength
- Reduce concrete durability
- Affect structure appearance
- Shorten structure service life
- Increase maintenance cost

For damaging ASR expansion to occur, the following conditions must be present simultaneously:

- A sufficiently alkaline pore solution
- A critical amount of reactive silica, such as microcrystalline or cryptocrystalline quartz
- A sufficient supply of water

Typical visual features of structures affected by ASR:

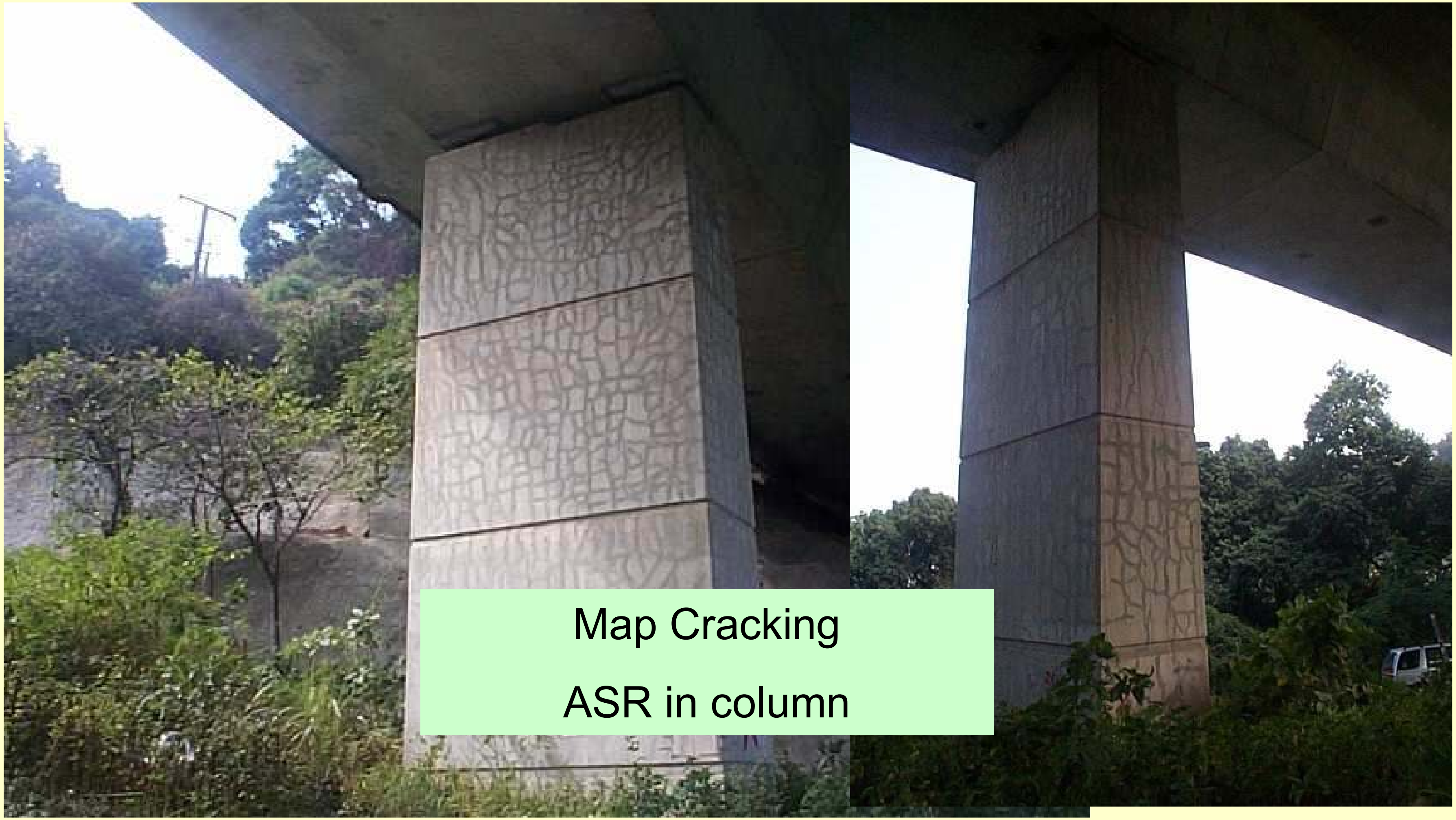
- Map pattern cracks
- Cracks parallel to the reinforcement
- Cracks occur several years after the structure being constructed
- Pop-outs or swelling of concrete

Time needed for ASR damage being visible:

ASR is very slow, normally around 10 years or more in HK.

