55º Congresso Brasileiro do Concreto
GRAMADO | RS

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Alkali Aggregate Reactions (AAR)

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FIFA WORLD CUP
Brasil

MANNVIT

NTNU – Trondheim
Norwegian University of
Science and Technology

NORSTONE
HEIDELBERGCEMENT Group

Concrete durability

Pantheon, Rome

27 BC - 124 AD

Height 43 meters


The Atlantic Road - Norway

Geothermal water plant - Iceland

Alkali Aggregate Reactions
AAR

- ASR – Alkali Silica Reaction
- ACR – Alkali Carbonate Reaction

Headlines of today:

- **WHAT** is AAR ?
  - Mechanisms
  - Cases
- **HOW** to diagnose AAR in existing structures !
- **How** to prevent AAR in future structures !
  - Mitigating AAR
  - Test methods
  - Regulations
- **The path forward – the future !**

What is AAR ?

Alkali Aggregate Reactions (AAR)

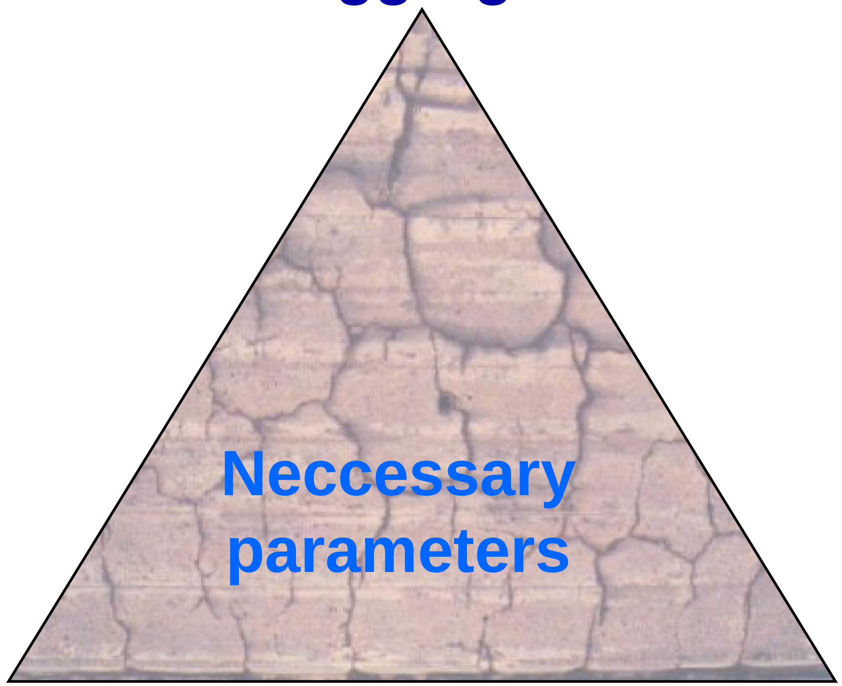
- Alkalies producing a silica-gel by dissolving soluble SiO_2 (e.g. Quartz) in the aggregate.
  - Gel has hygroscopic properties, leading to expansion under moist conditions.
- 5-50 years, depending on the type of aggregate and environmental conditions

Consequences

- Expansion and (map) cracking
- Constraining forces
  - Reduced capacity
- Influence on material properties
  - Reduced capacity
- Initialize other deterioration mechanisms
  - Frost damage
  - Rebar corrosion

Mechanisms of AAR

Reactive aggregates



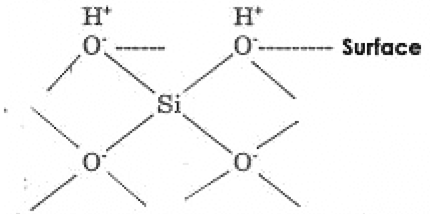
Alkalies

(usually supplied by the cement, although external sources can exist).

Water

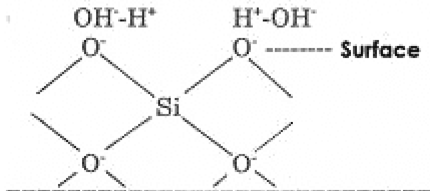
(or high moisture content)

start



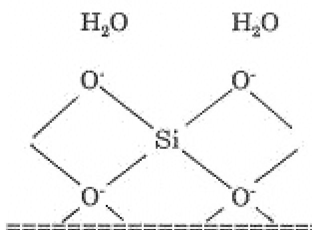
Original situation of the surface of a SiO_2 structure

1



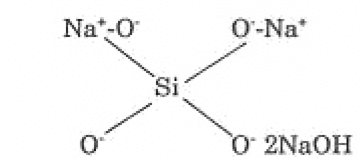
Acide-base reaction; Hydroxide from solution reacts with acidic silanol groups

2



H_2O is released

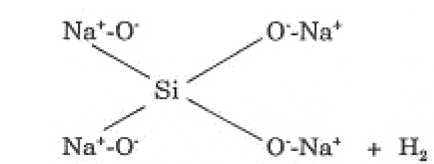
3



O^- is balansed with the Na^+ions that simultaneously diffuse into the structure

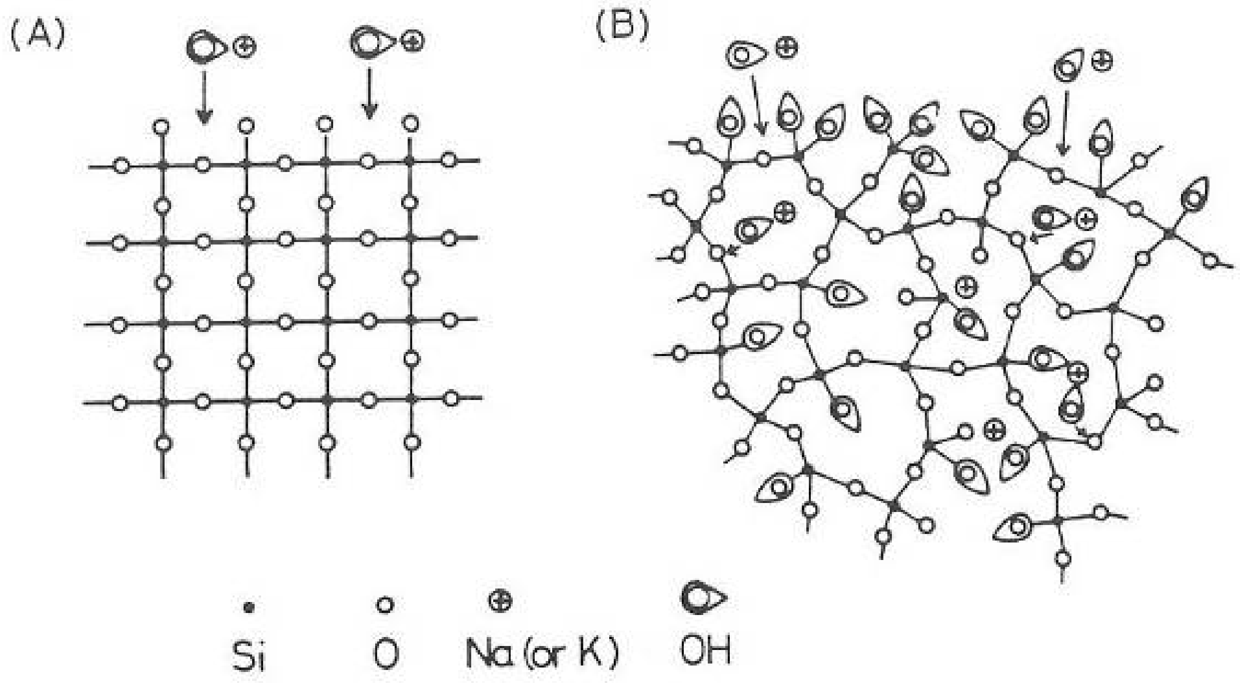
The siloxane bridges, that hold the whole mass together break and increase the capasity to absorb Na^+ and H_2O

end



Na-Si-gel + H_2 are produced
The SiO_2 structure is disintergrated

Chemistry of AAR

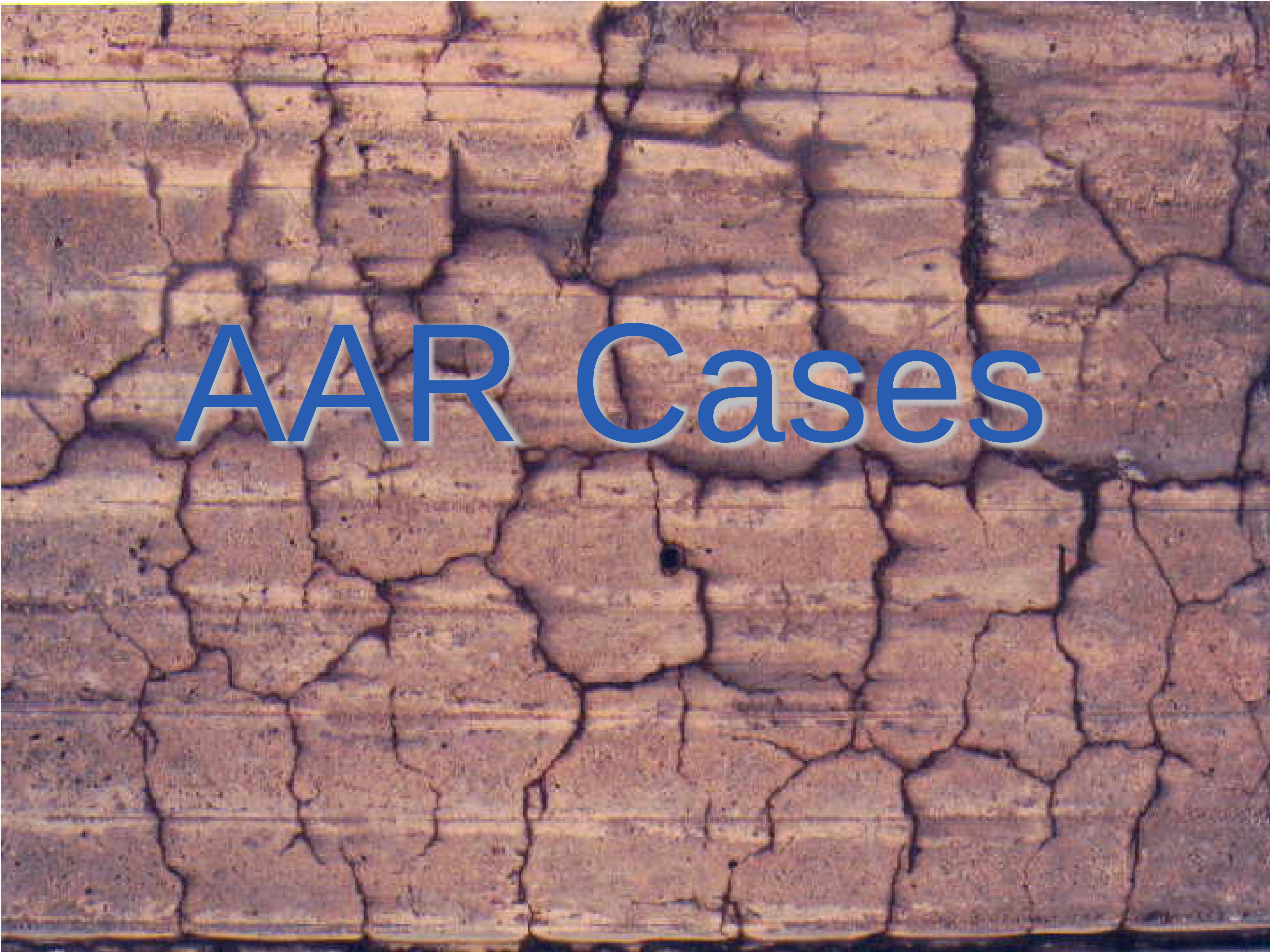


The attack of alkali on:

