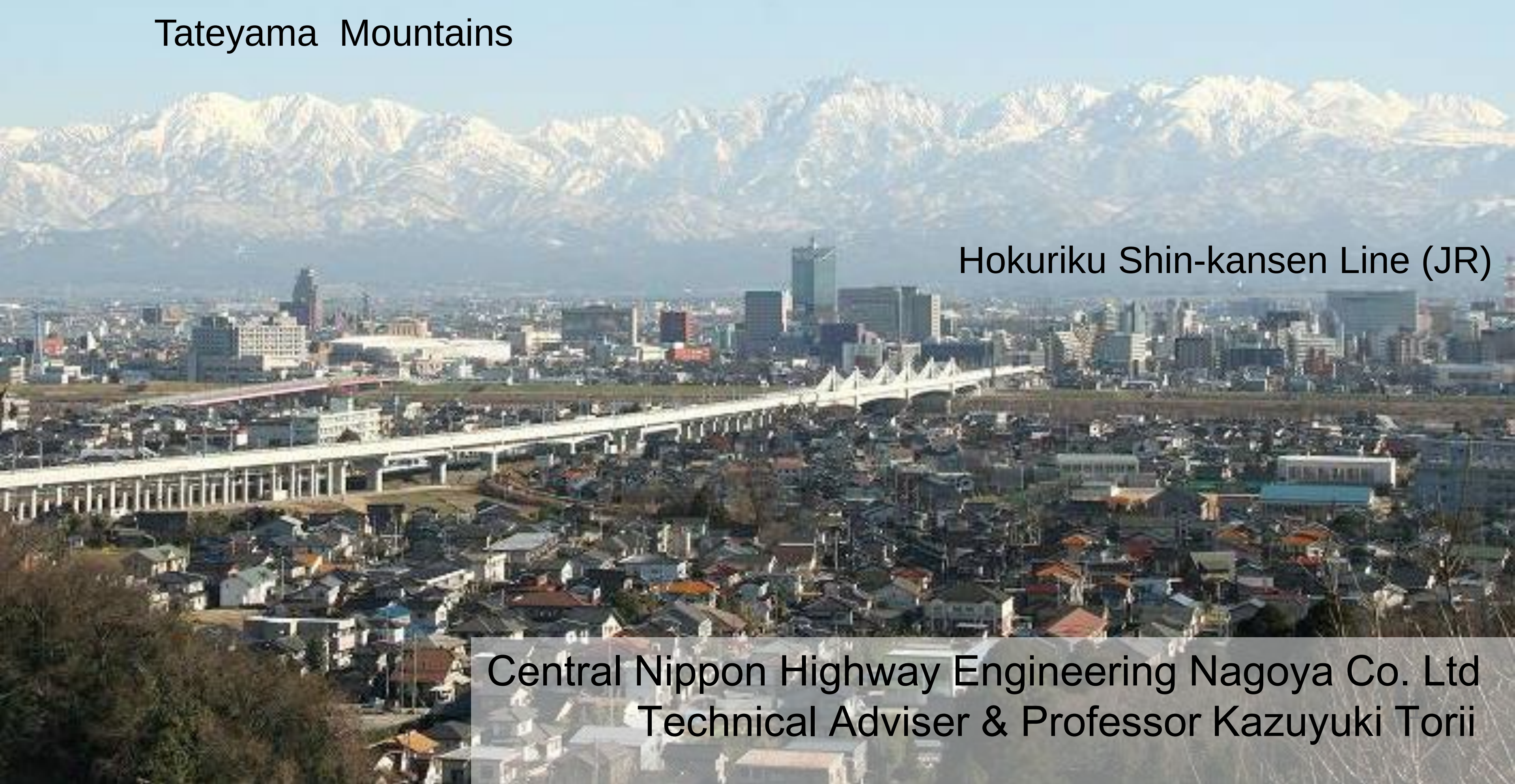
The Serious ASR Problems in Hokuriku District, Japan, and Its Mitigation Effect by Using Fly Ash Concretes



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Contents of Presentation

1. ASR Problems in Japan and Inadequate Countermeasures according to JIS A 5308

2. Serious ASR Problems of Concretes Using Very Reactive Andesitic Rocks in Hokuriku District

3. Recommendations of Standard Use of Fly Ash Concretes as ASR Mitigation Method in Hokuriku District

4. Successful Use of Fly Ash Concretes in Precast PC Electrical Poles in Hokuriku Electric Power Company

1. ASR problems in Japan

Map of ASR Affected Bridges in Japan

<u>Past 40 years ago</u>

Classical ASR such as Andesite

＊Hokuriku, Kansai, Kyushu etc.

<u>Last 20 years</u>

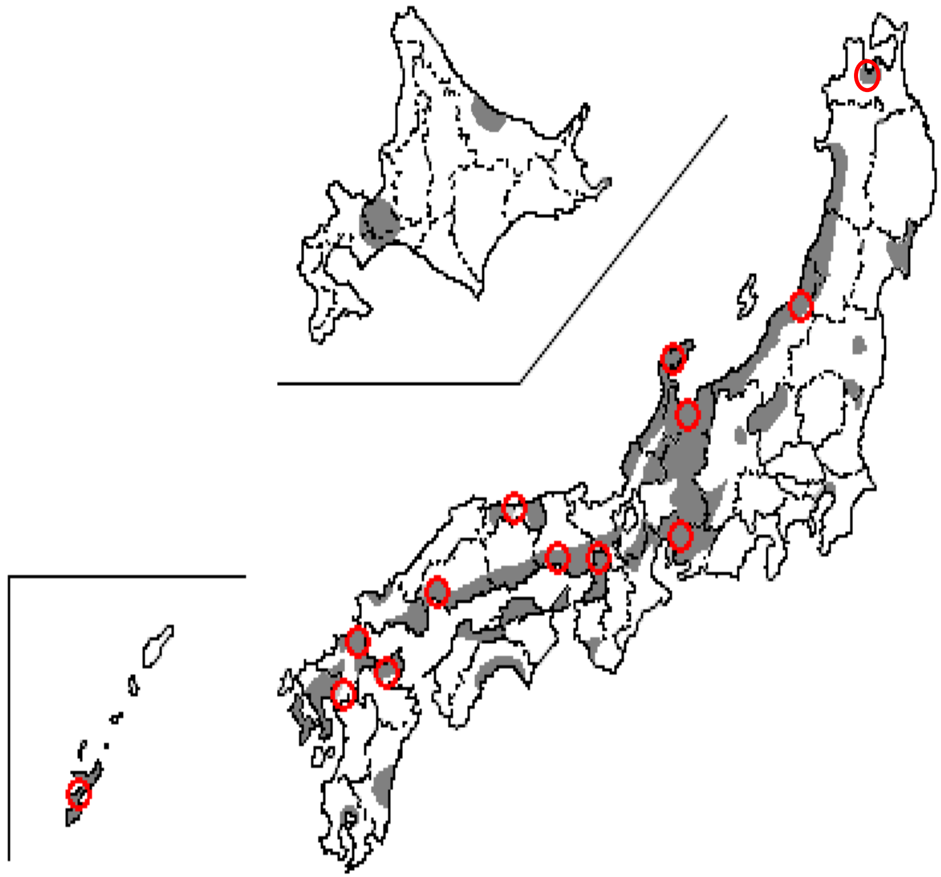
Late Expansive ASR such as

Chert, Silicious Slate

New Findings ; Okinawa, Tokyo,

Tohoku, Hokkaido etc.