Cases of ASR Damage in HK

Map cracking found in the column



Map Cracking

ASR in column

Shek Wu Hui Treatment plant

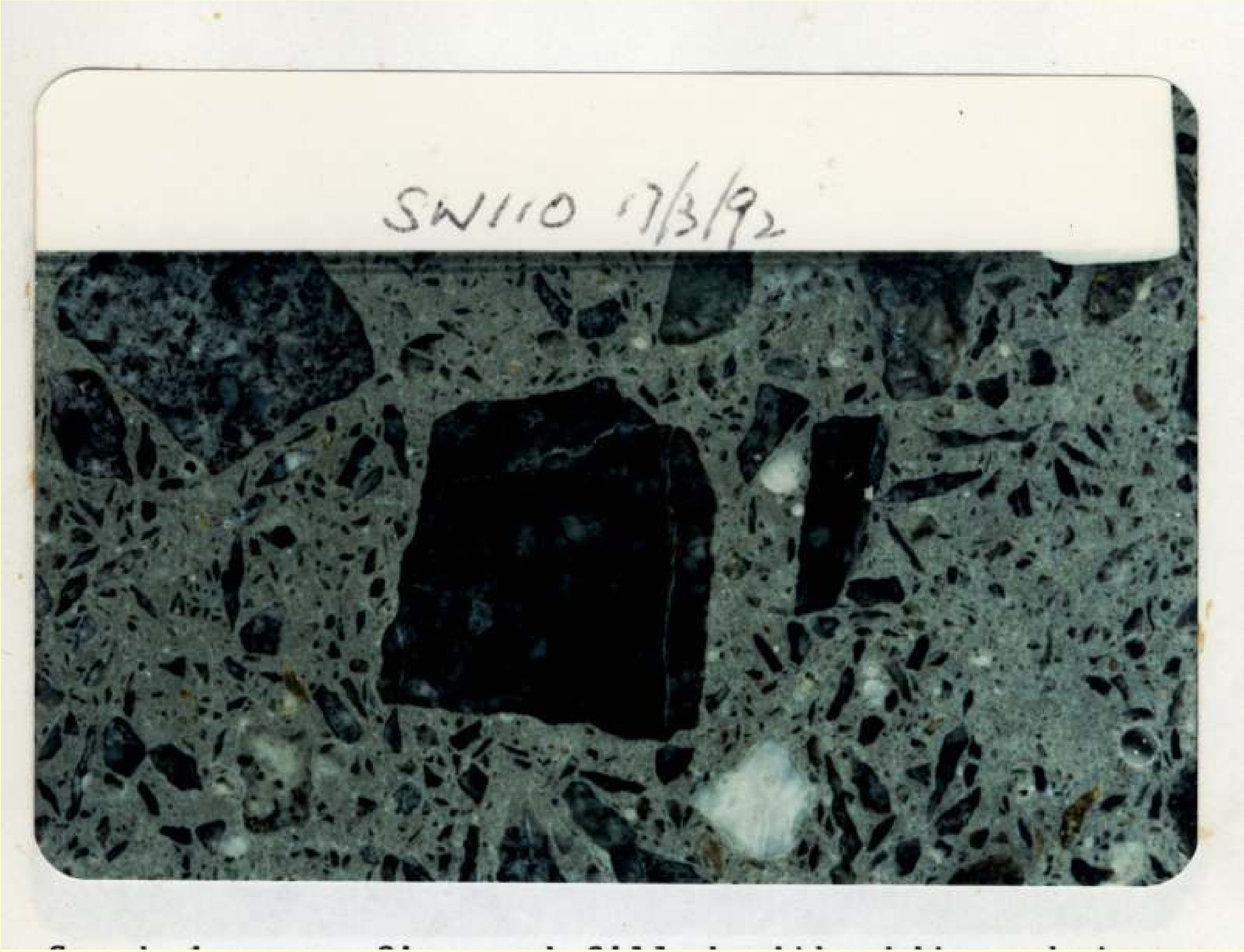
Shek Wu Hui Treatment plant

Shek Wu Hui Treatment plant: map cracks

Shek Wu Hui Treatment plant

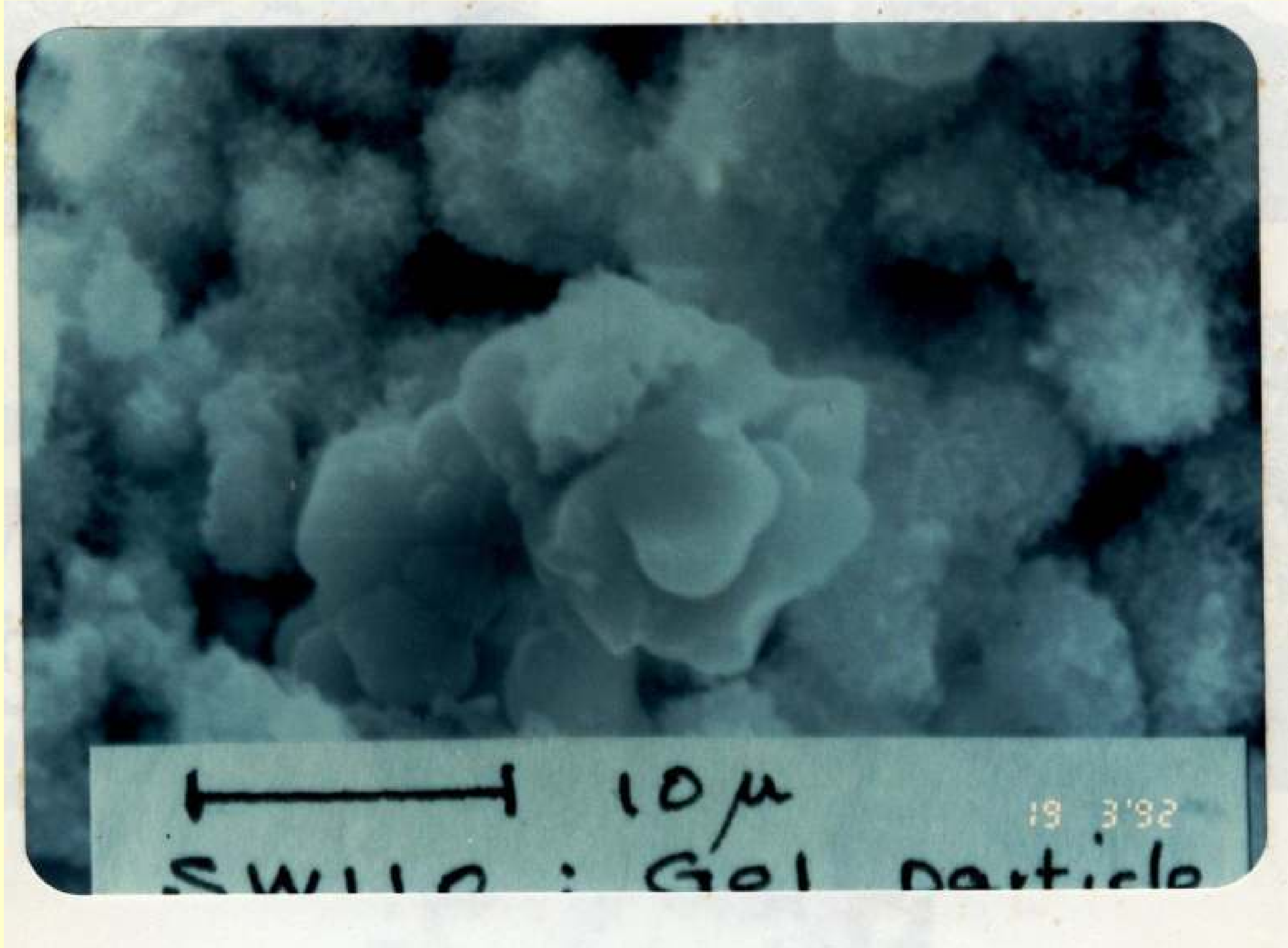
Thin section showing ASR damage

Thin section showing ASR damage



Expansion of white gel

Photomicrograph of white gel



X-ray spectrum of white gel

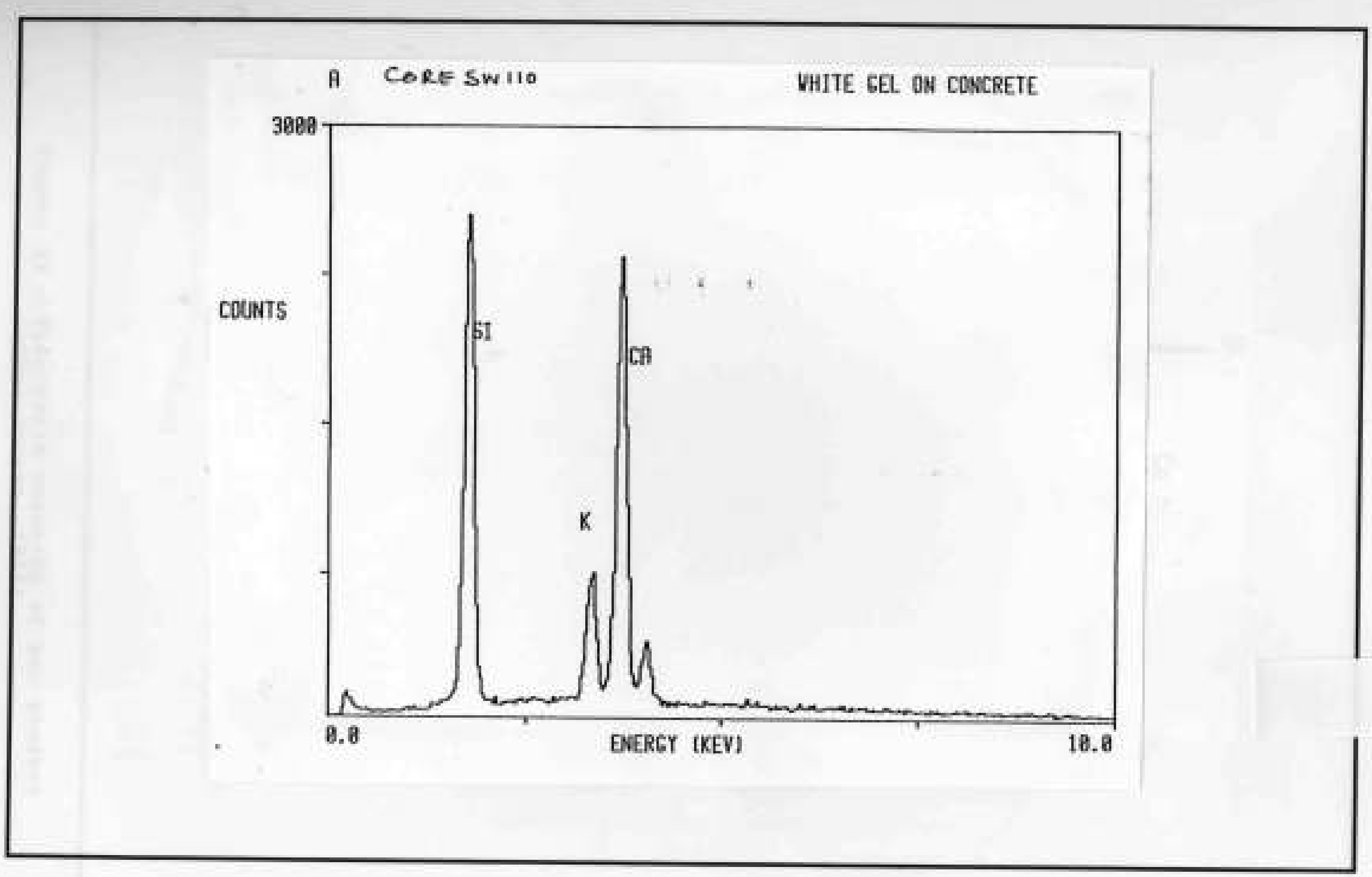
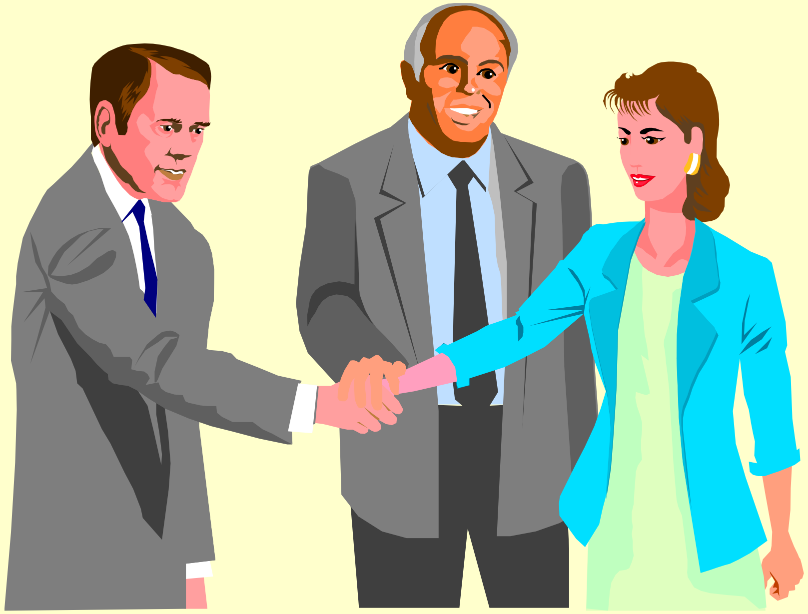


Figure 32 - Electronic scanning of extruded white substance

End of Presentation

Thank you!