- **(A) - well crystallized silica**
- **(B) - poorly crystallized hydrous silica**

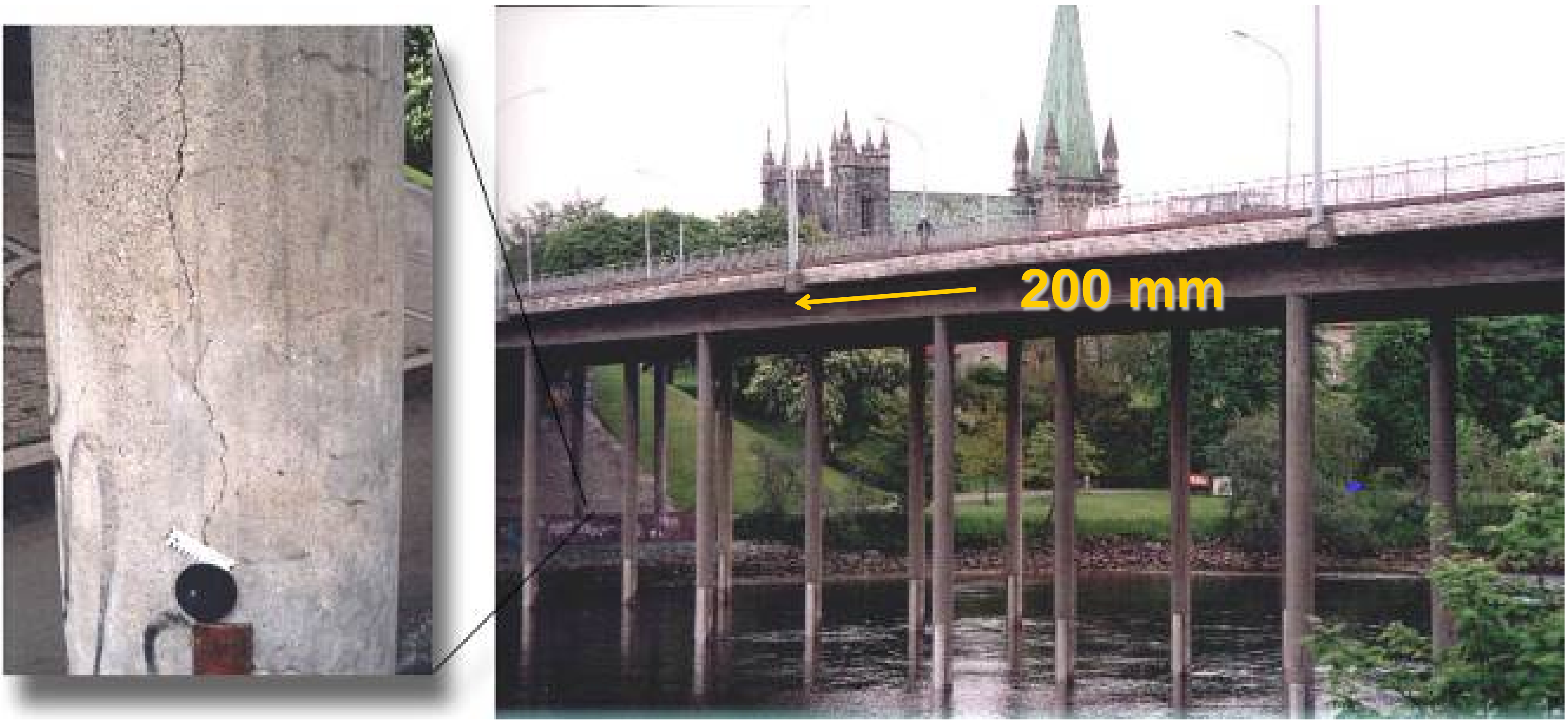
Crystall structure affecting the reactivity

AAR Cases



Elgeseter Bridge Trondheim, Norway

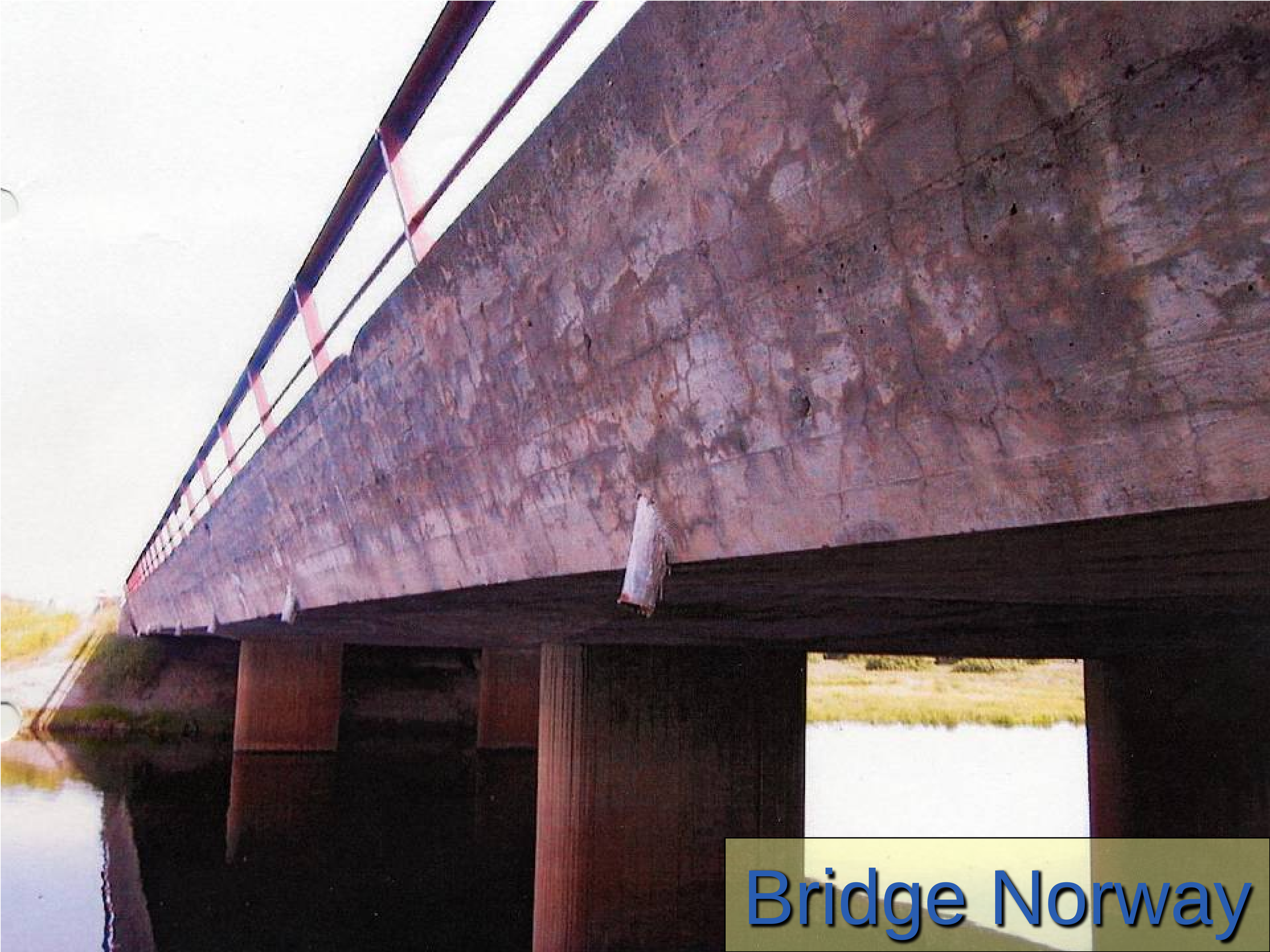
- Built 1949-51
- Length 220 m
- Width 23 m
- Height 17 m


200 mm

- Most cracked - west side
- Cracks 0,25 mm/year
- In-situ measurement of RH


Installation of new columns
200 mm

Confinement with Carbon Fibre Reinforcement Polymers (CFRP)