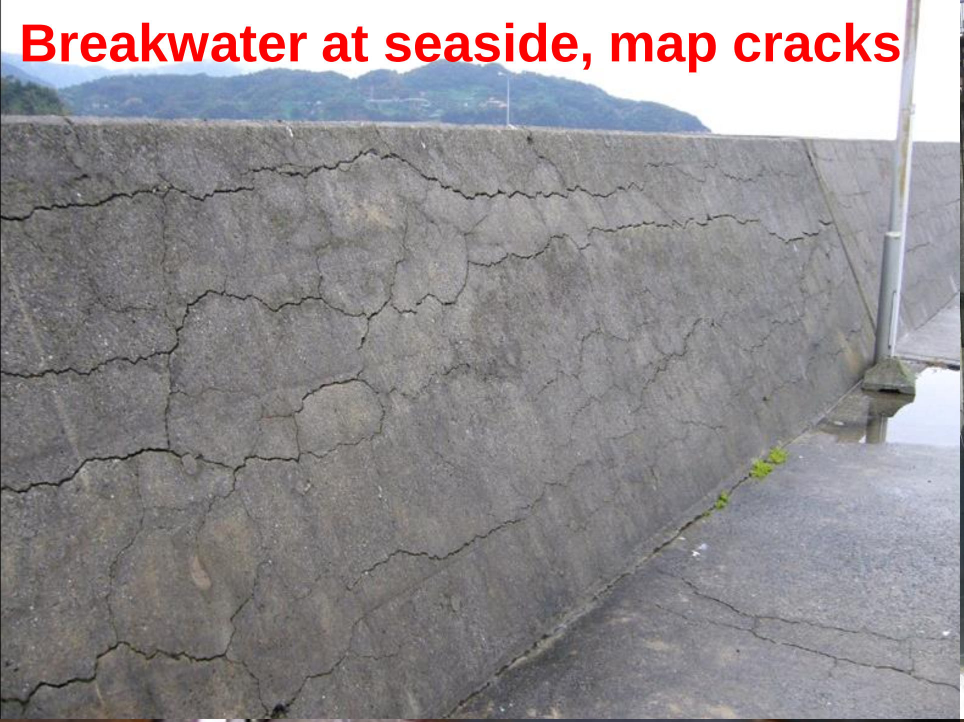
<u>**Now, ASR is a common problem everywhere all over Japan !**</u>



＊Occurrence of rebars broken

ASR: Alkali Silica Reaction

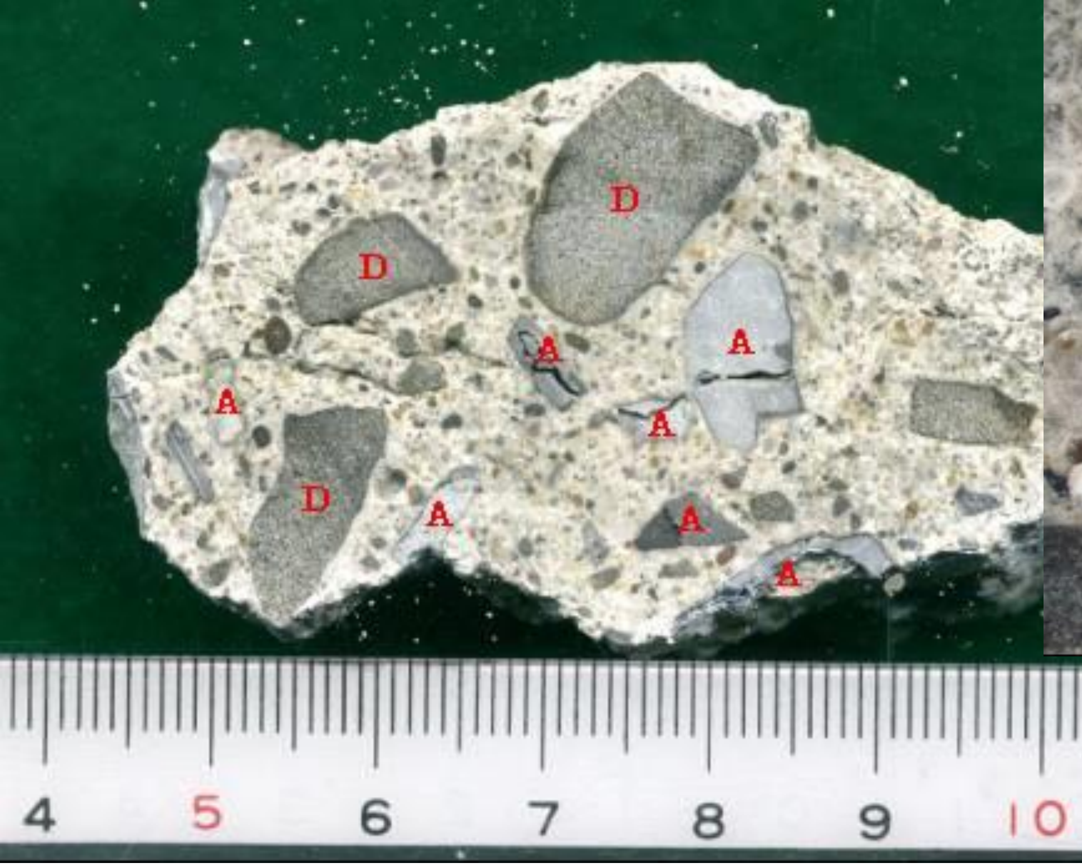
- Required condition: reactive aggregates, alkalis, and moisture. Higher temperature, wetting and drying cycles faster reaction.
- Process:
  - Alkalis from cement paste penetrate into aggregate.
  - Various silica bearing phases in aggregate react with alkalis.
  - Inside of aggregate, this reaction produces alkali silica gel (ASR gel) containing significant amount of water with larger volume.
  - ASR gel makes aggregate expansive phisicochemically.
  - Map cracks or oriented cracks develop in non-reinforced or in prestressed and reinforced concretes, respectively.
  - In extreme cases, steel reinforcement can also be broken.
  - Typically, decrease in strength is limited compared to drastic decrease in elastic modulus.