CEDD HKSAR Standing Committee on Concrete Technology

Annual Concrete Seminar 2012

(18 April 2012)

Control of ASR Damage in Concrete

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Geotechnical Engineering Office
Civil Engineering and Development Department

Outline

1. Development of Preventive Measures
2. ASR Control Requirements in General Specification
3. Aggregate Assessment: CS1:2010
4. Conclusions

1. Development of Preventive Measures

For damaging ASR expansion to occur, the following conditions must be present simultaneously:

- A sufficiently alkaline pore solution
- A critical amount of reactive silica
- A sufficient supply of water

Summary of Preventive Measures:

M1: Restrict the amount of alkali from the cement or other sources

M2: Use non-reactive aggregate, i.e. restrict the amount of Reactive Silica from the aggregate

M3: Reduce the access of moisture, i.e. restrict the amount of Water ingress from the environment

M4: Modify the properties of any gel such that it is non-expansive

Source: RILEM

M1: Restrict the amount of alkali from the cement or other sources

- Limiting the alkali content of the concrete
- Use of a low alkali cement
- Inclusion of a sufficient proportion of a low lime-fly ash or ground granulated blastfurnace slag in the concrete

M2: Use non-reactive aggregate

Using test methods in CS1:2010

Source: RILEM

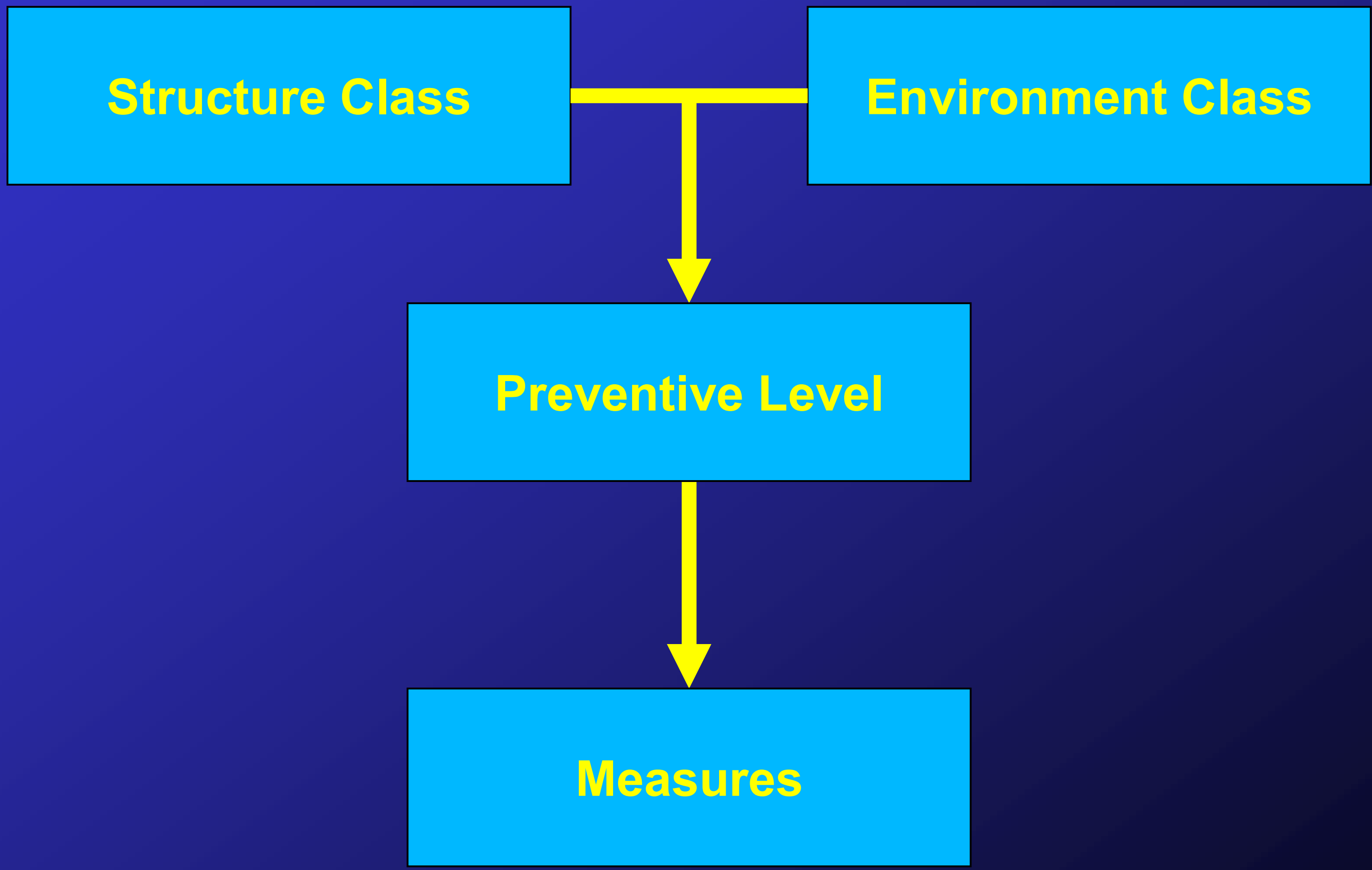
M3: Reduce the access of moisture

Use, for example, external cladding, well designed drainage, etc.

M4: Modifying the properties of the gel such that it is non-expansive

Use lithium salts, such as lithium nitrate, in the concrete mix water.

* *This measure is newly developed and there is little experience of using it in Hong Kong.*


Structure Class
Environment Class
Preventive Level
Measures

Structure Classification

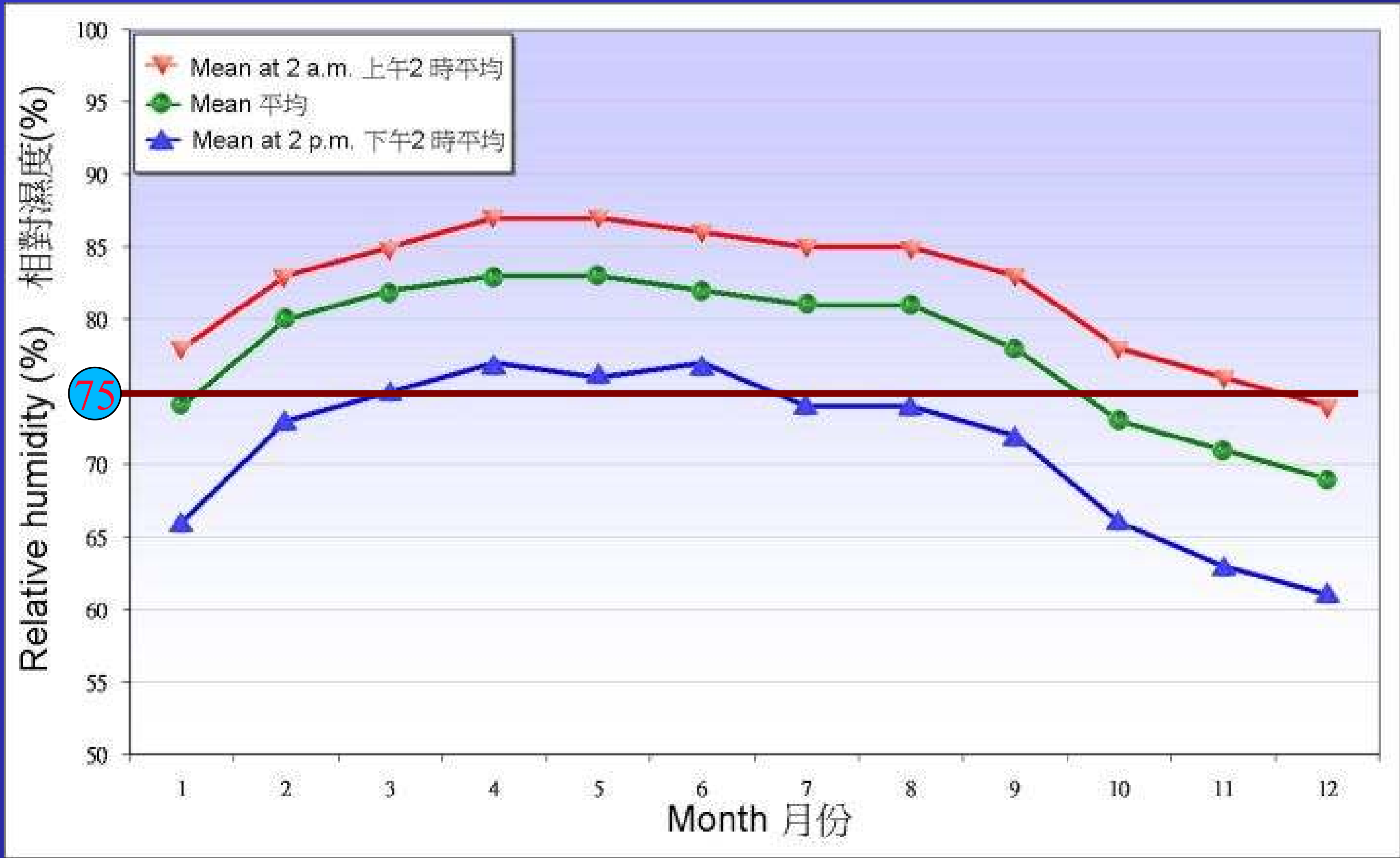
1. Structure Class according to Potential Consequence of ASR	
Class	Definition and Examples
S1	Some deterioration from ASR is acceptable e.g. temporary or short service life structures, easily replaceable elements, such as parapets of a bridge.
S2	Minor ASR or cosmetic cracking is acceptable e.g. most building and civil engineering structures, with a design life 10 – 100 years.
S3	No ASR damage is acceptable, even if only cosmetic – long service life or highly critical structures: e.g., nuclear installations, dams, tunnels, exceptionally important bridges or viaducts, structures retaining hazardous materials

Source: GEO Report No. 167, http://www.cedd.gov.hk/eng/publications/geo reports/index.htm

Classification of Environmental Condition

2. Environmental Condition	
Class	Definition and Examples
E1	Dry (RH<75%) and protected from extraneous moisture: e.g. internal concrete within buildings in dry service conditions.
E2	Exposed to extraneous moisture: e.g. most civil engineering works in Hong Kong.
E3	Exposed to extraneous moisture plus aggravating factors: e.g. marine environment.