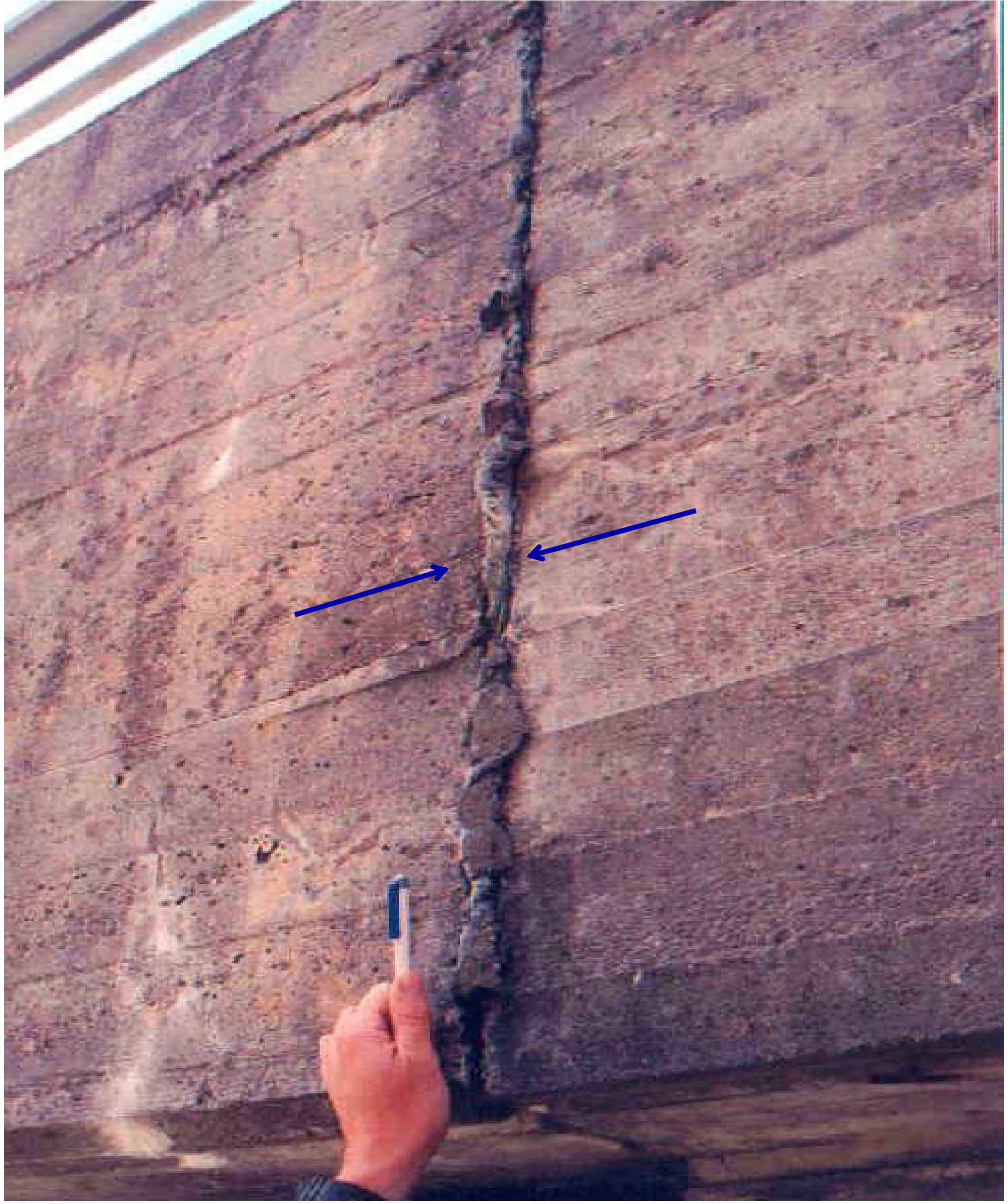
Bridge Norway

Bridge Norway

Bridge Norway

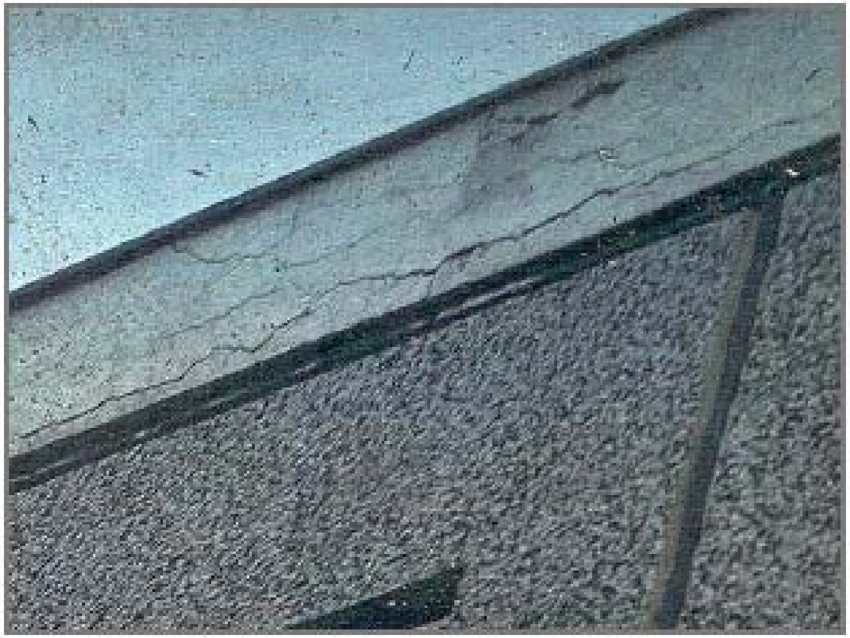
Bridge Northern Norway

Dam Northern Norway



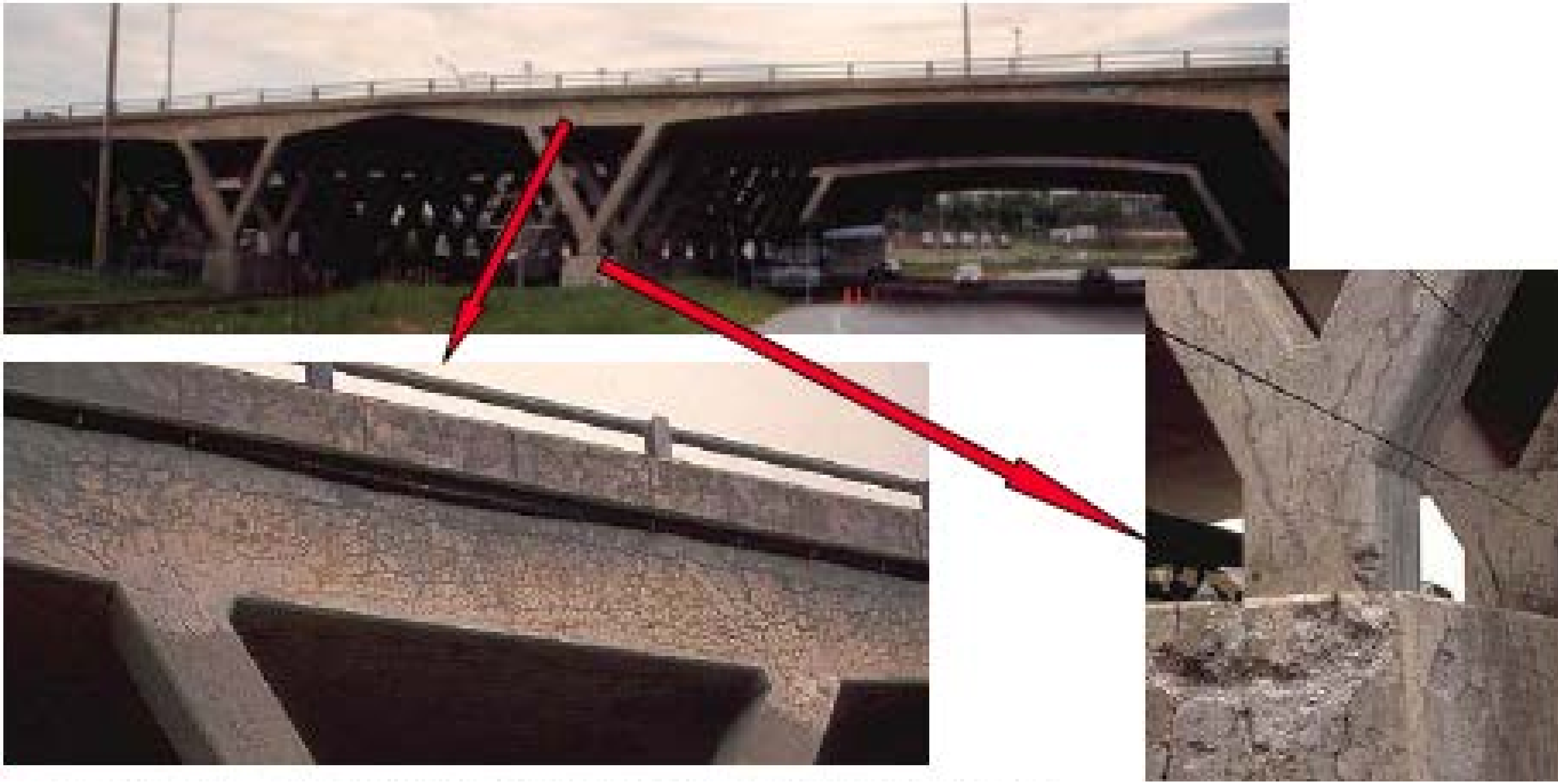
Dam
Norway






Switzerland

Bridge Canada



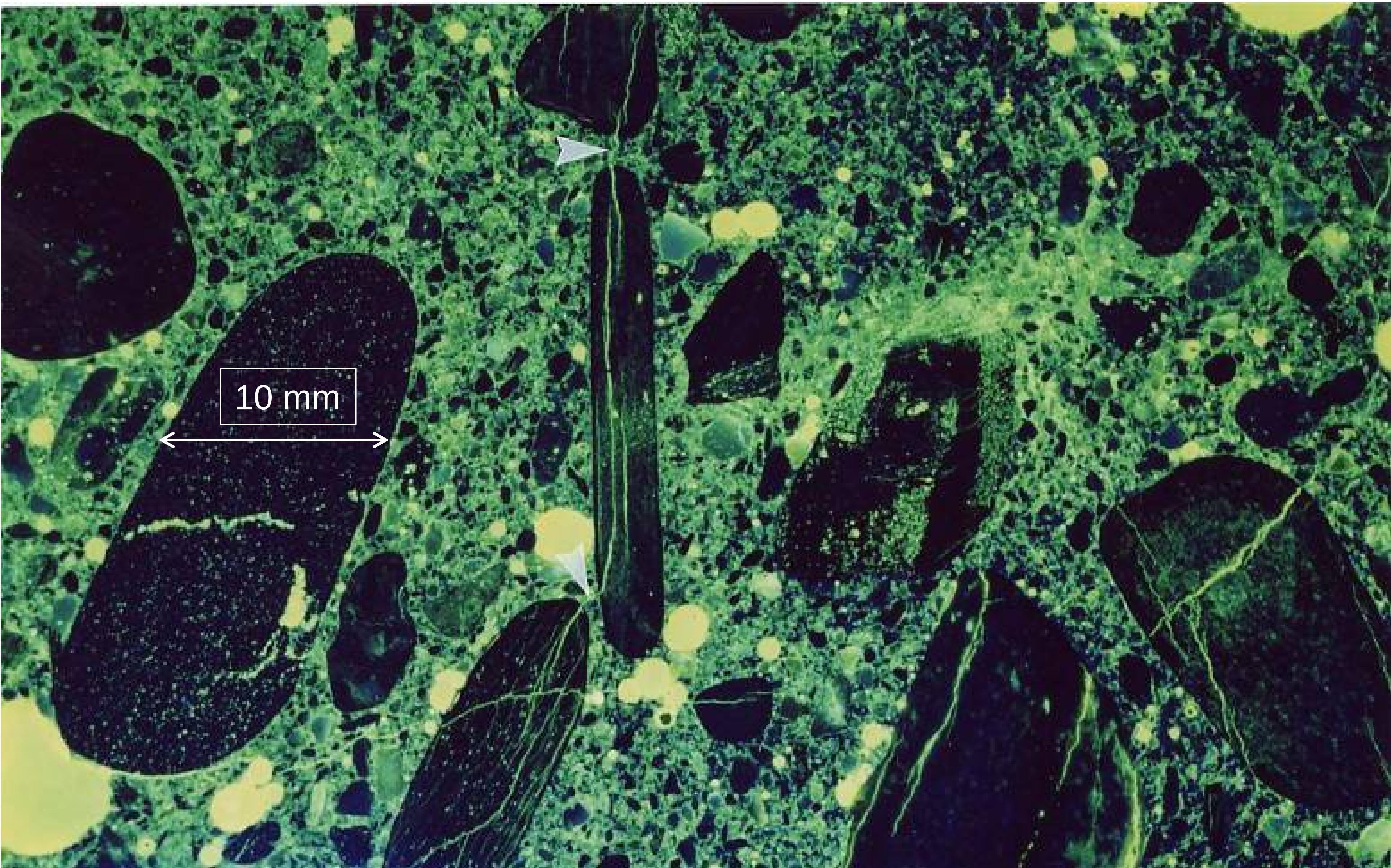
Pavement US

How to diagnose AAR in existing structures ?