Breakwater at seaside, map cracks


Dam gate in river


Bridge pier crossbeam in expressway
Broken rebar


Posttensioned PC girder in railway



Fractured Surface of Concrete Samples in Tohoku District

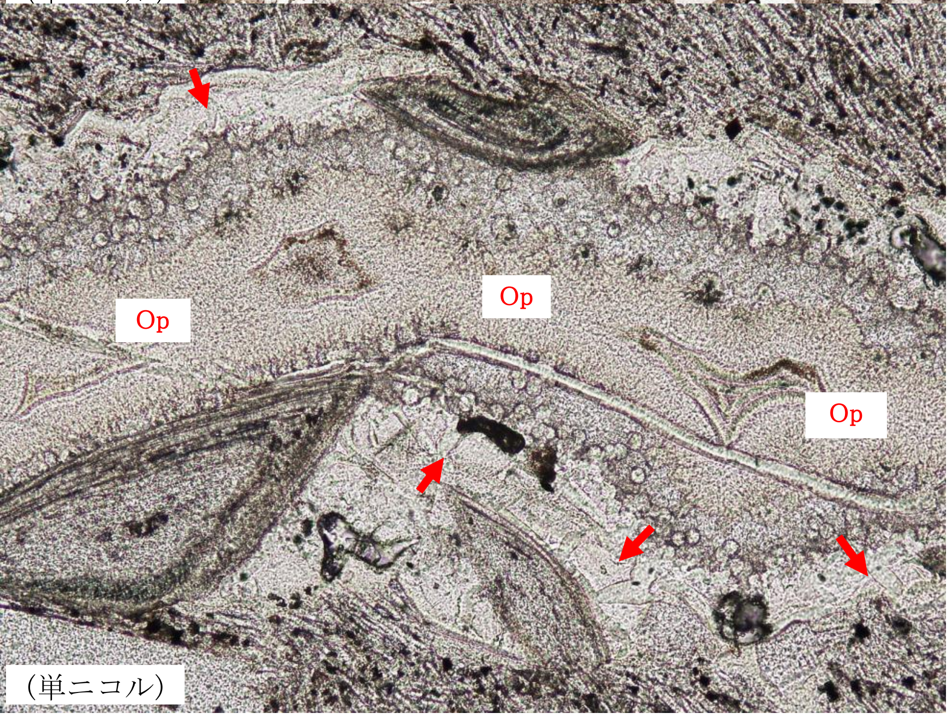
A: Andesitic Stone (very reactive)

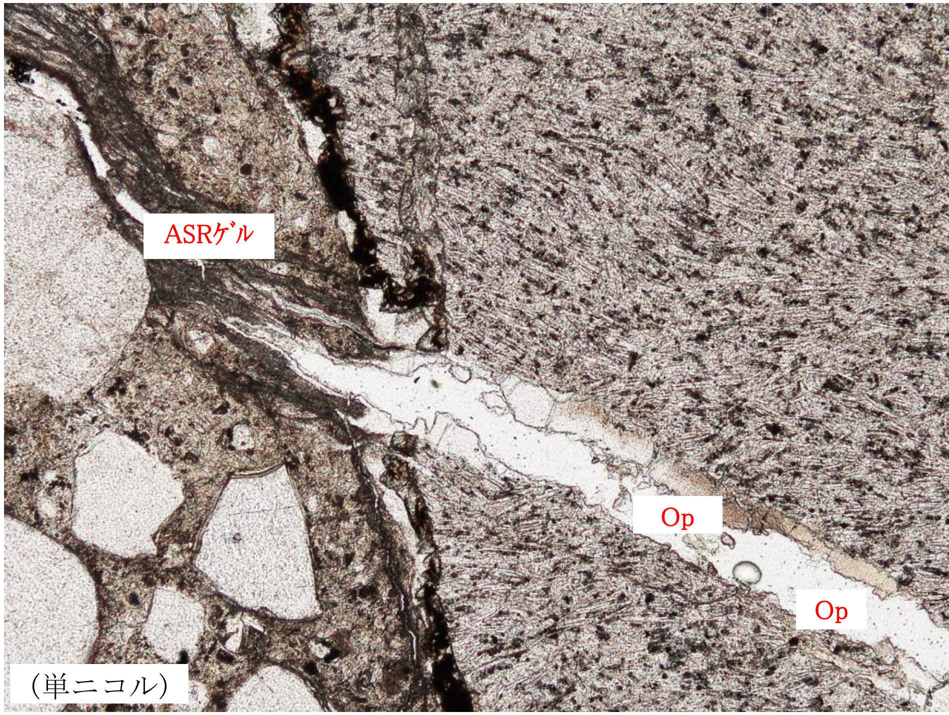
D: Dacitic Stone (moderately reactive) in Tohoku District

Thin section of core from PC slab-typed bridge girder of railway cracked in only few years after construction.

Polarizing microscope observation shows ASR gel from andesitic stones containing opal.

Op: opal, most reactive component





Industry standard for suppressing ASR in Japan

JIS A 5308 (1986)

We must select one of the following three countermeasures.

a) Restrict alkalis:

Alkali limit 3kg/m^3 Na_2Oeq

b) Use fly ash, slag and other pozzolans:

Recommended minimum proportions

Fly ash 15% and more

Blast furnace slag 40% and more

c) Use non-reactive aggregates

Applied most often. These measures are not enough.

Not applied.

- **Depending on conditions, ASR is still sometimes observed.**

How can we counter ASR?

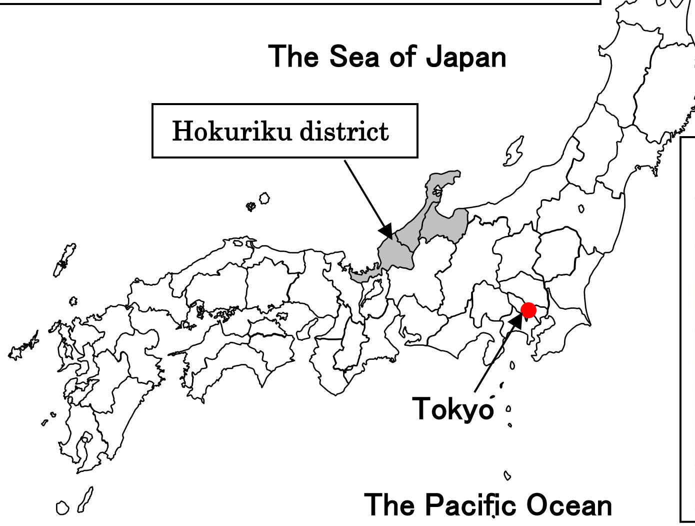
Why should we start using fly ash concretes?