Source: RILEM



Monthly mean of relative humidity recorded at the Observatory between 1981-2010

http://www.hko.gov.hk/cis/normal/1981 2010/normals e.htm

Preventive Levels

	Environmental Condition		
	E1	E2	E3
Structure Class	Preventive Level		
S1	P1	P1	P1
S2	P1	P2	P3
S3	P2	P4	P4

Source: RILEM

Preventive Level and Measures

	Environment		
	E1	E2	E3
Structure Class	Preventive Level		
S1	P1	P1	P1
S2	P1	P2	P3
S3	P2	P4	P4

Preventive Level P1

No specific preventive measure against ASR damage is necessary.

Provided that:

1. *Appropriate concrete specification*
2. *Adequate quality control for concrete production, such as the QSPSC*
3. *Good practice in placing and curing concrete*

* *Some damage from ASR may be possible.*

Source: RILEM

	Environmental Condition		
	E1	E2	E3
Structure Class	Preventive Level		
S1	P1	P1	P1
S2	P1	P2	P3
S3	P2	P4	P4

Preventive Level P2

Apply one of the preventive measures M1 to M4:

M1: *Restrict the amount of alkali from the cement or other sources*

M2: *Use non-reactive aggregate, i.e. restrict the amount of Reactive Silica from the aggregate*

M3: *Reduce the access of moisture, i.e. restrict the amount of Water ingress from the environment*

M4: *Modify the properties of any gel such that it is non-expansive*

Source: RILEM

	Environmental Condition		
	E1	E2	E3
Structure Class	Preventive Level		
S1	P1	P1	P1
S2	P1	P2	P3
S3	P2	P4	P4

Preventive Level P3

Apply one of the preventive measures M1 to M4.

Note: *The concrete shall also be designed to resist aggravating factor (E3), such as using the marine specification in Section 21 of GS.*

Source: RILEM

	Environmental Condition		
	E1	E2	E3
Structure Class	Preventive Level		
S1	P1	P1	P1
S2	P1	P2	P3
S3	P2	P4	P4

Preventive Level P4

Apply at least two of the preventive measures M1 to M4.

Note: *The concrete shall also be designed to resist aggravating factor (E3), such as using the marine specification in Section 21 of GS.*

Source: RILEM

2. ASR Control Requirements in General Specification

M1: To limit the amount of alkali in concrete

GS, Section 16

(8) … , the alkali content of the concrete, expressed as the equivalent sodium oxide (Na_2O) content per cubic metre of concrete … shall not exceed 3.0 kg.

Amd 1/2012

** Alkali in concrete = Alkali in cement + alkali from other sources (e.g. admixtures, PFA, GGBS, water, etc.)*

Calculation of equivalent sodium oxide content in the concrete

GS, Section 16

(9) The equivalent sodium oxide (Na_2O) content of the concrete shall be determined in accordance with the following expression:

Equivalent Na_2O content = A + B + C

where A = the sum of the acid-soluble alkali content (expressed as equivalent Na_2O) of cement, admixtures and water,

B = 1/6 of the total alkali content of PFA or

1/2 of the total alkali content of GGBS.

If the proportion of PFA and GGBS is less than 20% and 25% of the total cementitious content respectively, B = the total alkali content of PFA or GGBS, and

C = 0.76 times the chloride ion (Cl-) content of the aggregate.

…

Amd 1/2012

Alkali in Cement

Low Alkali Cements < 0.60 % Na_2Oeq in general

Alkali content of commonly available in HK:	% Na_2Oeq
Asano	0.51
Champion	0.57
Green Island Hong Kong – Emerald Brand	0.63
Feng Jiang	0.44
Golden Eagle	0.64
Onoda	0.48
Skyscraper	0.64
Green Island Hong Kong	0.63
Yue Xiu	0.46
China Resources Cement	0.41

Cement Circular, Issue Date: 3 Jan 12

M2: Use non-reactive aggregate

GS, Section 16

(5) Aggregates in the "Reactive" category shall not be used unless with the prior approval of the Engineer.

Amd 1/2012

To determine the potential alkali-reactivity of aggregate:

*Methods in **CS1:2010**:*

- *Ultra-accelerated mortar bar test*
- *Concrete prism test*

Summary of ASR Control Requirements in General Specification

GS, Section 16

(5) Aggregates in the "Reactive" category shall not be used unless with the prior approval of the Engineer.

(8) … , the alkali content of the concrete, expressed as the equivalent sodium oxide (Na_2O) content per cubic metre of concrete … shall not exceed 3.0 kg.

3. Aggregate Assessment: CS1:2010

To determine the potential alkali-reactivity of aggregates

Construction Standard CS1:2010

- Ultra-accelerated Mortar Bar Test

Expansion after **14** Days of Immersion in NaOH

- Concrete Prism Test

Expansion after **52** Weeks

Interpretation of results

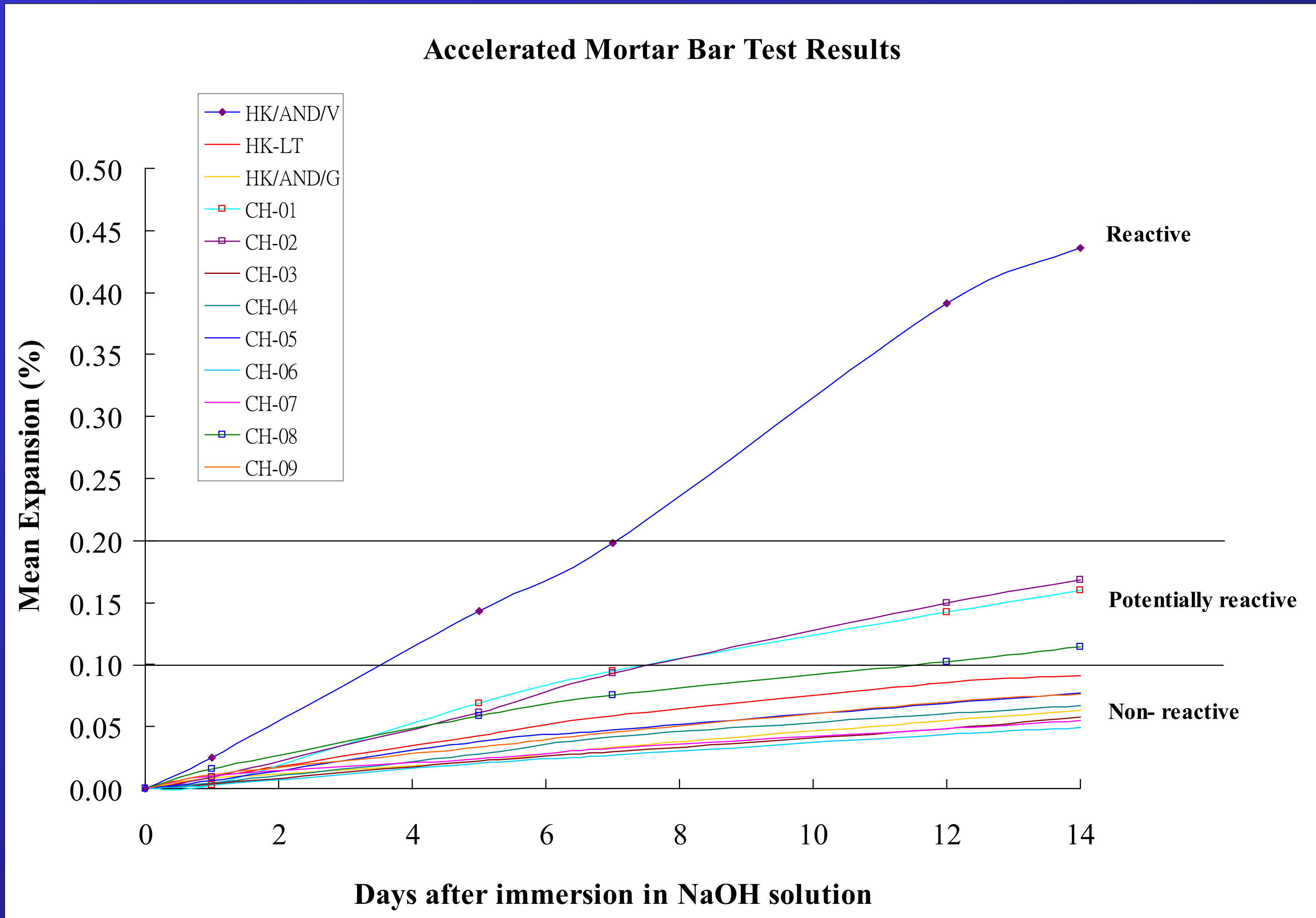
- Ultra-accelerated Mortar Bar Test

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

- Concrete Prism Test

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

UAMBT Results of Commonly Available Aggregates



4. Conclusions

- For normal concrete structures, aggregates in the "Reactive" category shall not be used.
- The alkali content of the concrete, expressed as the equivalent sodium oxide (Na_2O) content per cubic metre of concrete shall not exceed 3.0 kg.
- For special concrete structures, additional requirements shall be specified in the Particular Specification of the contract.