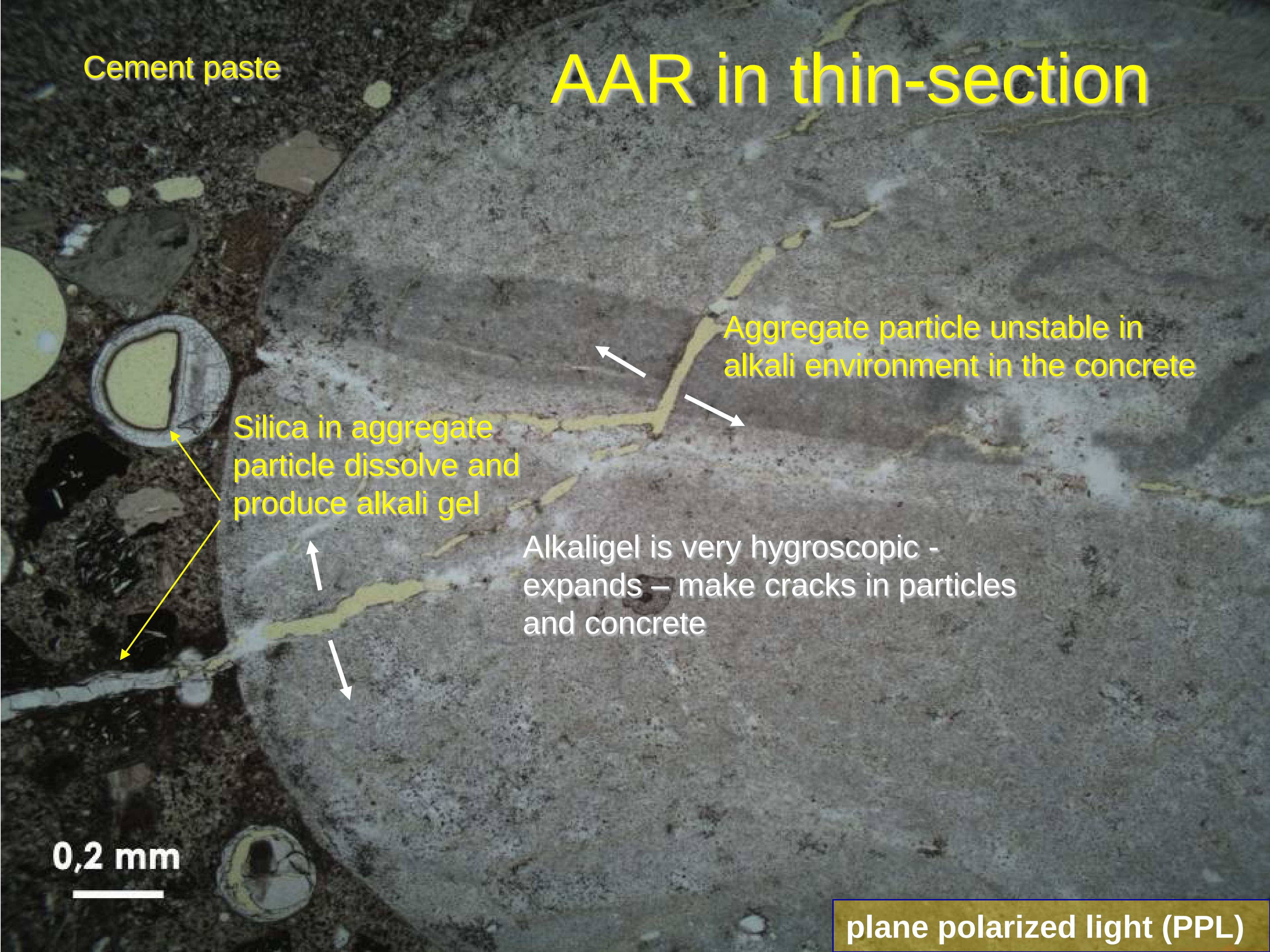
Sampling concrete cores

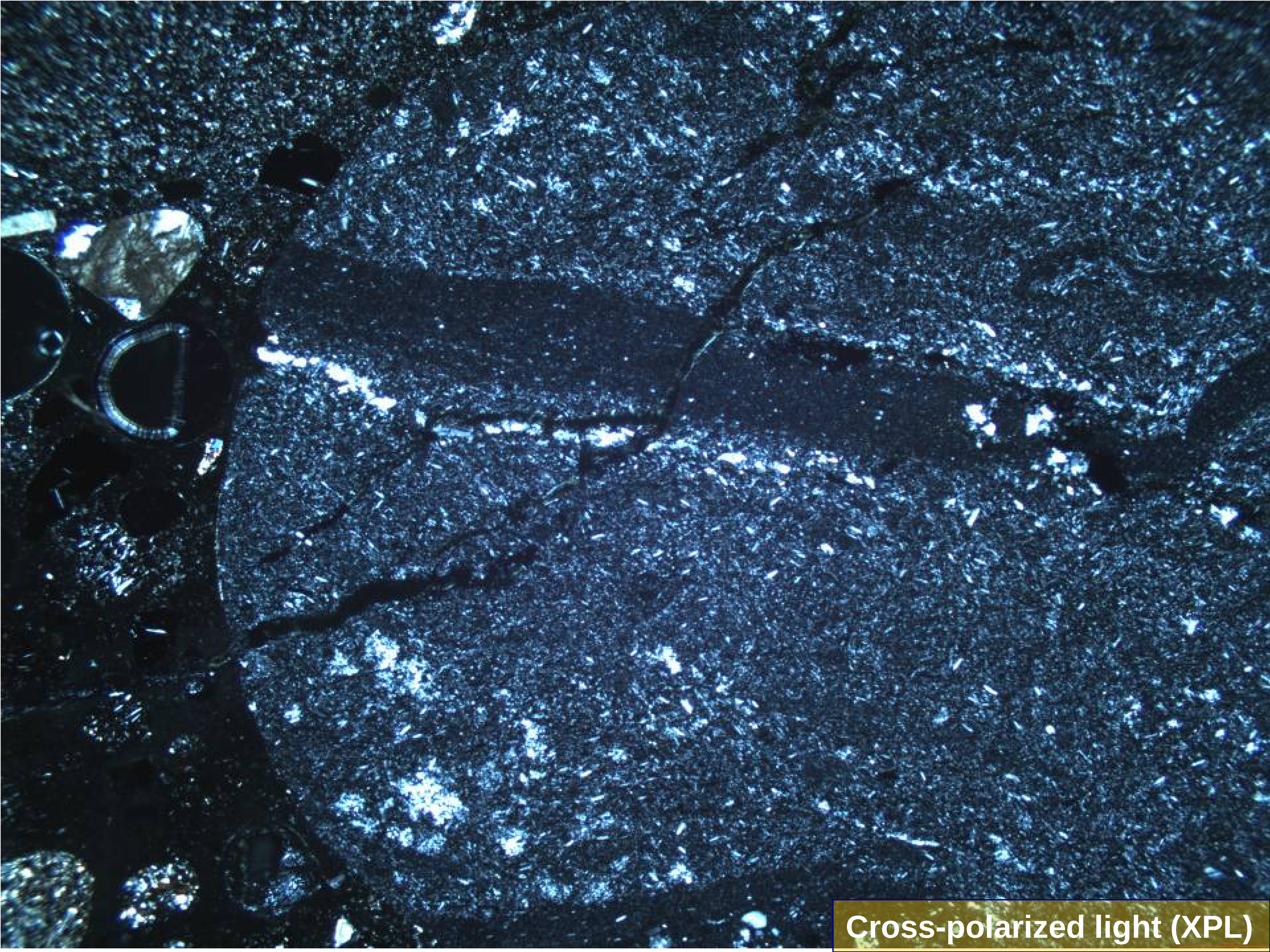
Fluorescence impregnated plane section

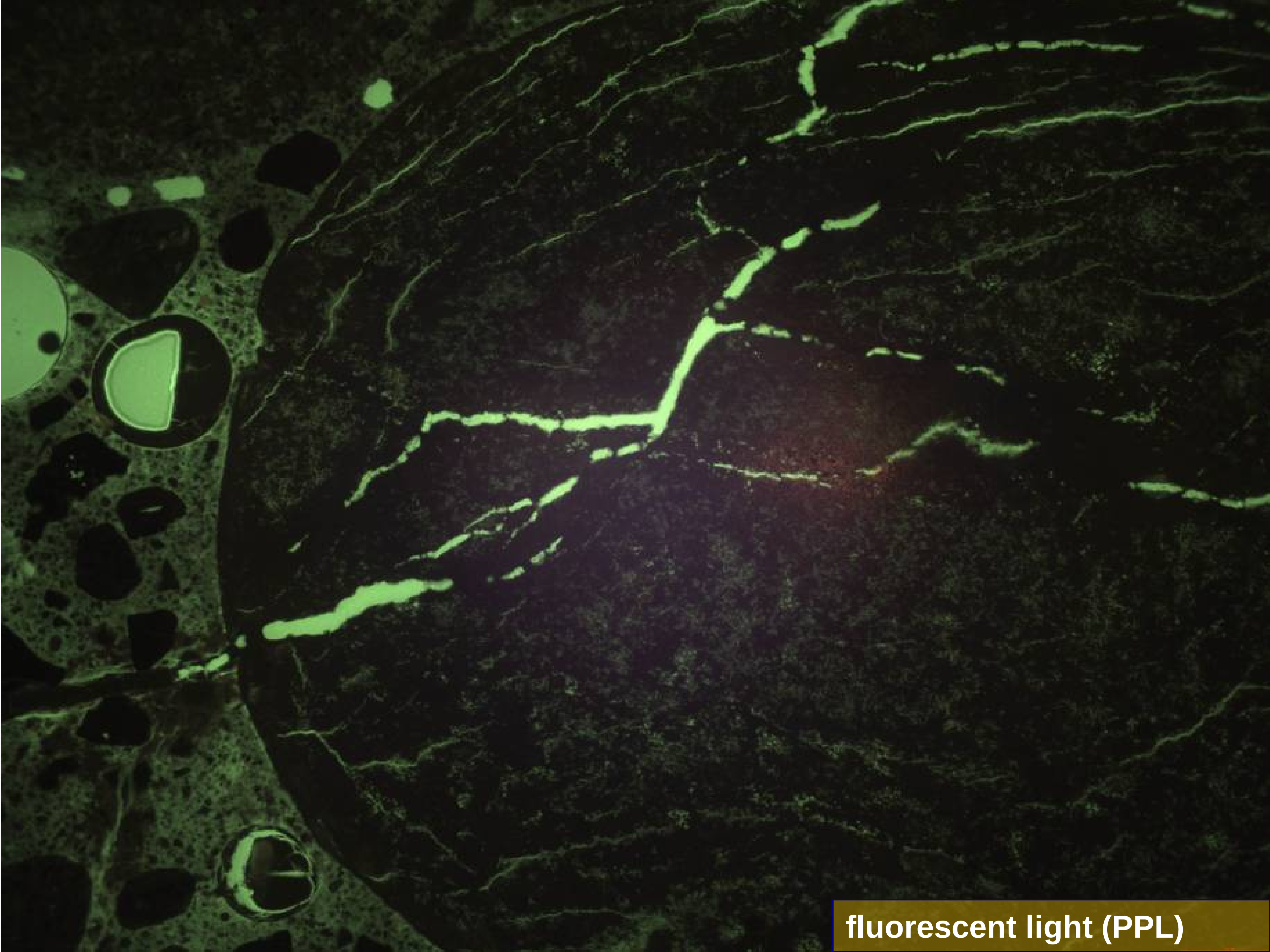
- Damaging Rate Index (DRI)



Thin-section examination

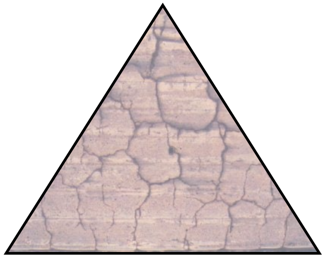

AAR in thin-section
Cement paste
Aggregate particle unstable in alkali environment in the concrete
Silica in aggregate particle dissolve and produce alkali gel
Alkaligel is very hygroscopic - expands – make cracks in particles and concrete
0,2 mm
plane polarized light (PPL)


Cross-polarized light (XPL)


fluorescent light (PPL)

How to prevent AAR in future concrete structures ?

Mitigating AAR

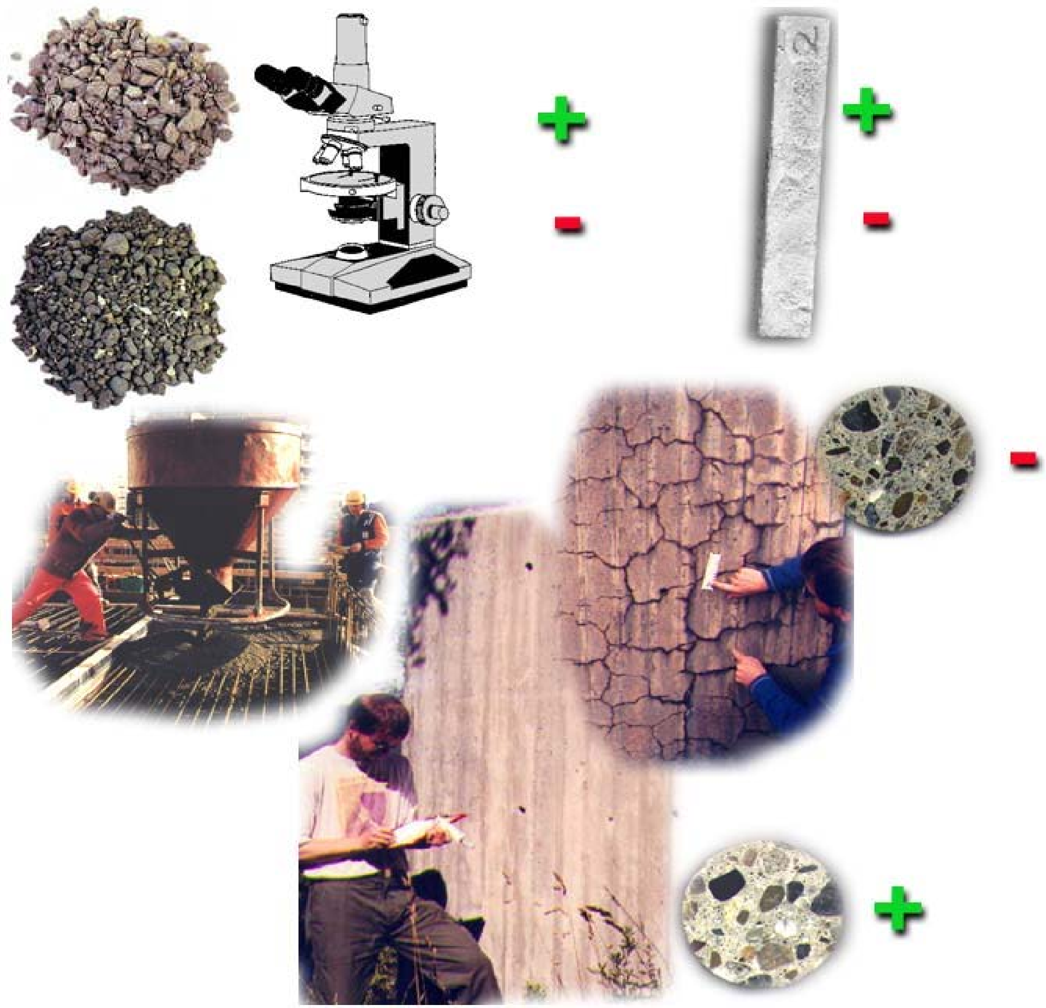


- Limit the total alkali content of the concrete mix;
- Use a non-reactive aggregate combination;
- Limit the degree of saturation of the concrete with water

Other measures:

- **Fly ash** - replacing up to 30% of the Portland cement (by mass)
- **Natural pozzolanic materials** with low lime content (<2% CaO)
- **Silica fume** 4-6% (Iceland)
- Ground granulated blast furnace slag (**GGBFS**) (50% by mass)