2. ASR Problems in Hokuriku District Located on Green-tuff Area in Japan

Background

【 Serious ASR and Chloride Attack Problems in Hokuriku District 】

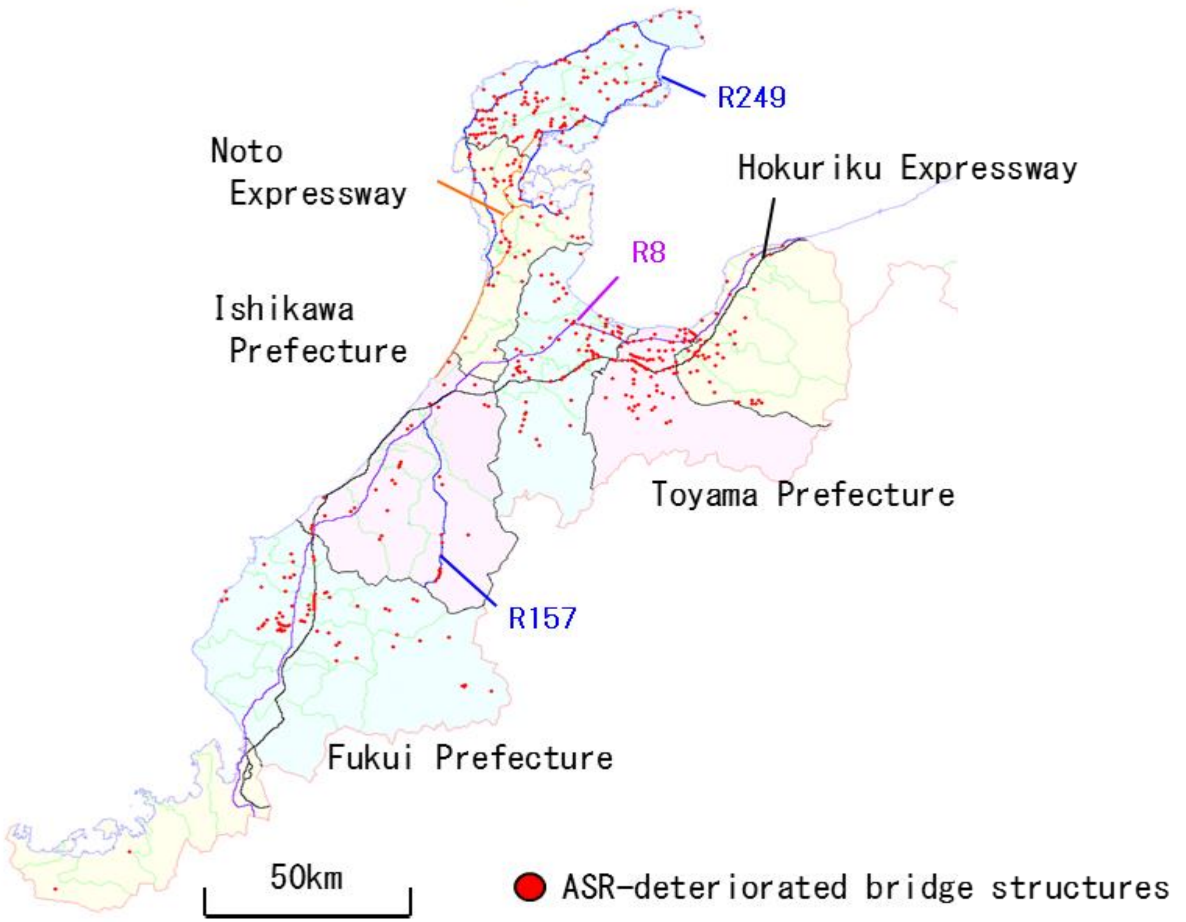
【ASR（bridge pier）】



【Chloride Attack (bridge girder) 】

In the Hokuriku district, a large number of concrete structures have been suffering from ASR and chloride attack . The approach to solve these problems has been considering both the repair of deteriorated structures and the use of preventive countermeasures. In the former case, action has been taken by government office, but in the latter case, they have not yet taken any action.

The Distribution map of ASR-deteriorated bridges in the Hokuriku District

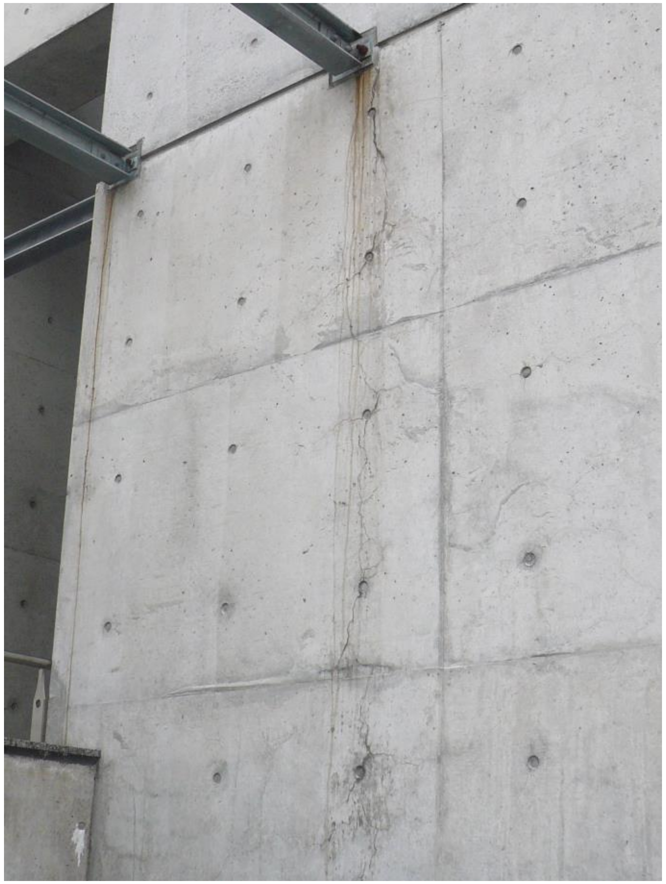


In order to confront the widespread ASR deterioration of concrete structures in the Hokuriku district, the problem-solving approach has been considered both the repair and retrofitting of deteriorated structures on the one hand, and the use of preventive countermeasures such as blended cements on the other hand.

The Reconstruction Case for Severely ASR-deteriorated Bridge Pier with Broken Rebars after Repairing in Toyama

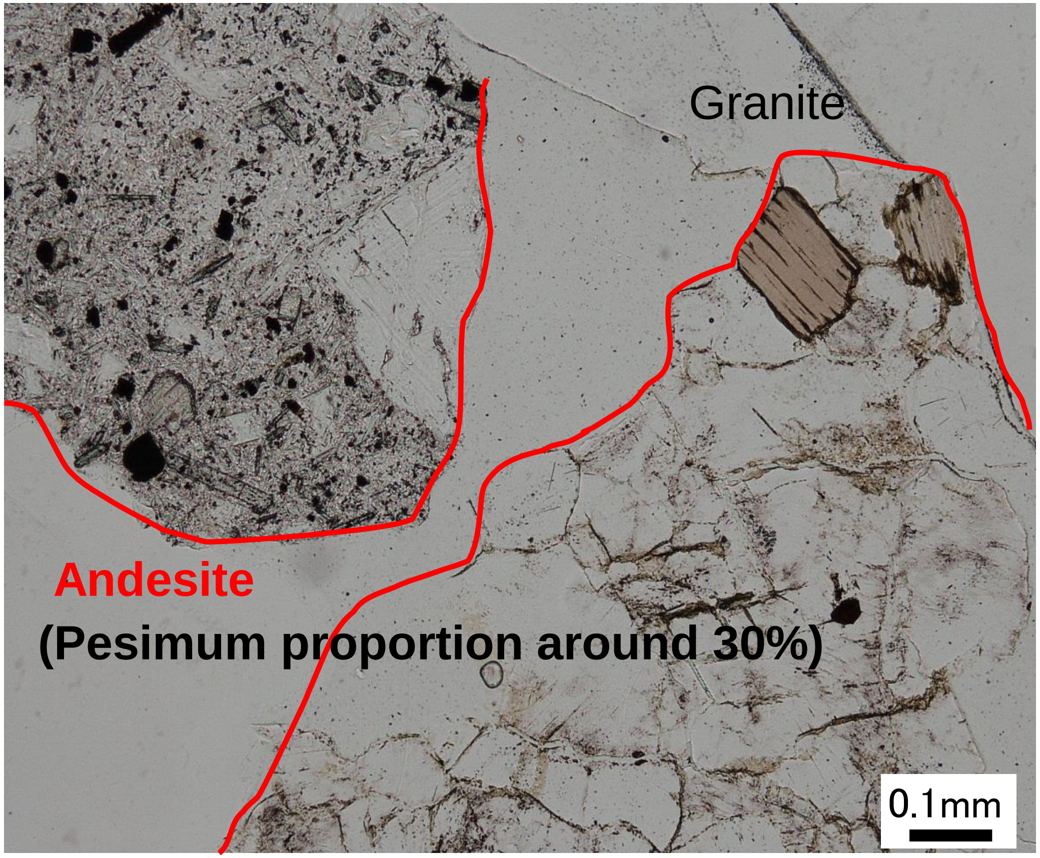
Within the whole watersheds of the Joganji and Jinzu Rivers in Toyama Prefecture, all aggregates possess a very high ASR reactivity, and in some cases a pessimumn content effect, because all these aggregates contain andesite particles with opal and/or cristobalite as a reactive component.