End of Presentation

Thank You

Ultra-accelerated Mortar Bar Test (UAMBT)

Objective: to determine the potential alkali-reactivity of aggregates by evaluation of the expansion of mortar-bars.

- Produce 3 mortar bars. Store the bars in a chamber for 24 hrs at 20°C and 90%R.H.
- Measure the starting length, L0.
- Immersed in distilled water container and placed in oven at $80 \pm 2^{\circ}$ C for 24 hrs.
- Place the bars in 1M NaOH solution at 80°C.
- Periodically measure the changes in length for 14 days.
- Calculate the expansion after 14 days.

Ultra-accelerated Mortar Bar Test

Preparing the mortar bar

Ultra-accelerated Mortar Bar Test

Measuring the expansion of mortar bar

Concrete Prism Test

Objective: to determine the potential alkali-reactivity of aggregates by evaluation of the expansion of concrete prism.

- Production of 3 concrete prisms. Cure at 20 ± 2°C. , RH ≥ 90 % for 24 ± 0.5 hours.
- Wrapping the prism with wet cloth and polythene bags and stored for 24 hrs at 20 ± 2°C
- Measure the starting length, L0.
- Stored in a cabinet maintained at 38 ± 2°C
- Measure the changes in length at the end of period 2, 4, 13, 26, and 52 weeks.
- Calculate the expansion after 52 weeks.

Alkali-Aggregate Reaction in Concrete

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GEOTECHNICAL ENGINEER/GEOLOGICAL SURVEY
GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
HONG KONG SAR GOVERNMENT

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CONTENT

A. What is alkali-aggregate reaction (AAR)?

B. Alkali-silica reaction (ASR)

- **Study of the ASR Potential of aggregates**
  (from geological point of view)

- **Study of ASR in hardened concrete**
  (from geological point of view)

C. Construction Standard on Aggregates for Concrete (CS3), Draft

A. What is Alkali-aggregate Reaction (AAR) ?

Definition:

A general term to describe the expansive **R**eaction between **A**lkalis in the cement paste/concrete pore solution and reactive minerals in the **A**ggregates.

Result:

Formation of alkali-gel and cracking in concrete.

Two main types of AAR:

(i) Alkali-silica reaction (ASR)

Reactive silica (in aggregates) + alkali (in cement/concrete pore solution)

→ alkali-silica gel (Na/K silicate hydrate) + moisture

→ expansion

(ii) Alkali-carbonate reaction (ACR)

- Expansive reaction between impure dolomitic limestone (in aggregate) and alkali (in cement/concrete pore solution)
- Worldwide, occurrence of ACR not as common as ASR
- Mechanism not as well known as ASR

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B. Alkali-silica Reaction (ASR)

Essential Components for ASR:

(i)Sufficient alkali in cement/concrete pore solution

(${Na_2}Oeq$, i.e. Na_2O mass % + 0.658 K_2O mass %)

(ii)Presence of reactive forms of silica in aggregates, such as

- opal
- volcanic glass or devitrified glass
- microcrystalline (<0.062 mm) or cryptocrystalline (<0.004 mm) quartz
- metastable silica (e.g. chalcedony, tridymite, cristobalite)
- disordered silica (e.g. strained quartz

(iii) Sufficient moisture to cause expansion of alkali-silica gel

Study of the ASR Potential of aggregates:

(i) Inspection of Quarry Rock

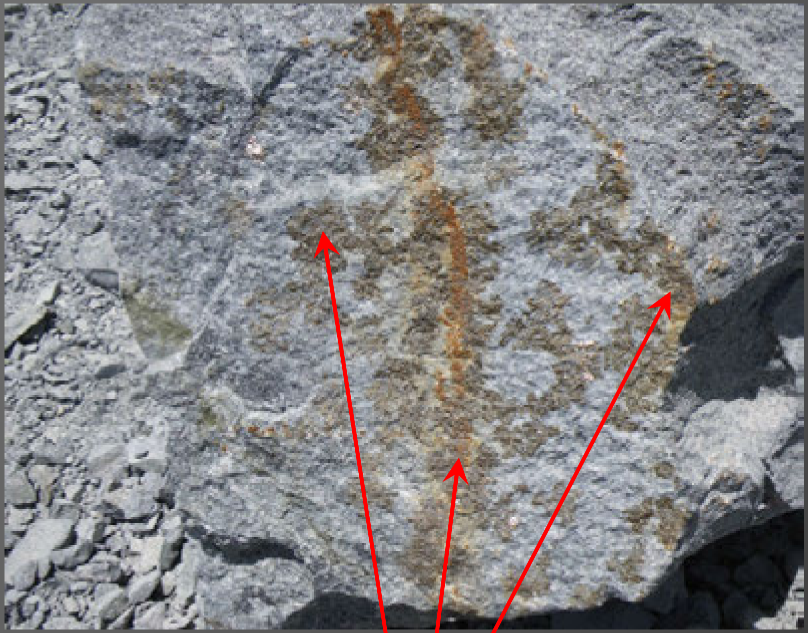
An active quarry site

Things to note:

- Different rock types?
- Any dyke intrusion?
- Any shearing/alteration/ metamorphism/ mineralisation in the rocks?
- What is the weathering condition of the rock.

(Representative rock samples can be collected for further examination in the laboratory.)

Areas to attract special attention:



(a) Disseminated pyrite (may have deleterious effect in concrete) in diorite

(b) A microcrystalline siliceous dyke (potentially alkali-reactive) in granite

Areas to attract special attention:

(c) Mafic dykes in granite

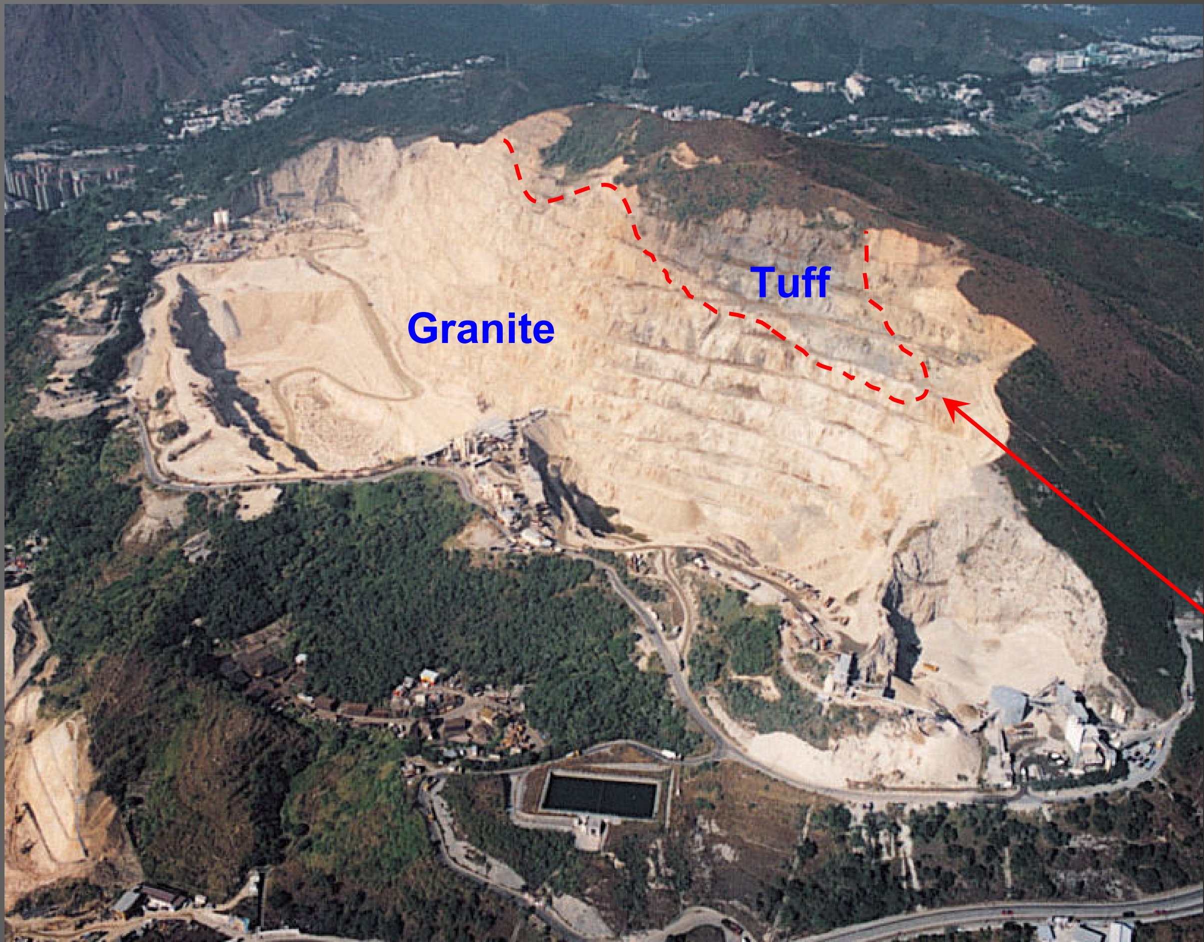
Mafic rocks may be potentially alkali-reactive if:

- Silica content (SiO_2) of the bulk composition exceeds 50%
- Contains volcanic glass in the matrix

Areas to attract special attention:

(d) The rock is sheared (the quartz may be strained and become alkali-reactive).