- **Lithium** - amount can be high and varies depending on the aggregate

Test methods



Test methods by RILEM

- Three successive Technical Committees (TC)
- Initially focused on accelerated tests for aggregate reactivity
- Extended to :
  - Specification
  - Diagnosis and assessment
  - Appraisal and repair
  - Modelling of structures
  - Performance testing
  - Releasable alkalis in aggregates
  - Petrographic atlas

International Union of Laboratories and Experts in Construction Materials, System and Structures

Test Methods

1. Petrographic examination (RILEM AAR-1) *[ASTM 295]*
2. Accelerated mortar bar test (RILEM AAR-2) [ASTM 1260]
3. Concrete prism tests (RILEM AAR-3 & 4) [ASTM 1293]

- Performance testing
- Field exposure sites

The petrographic metod (RILEM AAR-1)

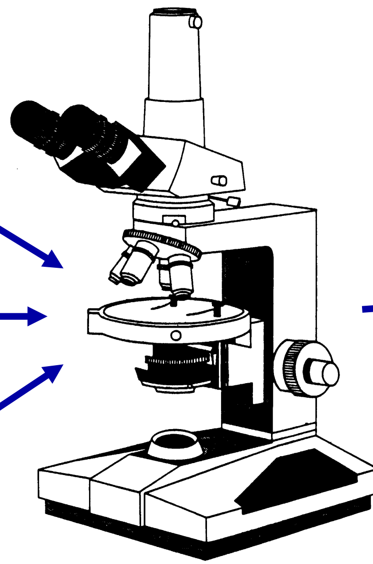
1-2 mm

1000
points
counted

2-4 mm

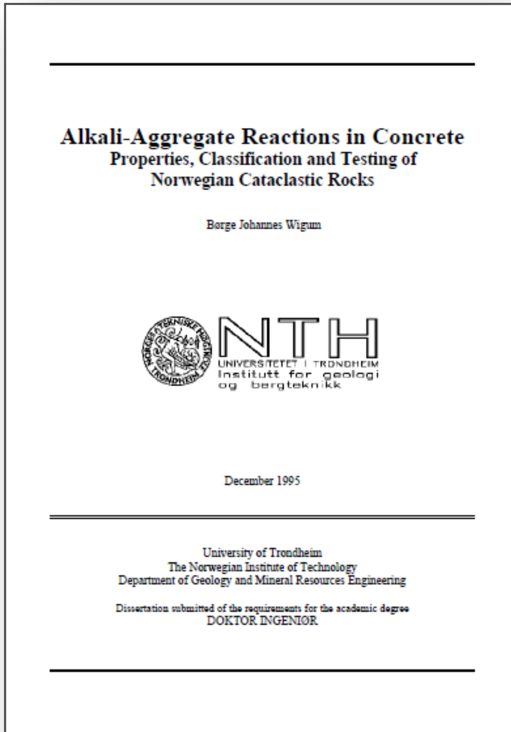
1000
points
counted

2-4 mm



The content of potentially
alkali reactive rock types

Norway:
20% critical content


Alkali-Aggregate Reactions in Concrete
Properties, Classification and Testing of
Norwegian Cataclastic Rocks