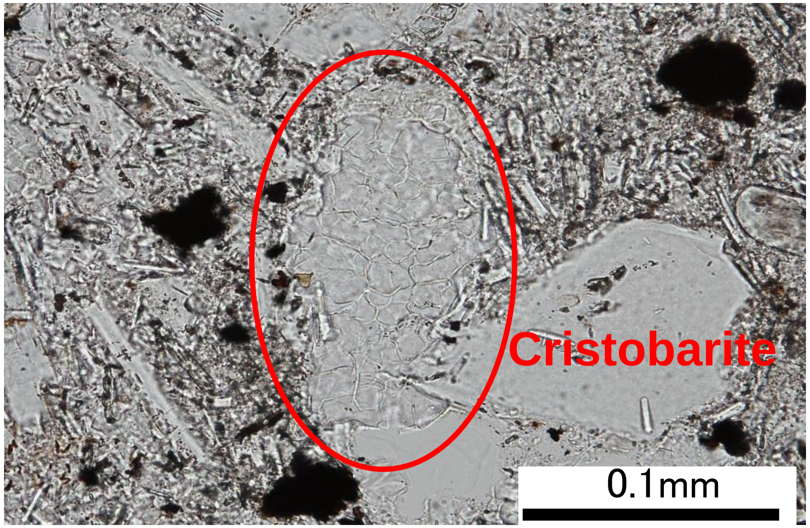
The Recent Case of ASR Cracking Occurred in RC Building Wall after JIS A5308 Regulation in Toyama

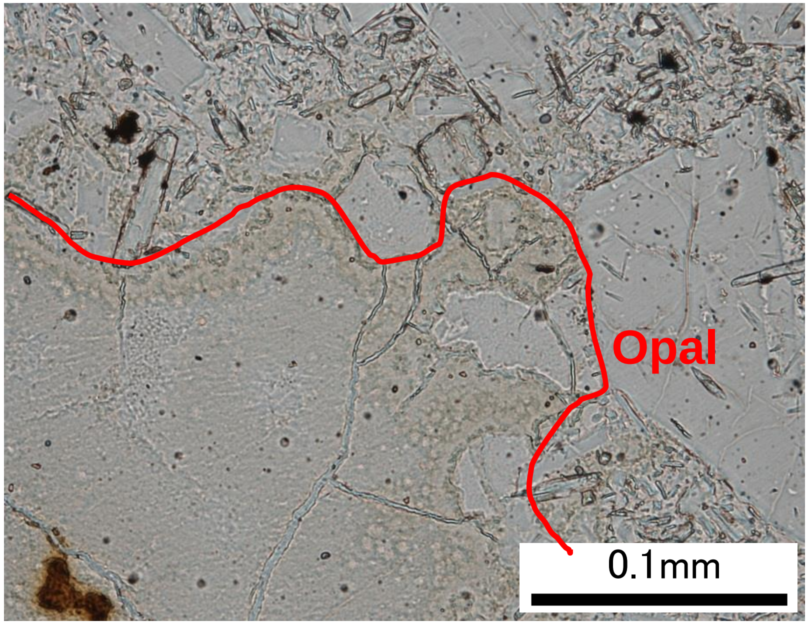


The fine and coarse aggregates from the Jinzu River have been assessed as "innocuous" and the total alkali content of the concrete has been kept below 3kg/m^3, presumably around 2.4kg/m^3. Nevertheless, the severe ASR recently occurs. Why does ASR occur and still continue ?

The Pesimum Properties of Very Reactive Jyoganji-river Gravels







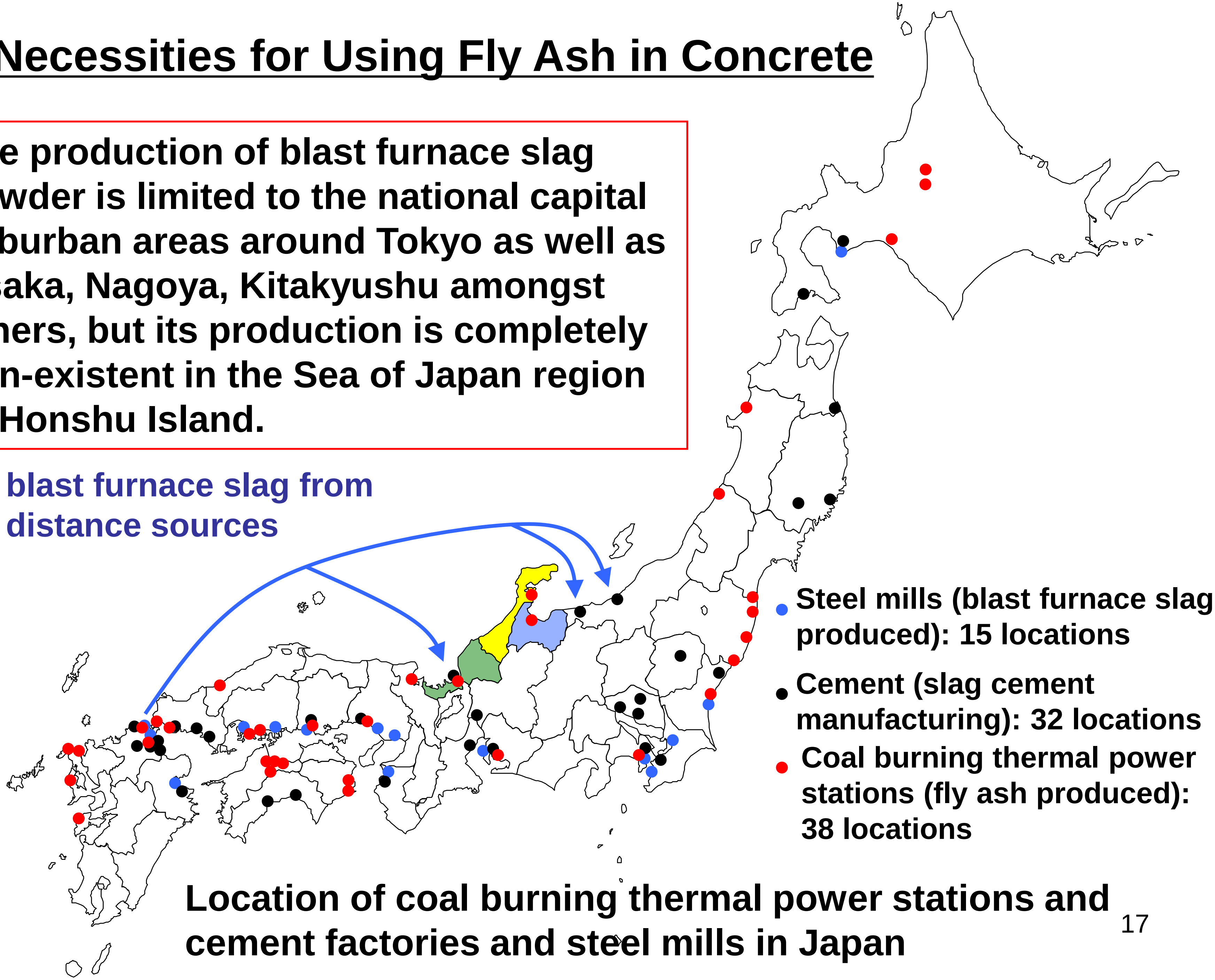
The gravels and the sands of the Jyoganji River in Toyama Prefecture include andesite particles which contain cristobarite and/or opal which are reactive components. (pesimum proportion around 30%)