Areas to attract special attention:



(e) Photograph showing a contact between granite and volcanic tuff.

The tuff is alkali-reactive.

Study of the ASR Potential of Aggregates:

(ii) Examination of Crushed Rock Aggregates
(a) By visual inspection

Crushed rock aggregates stock piling in the quarry

Crushed rock aggregates

A Typical Hand Lens (Ruper 'original' chrome metal loupe)

A Typical Stereoscopic Microscope (VanGuard Binocular Stereo Dual Magnification Microscope)

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Study of the ASR Potential of aggregates:

(ii) Examination of Crushed Rock Aggregates
(b) By petrographic examination

Petrographic examination

- Generally involves identification of rock and mineral constituents present in the aggregates.
- Particular attention is drawn to the constituents which may have deleterious effects in concrete.
- For study of very fine-grained rocks, additional procedures may be employed, such as X-ray diffraction analysis.

Point counting

To quantify the relative proportions of the deleterious constituents in the aggregate sample.

Equipment and machinery for petrographic examination

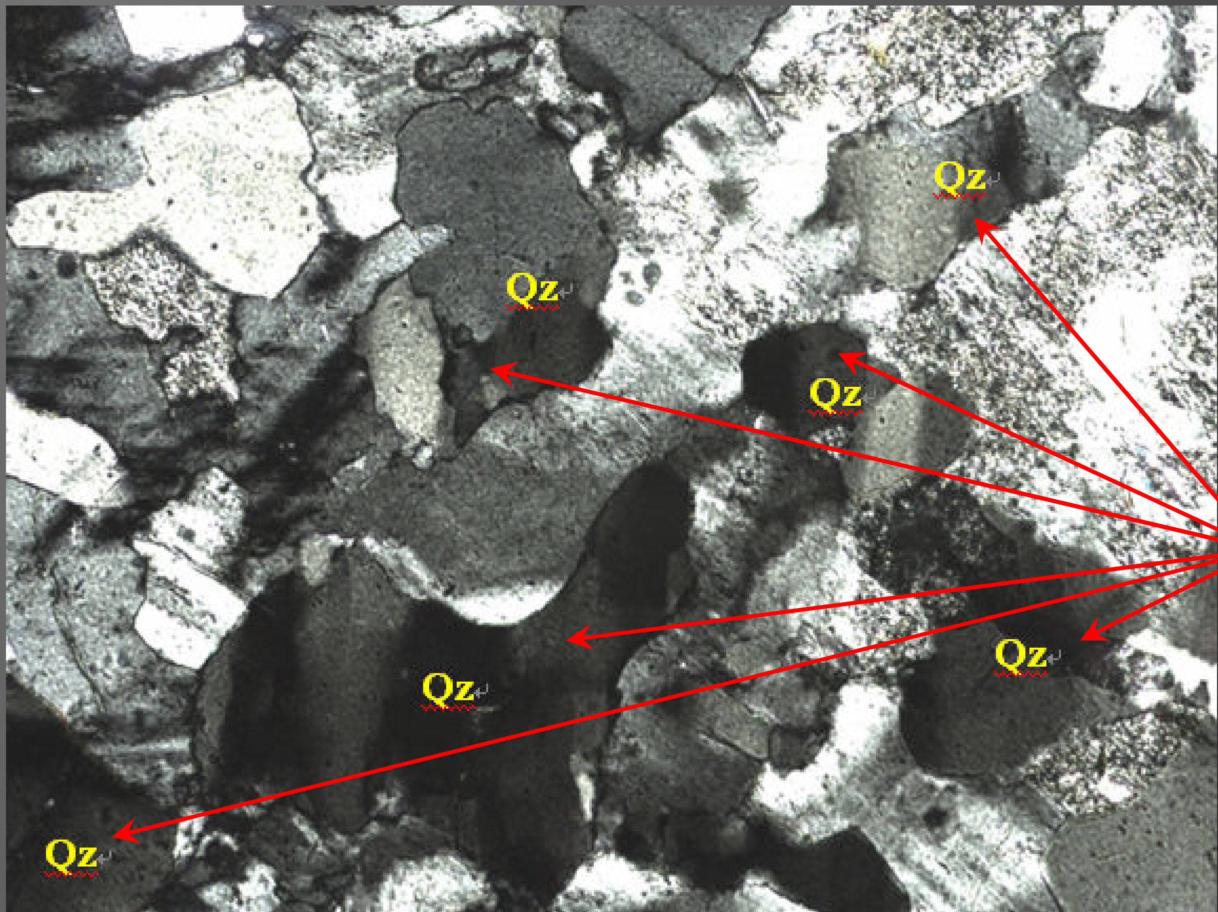
(i) Aggregate thin section

(ii) A petrographic microscope

(iii) A point counting device

(MAX-200T Trinocular Microscope)

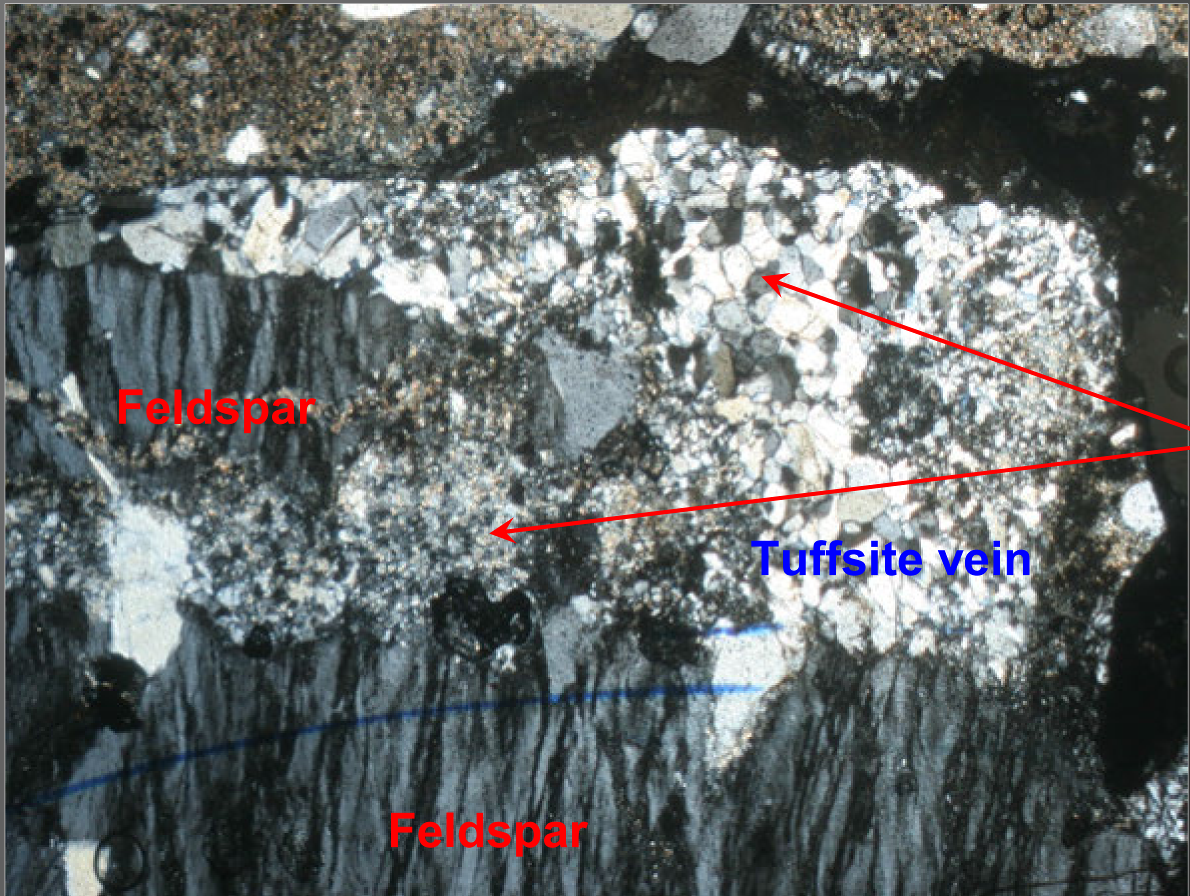
Special features under the microscope:



(a) Photograph showing undulose extinction in strained quartz (Qz) in gfm (XPL, Field of View = 1.0 mm)