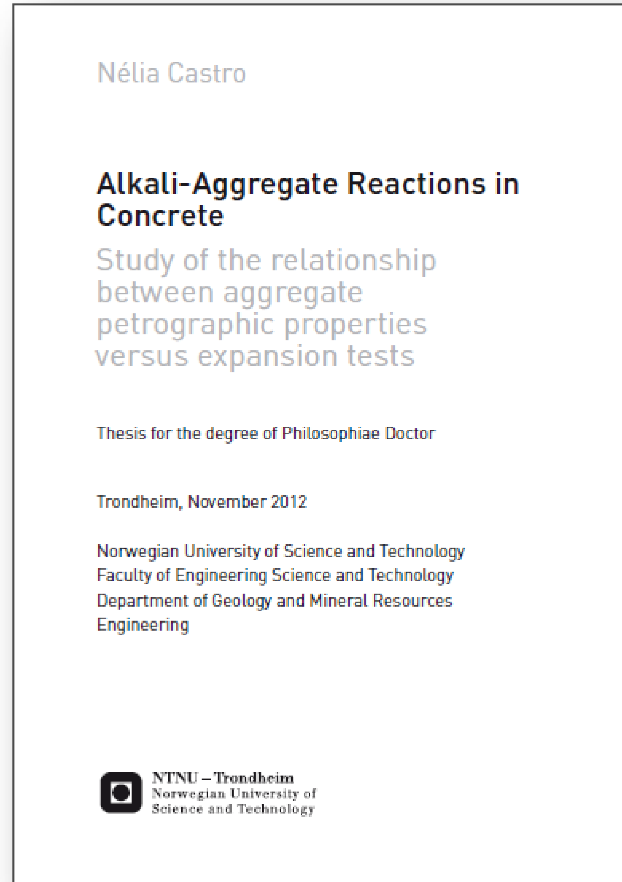
Børge Johannes Wigum

NTH
UNIVERSITETET I TRONDHEIM
Institutt for geologi og bergteknikk

December 1995

University of Trondheim
The Norwegian Institute of Technology
Department of Geology and Mineral Resources Engineering

Dissertation submitted of the requirements for the academic degree
DOKTOR INGENIØR


Nélia Castro

Alkali-Aggregate Reactions in Concrete

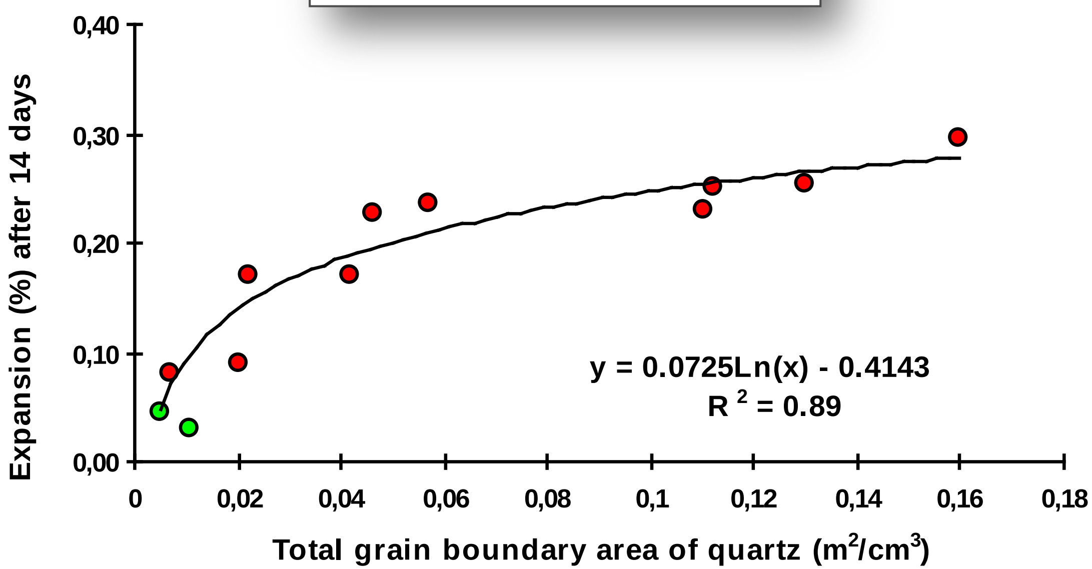
Study of the relationship between aggregate petrographic properties versus expansion tests

Thesis for the degree of Philosophiae Doctor

Trondheim, November 2012

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Geology and Mineral Resources Engineering

NTNU – Trondheim
Norwegian University of Science and Technology



Petrographic Atlas with Micrograph examples;

FARIN

Forum on Alkali-Reactions In Norway

www.farin.no

Accelerated Mortar Bar Test (RILEM AAR-2)

1N NaOH – 80°C – 14 days

bars 25 x 25 x 285mm

Used as a performance test ?

Concrete Prism Tests

prisms 75 x 75 x 285mm

RILEM AAR-3

RILEM AAR-4

RILEM AAR-3, AAR-4, (ASTM C 1293 & Norwegian method)

- 38°C or 60°C
- Wrapped (W) or Unwrapped (U) prisms
- Prism cross section: 70 mm or 100 mm
- All methods: prisms stored on grids over water (~100 % RH)

RILEM AAR-4.1 "Standard“

RILEM AAR-3
RILEM AAR-4.1 "Alternative"

ASTM-C1293
Norwegian

RILEM AAR-3

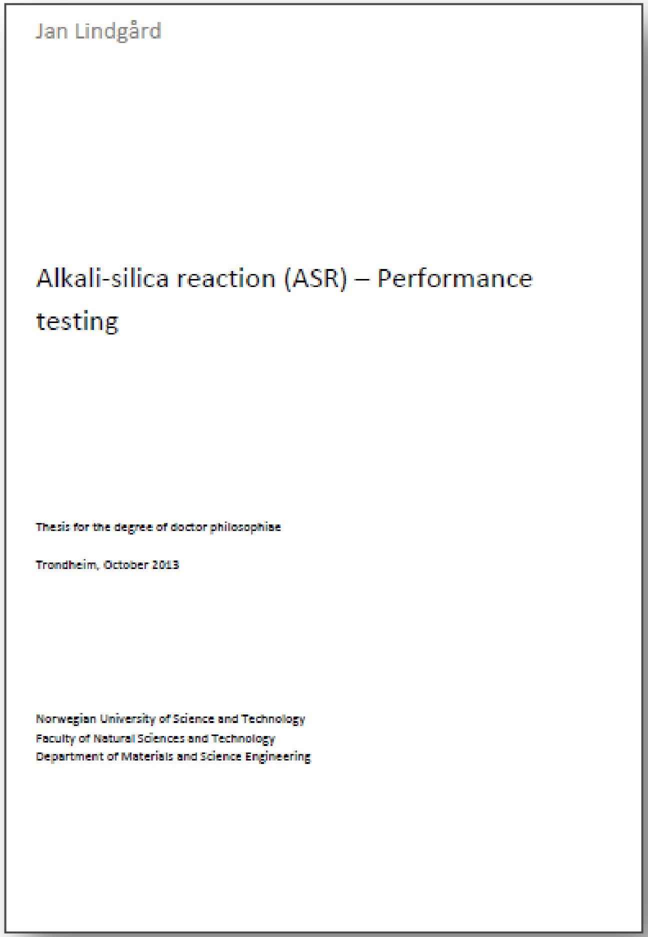
100%Rh –
38°C – 1 year

RILEM AAR-4

100%Rh –
60°C – 20 weeks

Parameters affecting expansion

- Wrapped or unwrapped
- Temperature ($38^{\circ}C$ – $60^{\circ}C$ – $80^{\circ}C$)
- Prism size
- Preconditions, curing etc.


Jan Lindgård

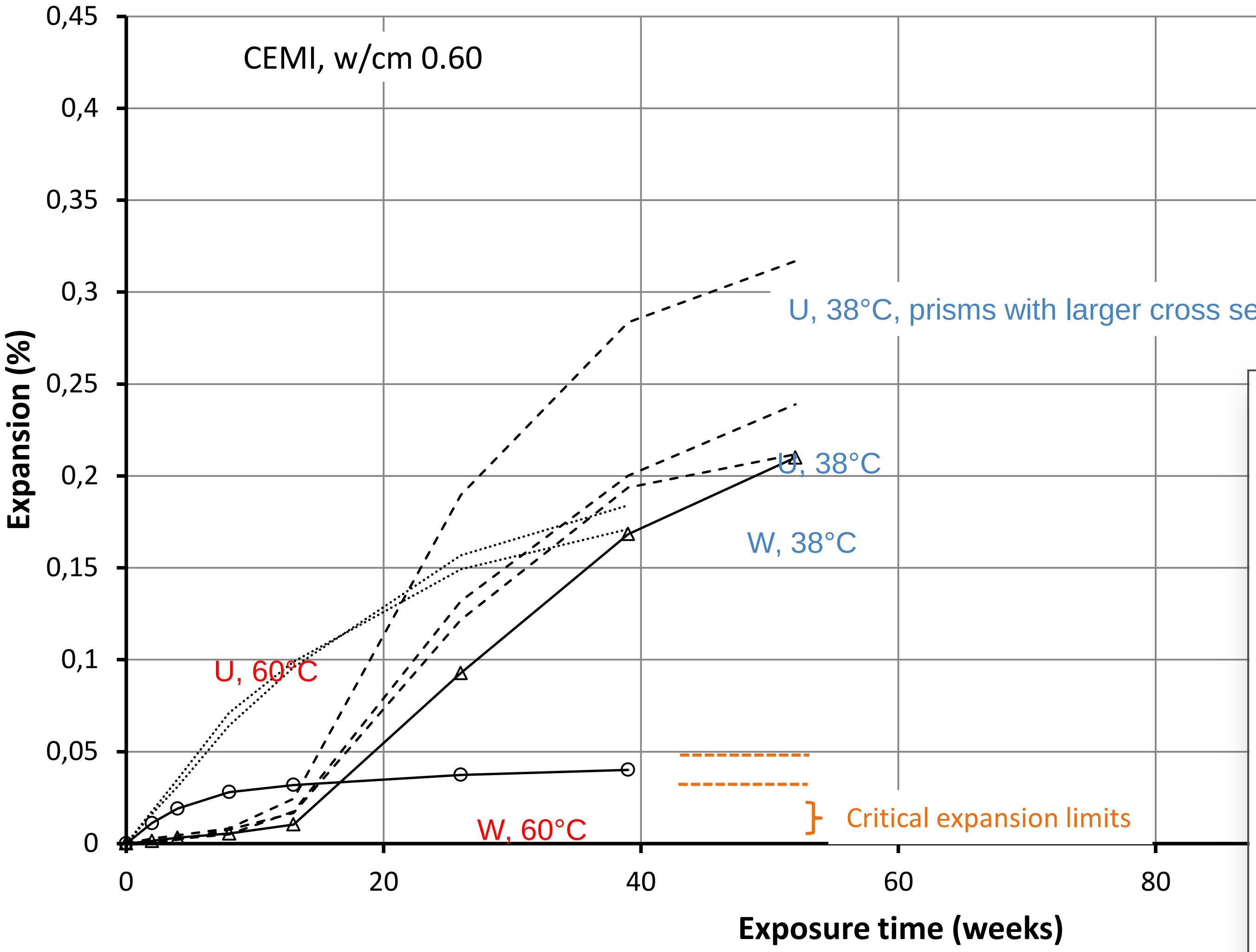
Alkali-silica reaction (ASR) – Performance testing