It is said the gravels produced in the Jyoganji River are some of the most reactive ones in Japan.

3. ASR Countermeasures by Standard Use of Fly Ash concretes in Hokuriku District

The Necessities for Using Fly Ash in Concrete

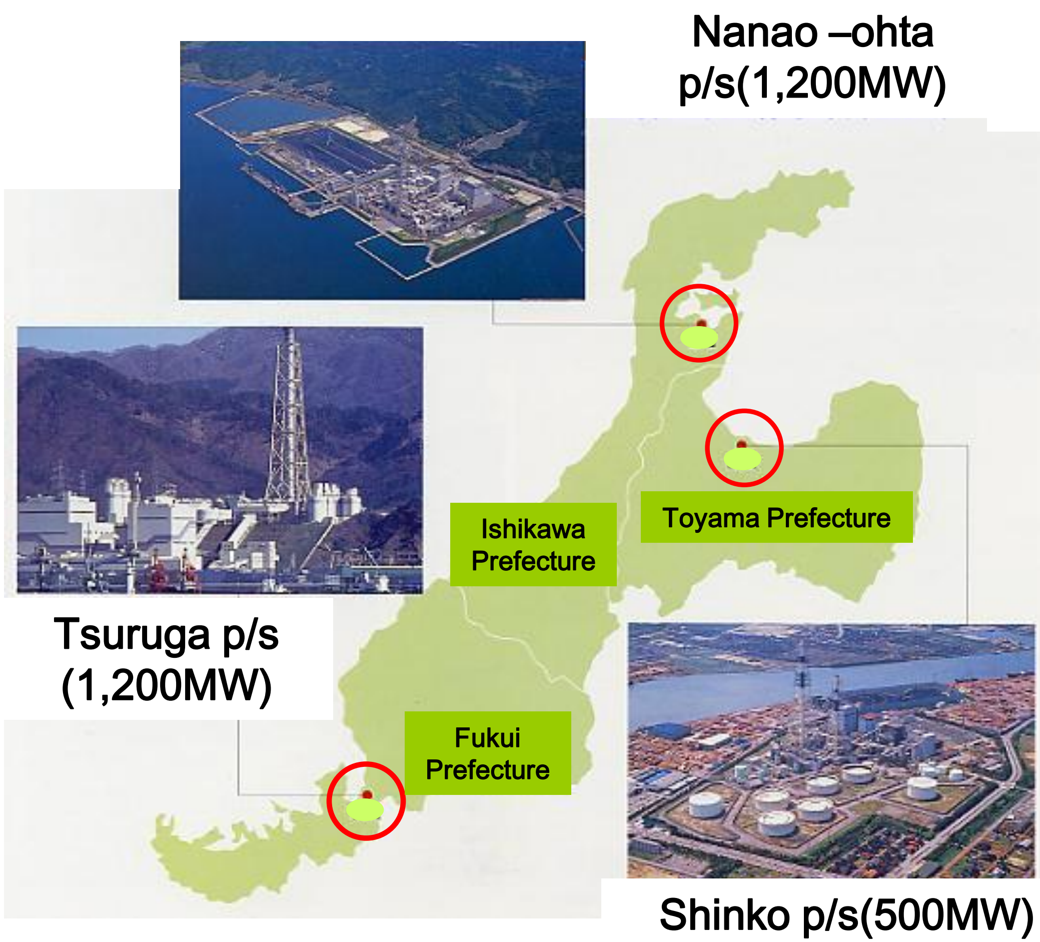
The production of blast furnace slag powder is limited to the national capital suburban areas around Tokyo as well as Osaka, Nagoya, Kitakyushu amongst others, but its production is completely non-existent in the Sea of Japan region of Honshu Island.



Location of coal burning thermal power stations and cement factories and steel mills in Japan