Potentially reactive constituents – Strained quartz

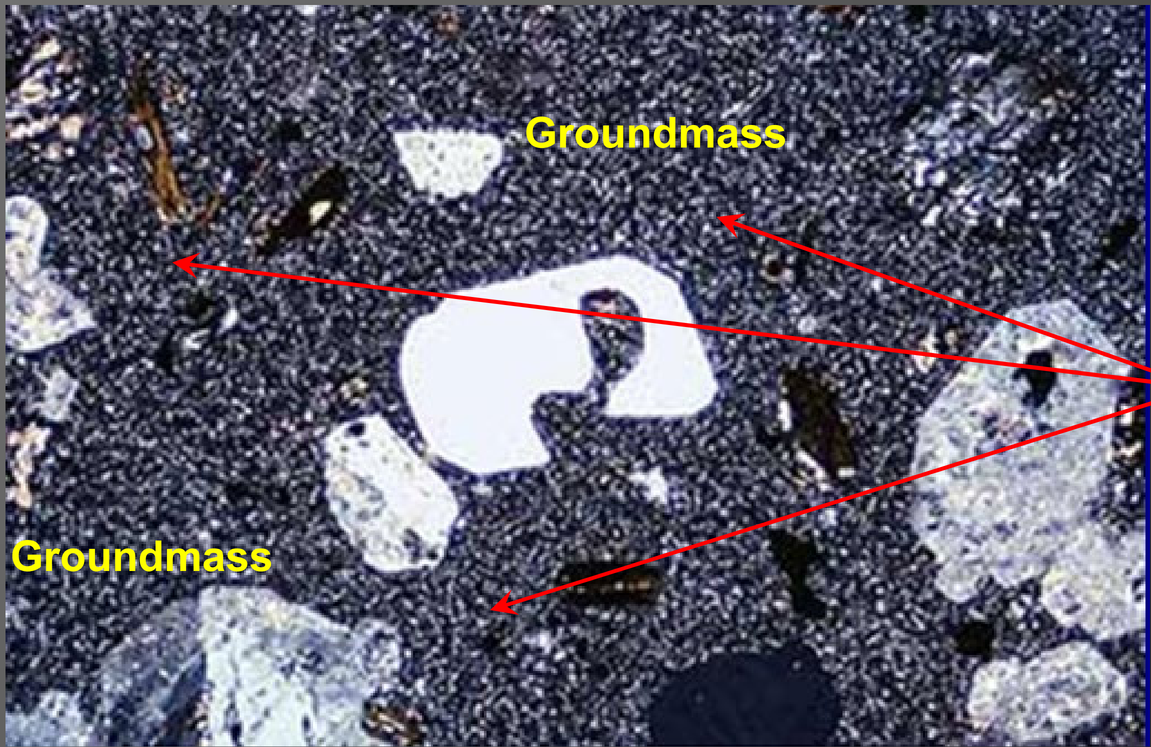
Special features under the microscope:



(b) A tuffisite vein within a gm aggregate (XPL, FoV = 1.44 mm)

Potentially reactive constituents – Microcrystalline to cryptocrystalline quartz associated with tuffisite veins

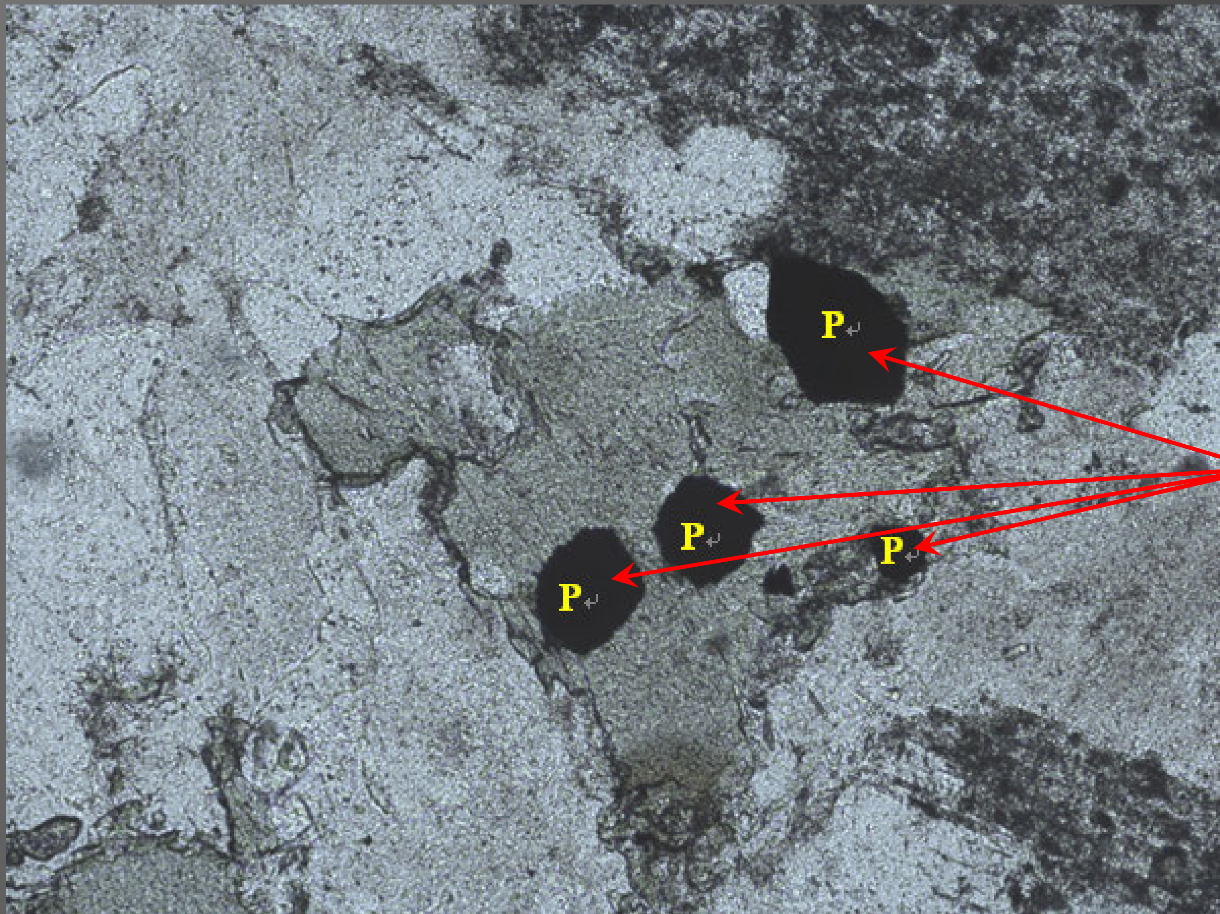
Special features under the microscope:



(c) A rhyolite dyke
Contains quartz and feldspar phenocrysts in a very fine-grained groundmass (XPL)

Potentially reactive constituents – Microcrystalline to cryptocrystalline quartz/devitrified glass in the very fine-grained groundmass

Special features under the microscope:



(d) Photograph showing pyrite minerals (P) in megacrystic fine-grained diorite (PPL, Field of View = 1 mm)

Potentially reactive constituents – Pyrite (some forms of pyrite are capable of decomposing in an alkaline environment accompanied with a volume increase in concrete)

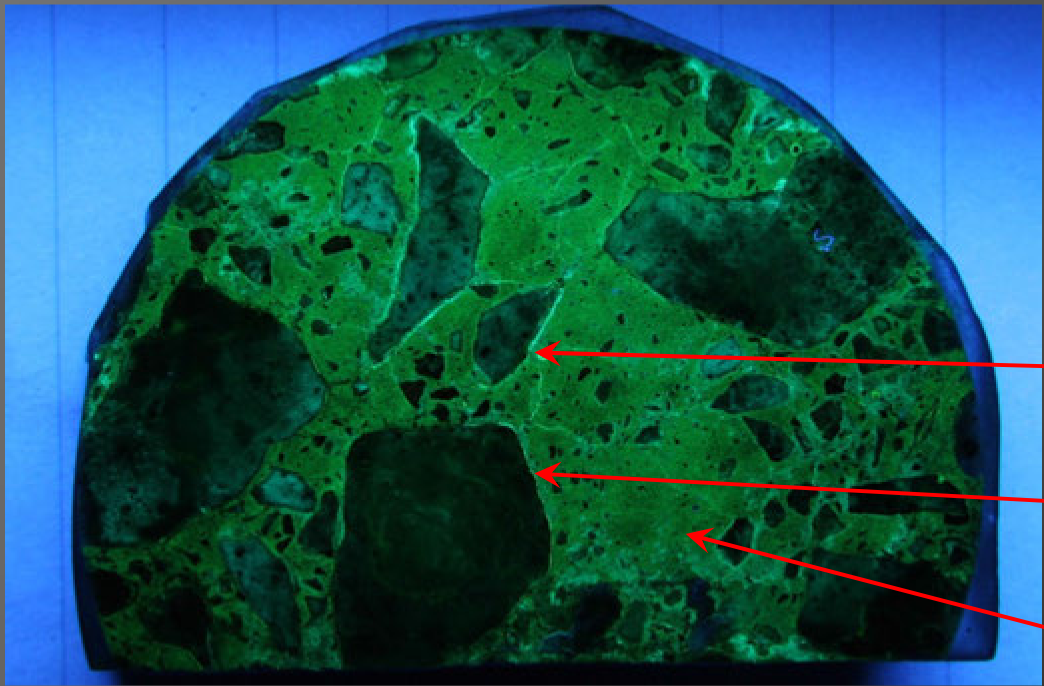
Study of ASR in hardened Concrete:

(a) By visual inspection

Severe ASR type cracking and beige discoloration

Study of ASR in hardened Concrete:

(b) By uranyl acetate test



Uranyl acetate test on a concrete polished slab

Regarded as ancillary rather than diagnostic test for alkali-silica gel because not only alkali-silica gel may fluoresce in the concrete under shortwave UV light.