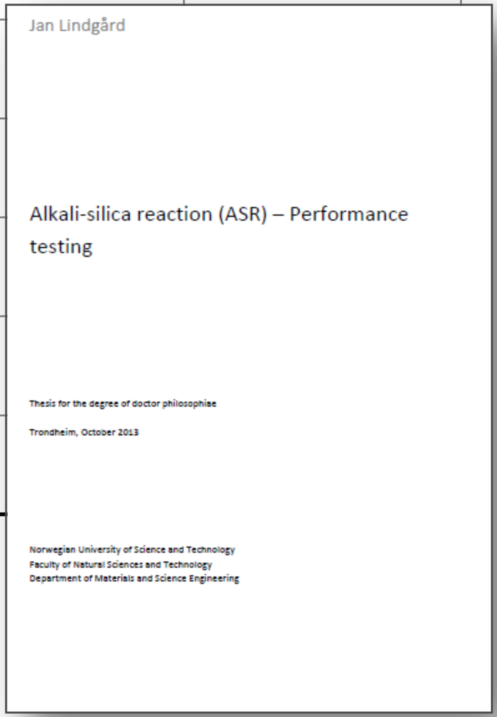
Thesis for the degree of doctor philosophiae

Trondheim, October 2013

Norwegian University of Science and Technology
Faculty of Natural Sciences and Technology
Department of Materials and Science Engineering

Parameters affecting expansion

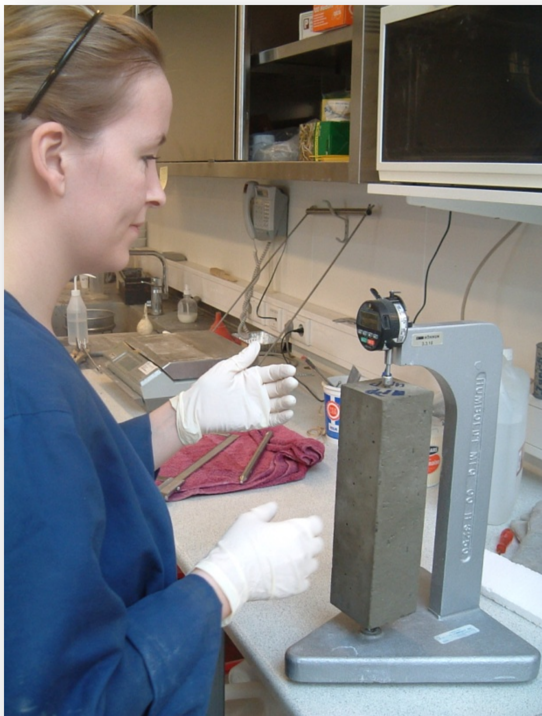




Expansion primarily controlled by rate and extent of alkali leaching !

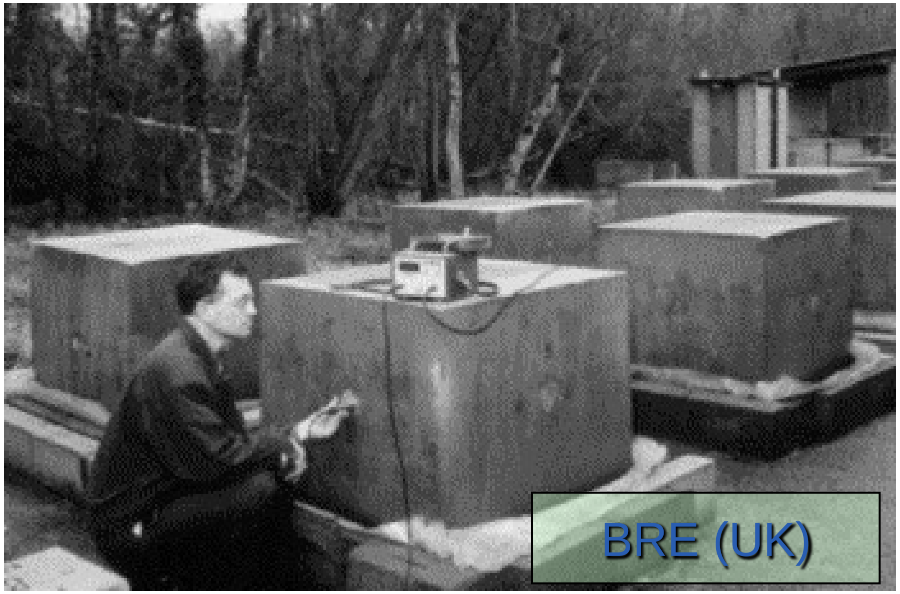
Larger prism cross-section: less alkali leaching

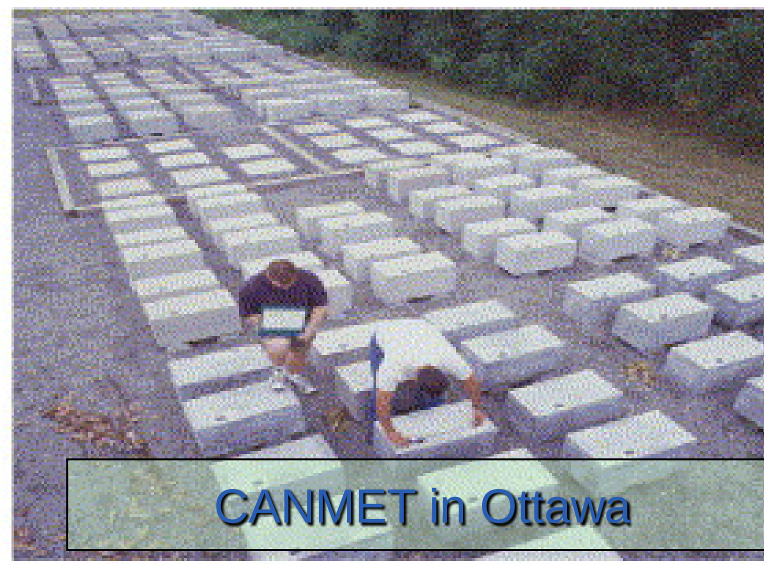
Performance testing; lab. vs. field
Comparing apples and pears?



The outcome of accelerated laboratory tests may depend on the extent of **leaching** of alkalis.

Exposure Sites






Valencia - Spain

Dusseldorf - Germany

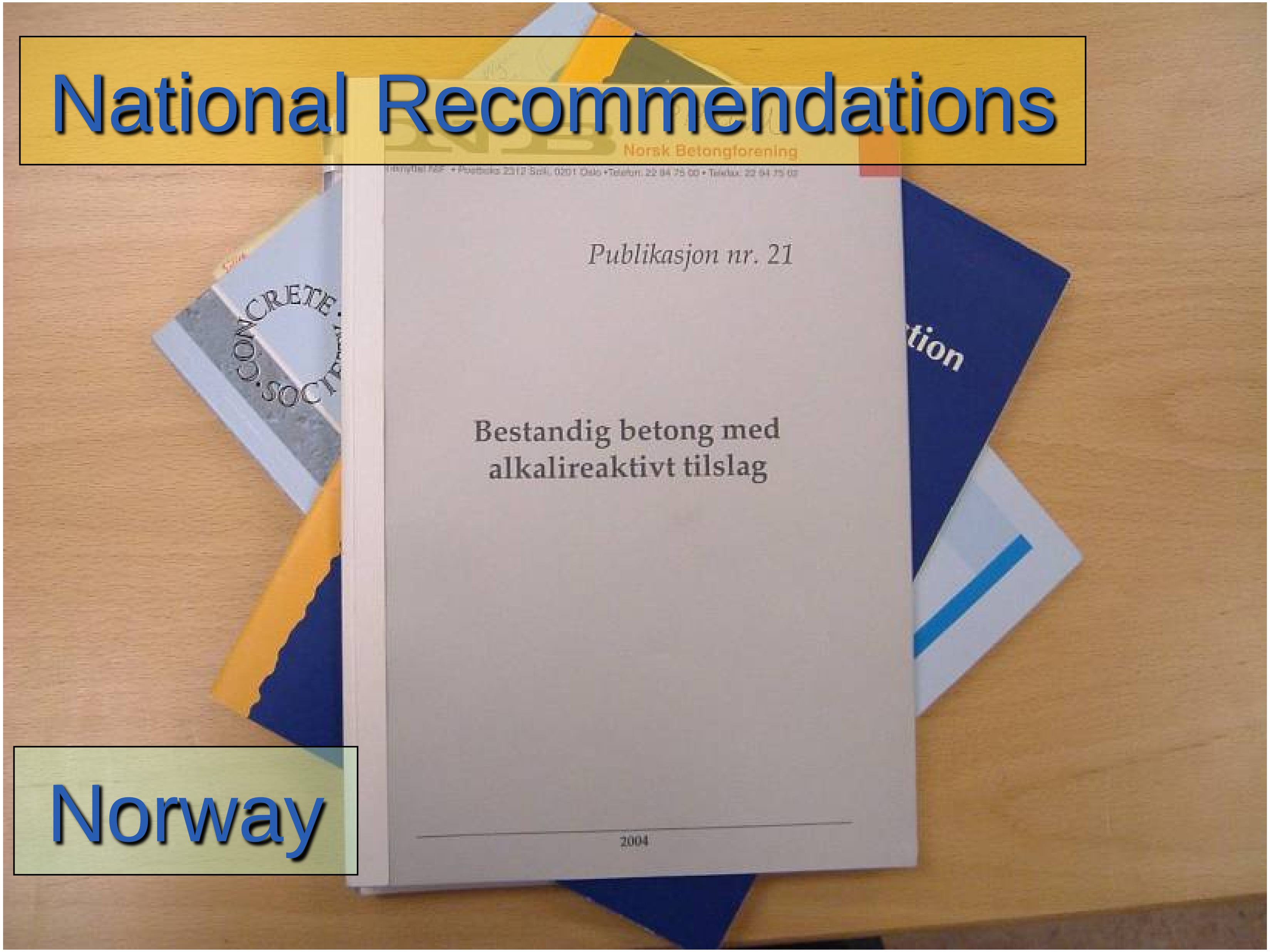
Reykjavik- Iceland

National Recommendations

In the European aggregate standard, EN 12620:2002, it is stated;