Background

【 Problems of Energy Security in the Hokuriku District 】

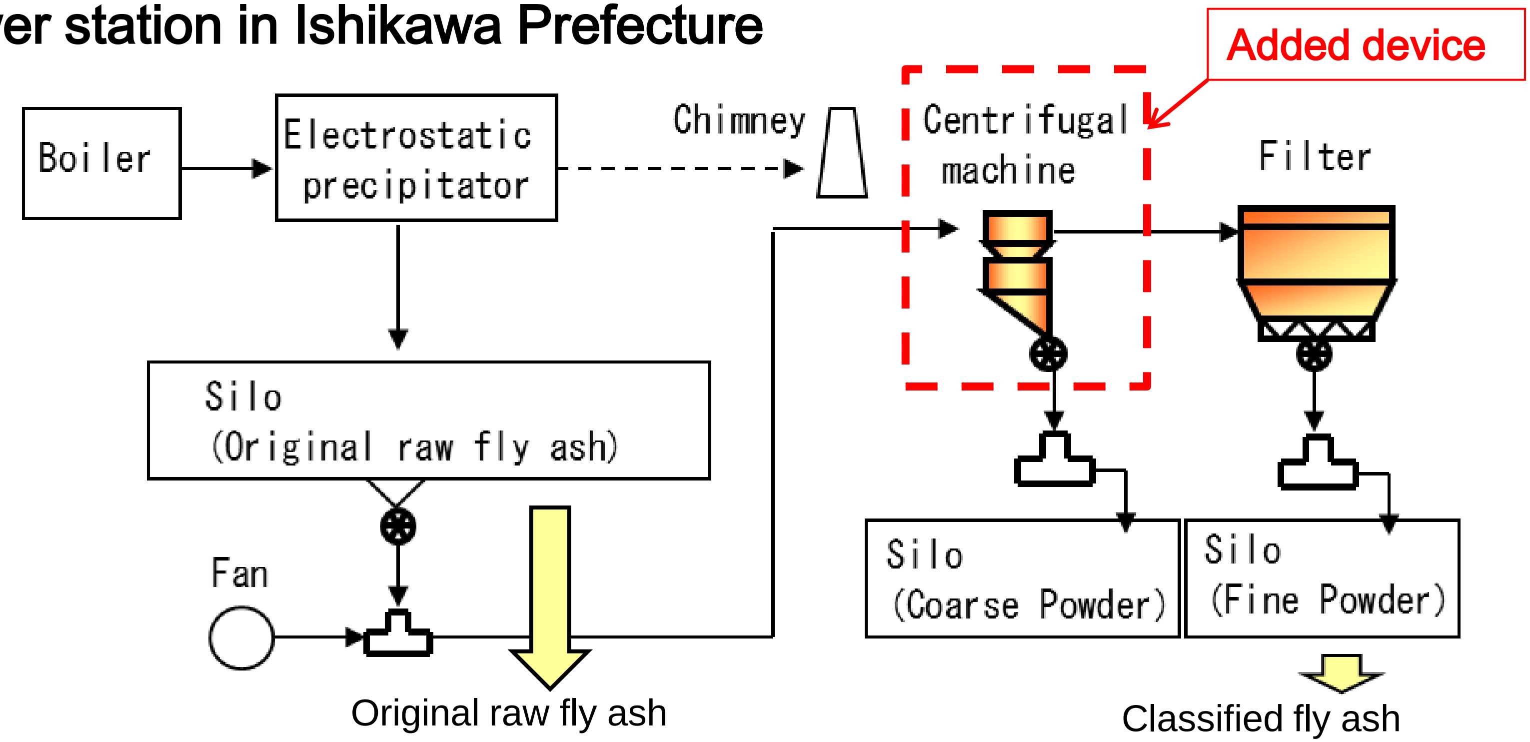


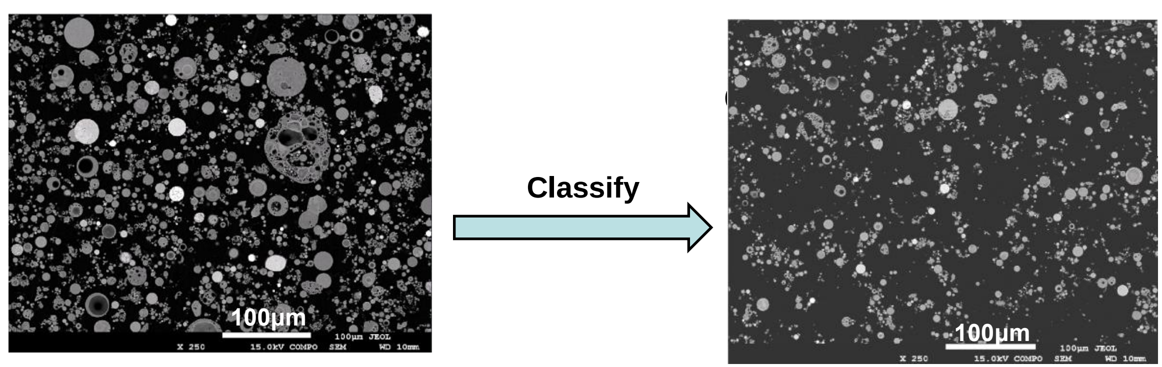
Coal burning power stations in the Hokuriku District

After the 2011 Tohoku Great Earthquake and Tsunami disaster, all nuclear power stations were shutdown.
In the Hokuriku district, approximately 64% of the electricity supplied was generated by coal burning power stations in 2012 . (44% in 2010)

Action 【Enhancement of Supply System of good-quality Fly Ash 】

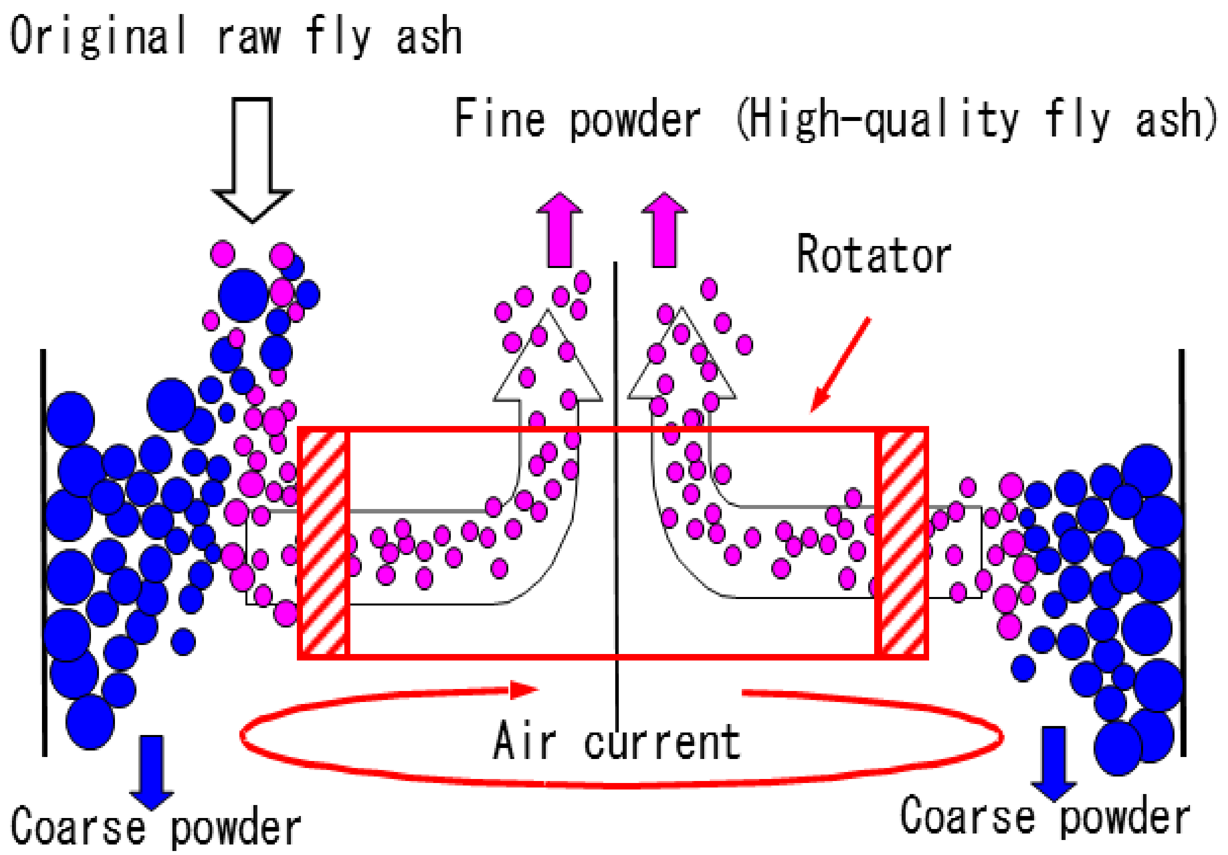
Production process of classified fly ash in the Nanao-Ohta coal burning power station in Ishikawa Prefecture