- Alkali-silica gel (with bright greenish yellow fluorescence)
- Ettringite (with weak green fluorescence)
- Carbonated areas of concrete (with very faint green fluorescence) may also fluoresce

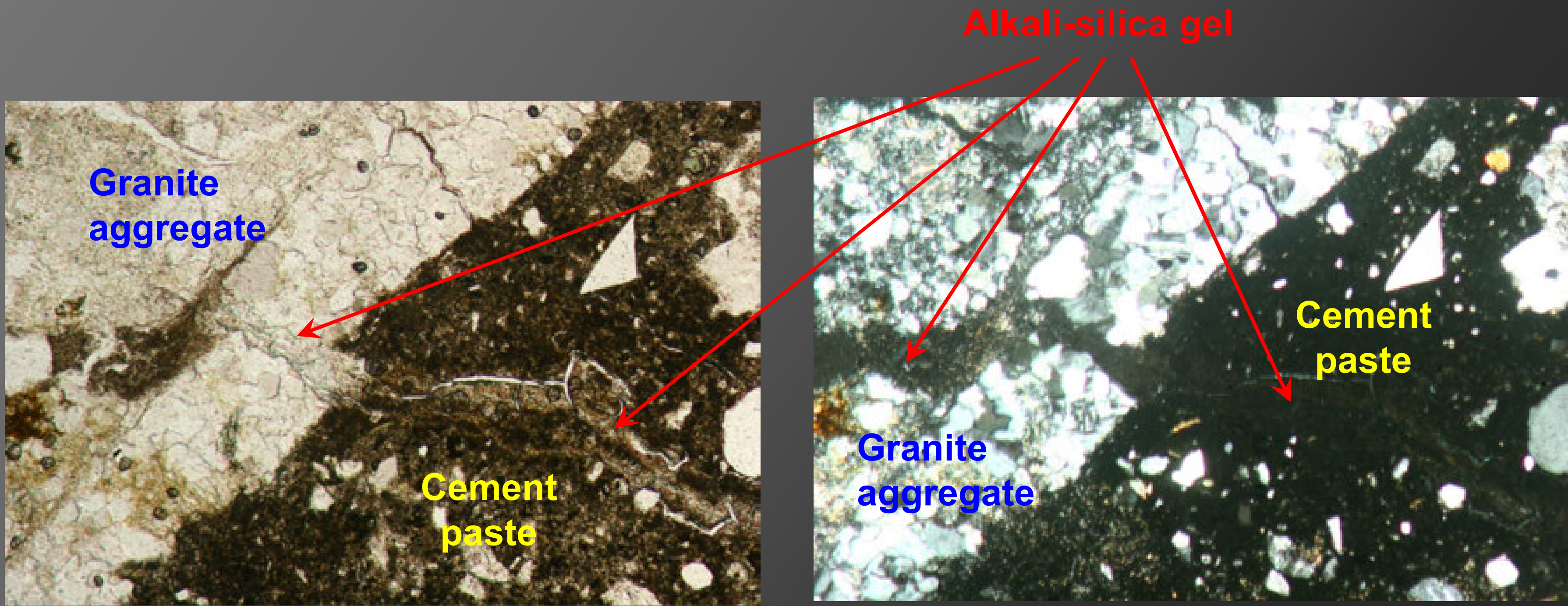
Study of ASR in hardened Concrete:

(c) By petrographic examination

A concrete thin section

A petrographic microscope
(MAX-200T Trinocular Microscope)

ASR features under the microscope:

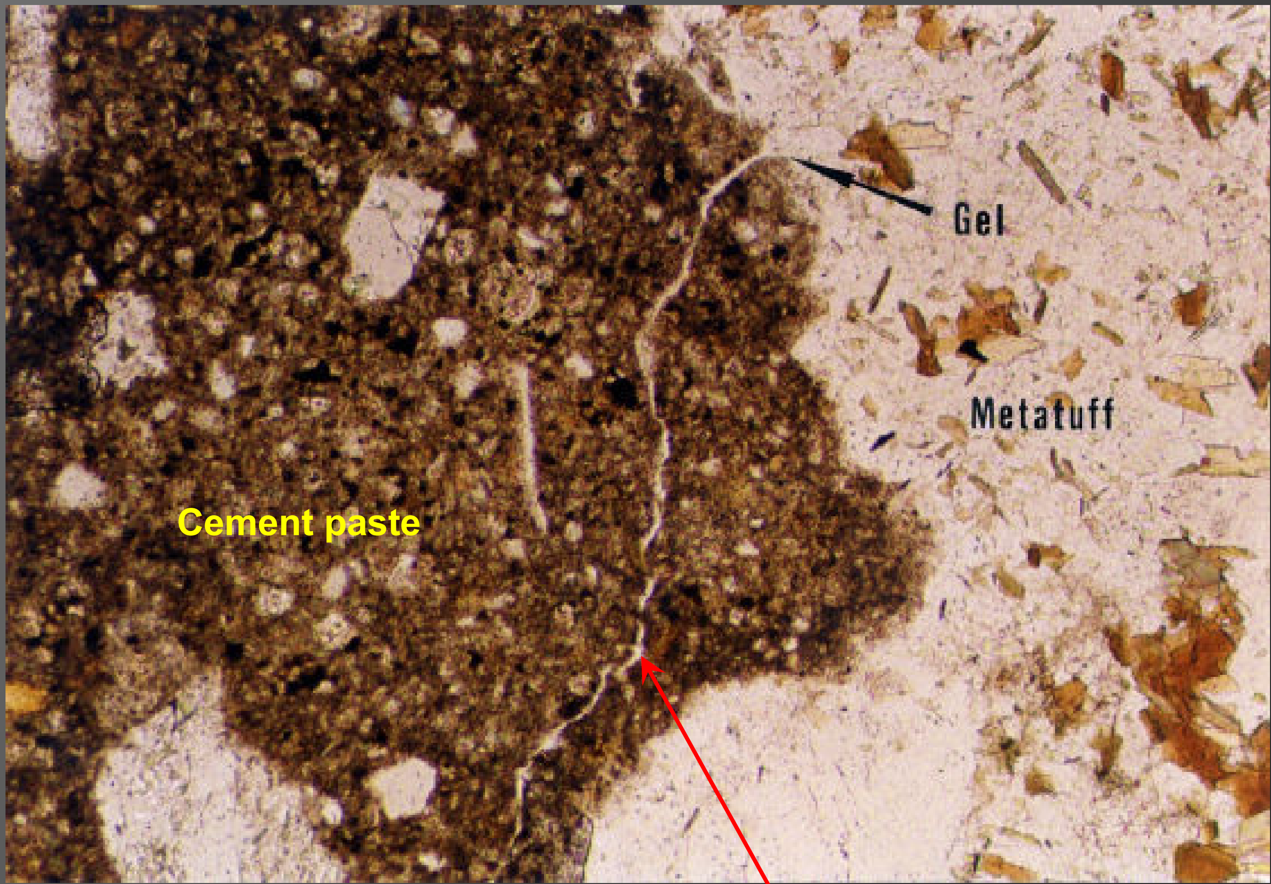


Under PPL

Under XPL

Photographs showing a concrete thin section with alkali-silica gel extruding from a tuffisite vein (alkali-reactive) in fine-grained granite into adjacent cement paste (FoV = 1.44 mm).

ASR features under the microscope:



A concrete thin section showing a microcrack in cement paste infilled with alkali-silica gel emanating from a metatuff aggregate (alkali-reactive) (PPL, F0V = 3.6 mm)

C. Construction Standard on Aggregates for Concrete (CS3), Draft

CS3 – Section 9 (Method for Petrographic Examination of Aggregates)

Scope

Covers the method and procedures for petrographic examination of materials intended for use as aggregates in concrete

Principle

To identify and quantify the rock and mineral constituents present in the aggregates.

Focusing on any materials/mineral constituents whose properties may influence the behavior of concrete, such as AAR.

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Sampling

Materials including:

- rock sample/drilled core from undeveloped quarries
- natural aggregate
- crushed rock aggregate

Sampling be carried out or directly supervised by a geologist

Petrographic Examination

- Be carried out by a qualified petrographer:

(i) either have a degree pertaining to geology, mineralogy, petrography and optical mineralogy, knowledge and at least 5 years of relevant experience in materials used in concrete, or

(ii) have obtained equivalent knowledge and experience through on-the-job training.

- Examination through:

(i) Visual inspection of hand specimen

(ii) Examination of rock/aggregate thin section under a petrographic microscope, with point counting (if necessary)

Report

- To describe fully all essential physical properties of the sample.

- To describe both qualitatively and quantitatively for sample that is found to have potential deleterious effects in concrete and the suspected unfavorable effects in concrete, such as AAR

- To classify the sample into 3 categories in terms of its potential alkaline reactivity: *Non-reactive/Potentially Reactive/Reactive*

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THE END