- *"When required the alkali-silica reactivity of aggregates shall be assessed in accordance with the provisions valid in the place of use and the results declared".*

National Recommendations



Norway

How to produce durable concrete with alkalireactive aggregates

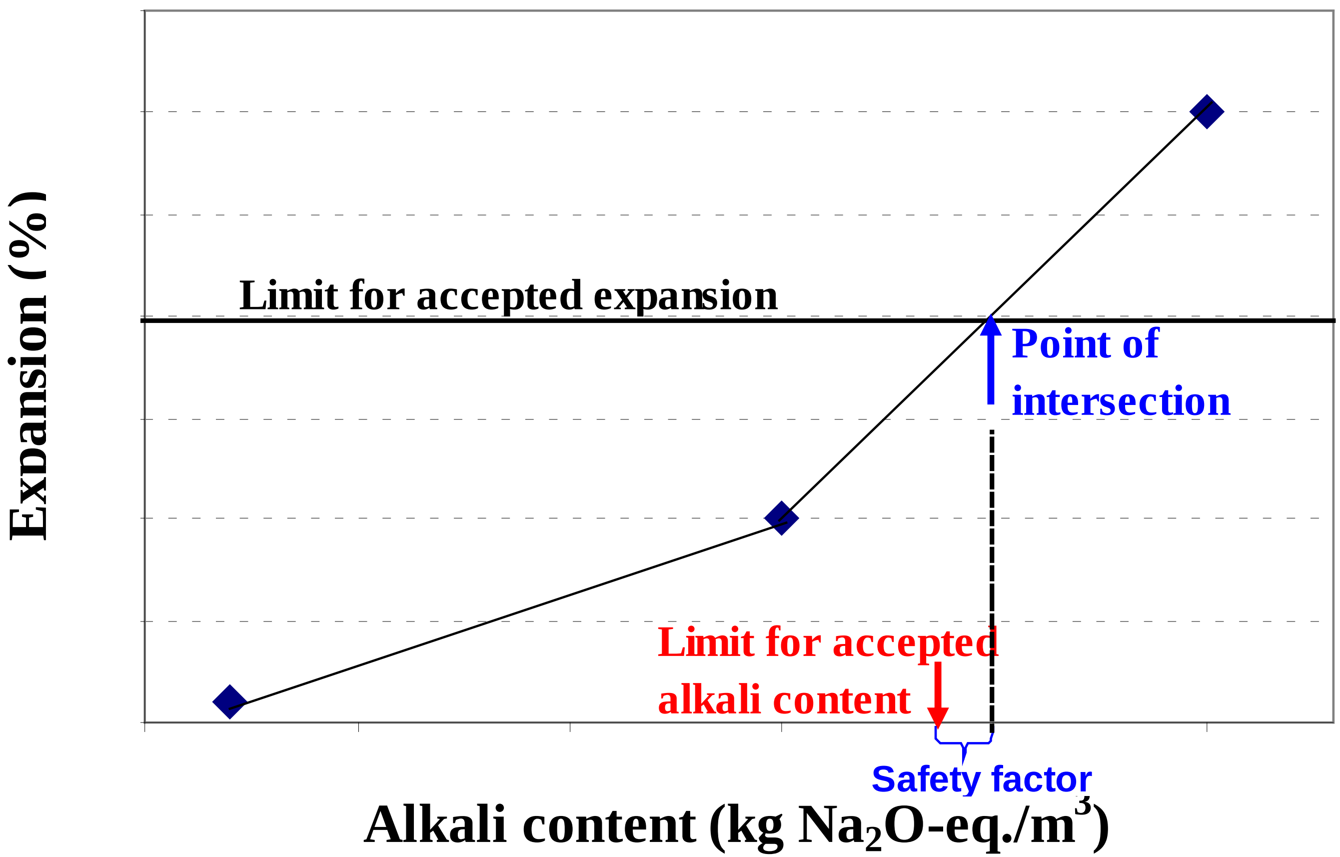
Overview of critical limits for test methods for documentation of alkali-reactivity of singel aggregates or blends of aggregates

	Critical limits for laboratory test methods		
Documentation of	Petrographic analysis **(1)**	Accelerated mortar bar method **(2)**	Concrete prism method **(3)**
Fine aggregate and blend of fine	20.0 %	0.14 %	0.040 %
Coarse aggregate and blend of coarse		0.08 %	0.040 %
Fine coarse aggregate		0.11 %	n/a
Blend of a fine- and coarse aggregate, where the fine or coarse is alkali-reactive	20.0 %	0.11 %	0.050 %

Performance testing – Norwegian Concrete Test

- Binders tested with a specified highly reactive Norwegian aggregate combination (worst case); increasing alkali content.

Determination of acceptance limit for alkali content



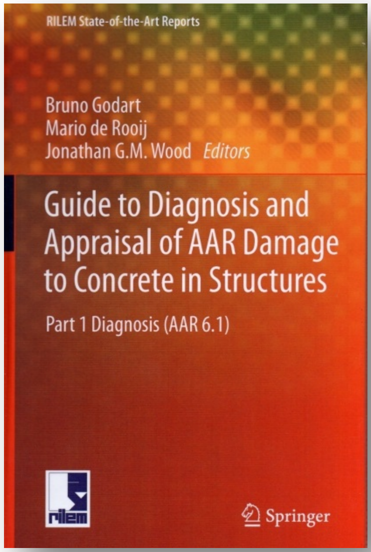
Requirements for maximum allowed alkali content for production of non-reactive concrete when using alkali reactive aggregate **(worst case)**

Binder	**Limit, alkali-content**
Norcem Standard FA Cement [CEM II/A-V, NS-EN 197-1, flyash > 17 %]	Na_2O eq. $\leq$ 7.0 kg/m^3
Portlandcement + silica fume [CEM I, NS-EN 197-1 in combination with minimum 10 % silica fume (of cement weight)]	Na_2O eq $\leq$ 5.5 kg/m^3

The path forward – The future

RILEM deliverables

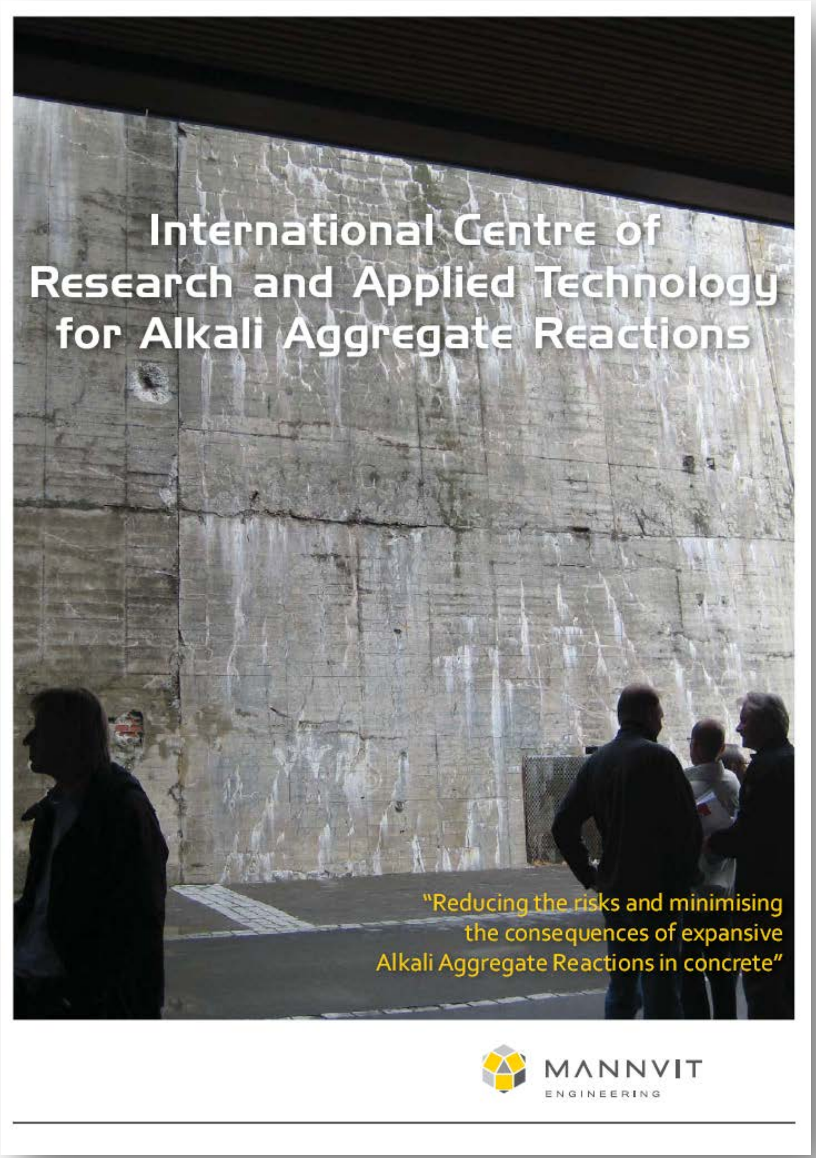
- AAR-1 Petrographic method
  - Petrographic Atlas (AAR-1.2)
- AAR-2 Accelerated mortar bar test
- AAR-3 Concrete prism test (38ºC)
  - Performance test (AAR-3.3)
- AAR-4.1 Accelerated concrete prism test (60ºC)
  - Performance test (AAR-4.2)
- AAR-5 Screening test for carbonates
- AAR-6.1 Diagnosis & Prognosis
- AAR-6.2 Appraisal & Repair
- AAR-7.1 ASR specification
- AAR-8 Releasable alkalis
- AAR-9 Modelling of structures

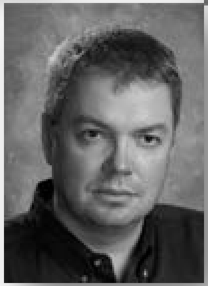


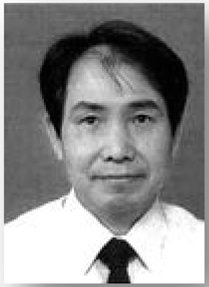
RILEM New TC (?)

- 2014 - ?
- Implementation of results & methods
  - Performance testing
  - Releasable alkalies
- Specification for very long term reactions in massive structures like dams follows liaison with ICOLD
- Web-based communication
- Chaired by BJW

ICRAT







www.mannvit.com/TestingResearchLab/

International Conference on Alkali Aggregate Reactions (ICAAR)

13th
ICAAR
TRONDHEIM 2008

14th
ICAAR
Texas 2012

15th
ICAAR
Sao Paulo 2016

Chairman: Haroldo Bernardes

www.ibracon.org.br/icaar2016