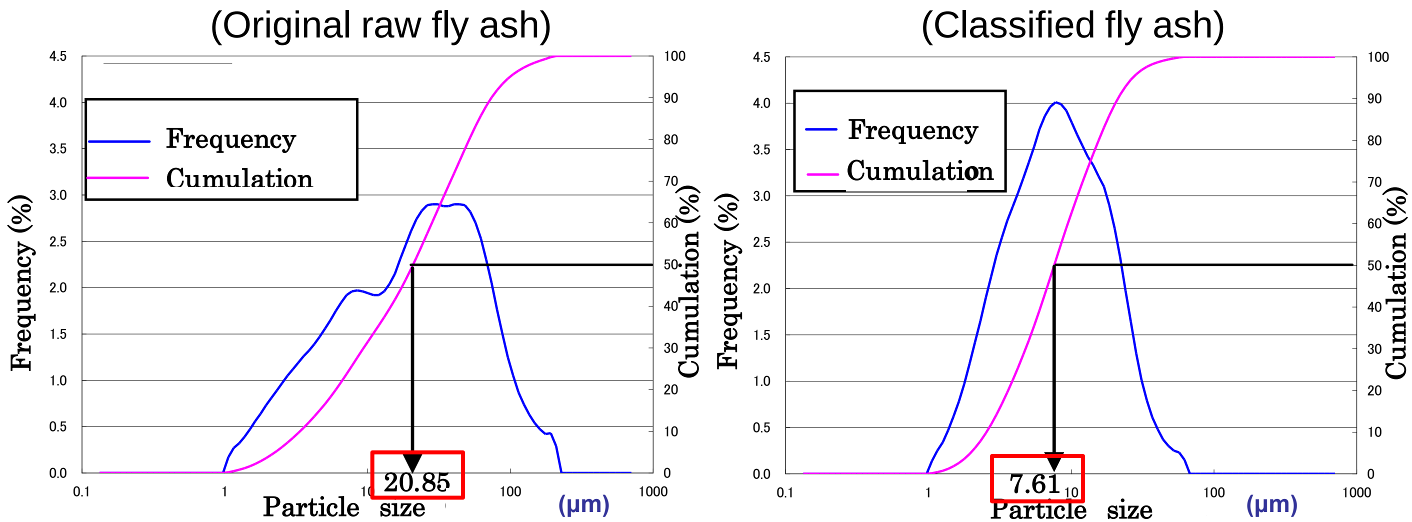


(The particle size is refined to less than 20μm in diameter)

The Schematic Diagram of Centrifugal Machine in Production of Fine and High-quality Fly Ashes



The physical and chemical properties of fly ash produced are well in line with the quality standard of the highest level “Class I” according to JIS A6201.



Comparison of particle size and frequency between original and classified fly ash

The physical properties of fly ash can be improved from 21μm to 8μm at the average particle size by classification.

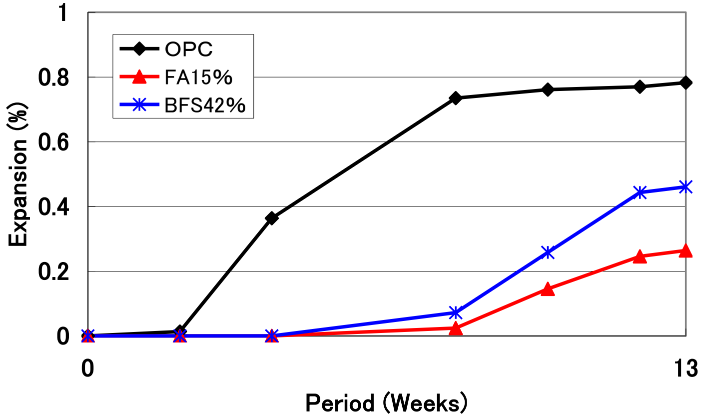
Comparison in mineralogical properties between original and classified fly ash

Fly ash type	Physical properties		Mineralogical properties(%)				
	Density (g/cm^3)	Blaine fineness (cm^2/g)	Quartz	Mullite	Magnetite	Lime	Glass
Original	2.36	3390	5.4	26.7	2	0.8	65.1
Classified fine fly ash	2.43	4780	5	20.6	1	0.2	73.2

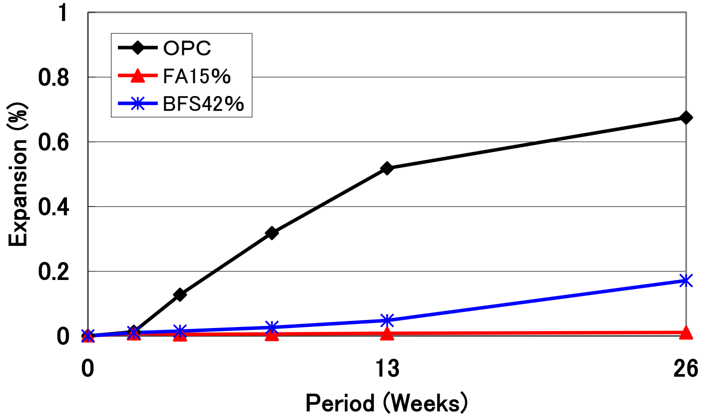
The chemical properties of fly ash can be improved that the glassy phases of fly ash are increased from 65% to 73% by classification.

The Advantages of Fly Ash Concrete as ASR Mitigation Method

Expansion behaviors
(Danish method)

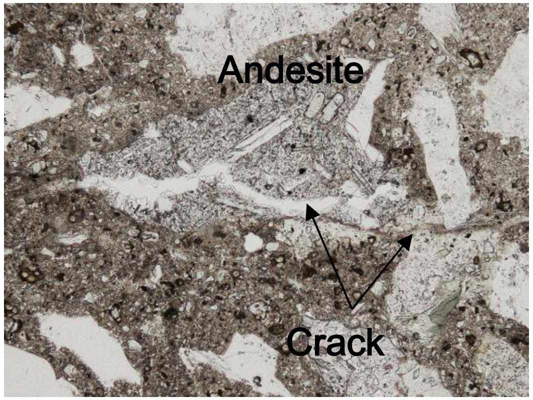


Expansion behaviors
(JIS A1146 method)

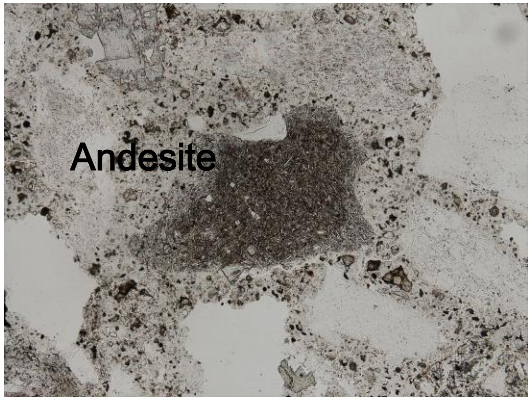


It became clear that the ASR expansion of mortars was controlled over the long term by using high-quality fly ash.

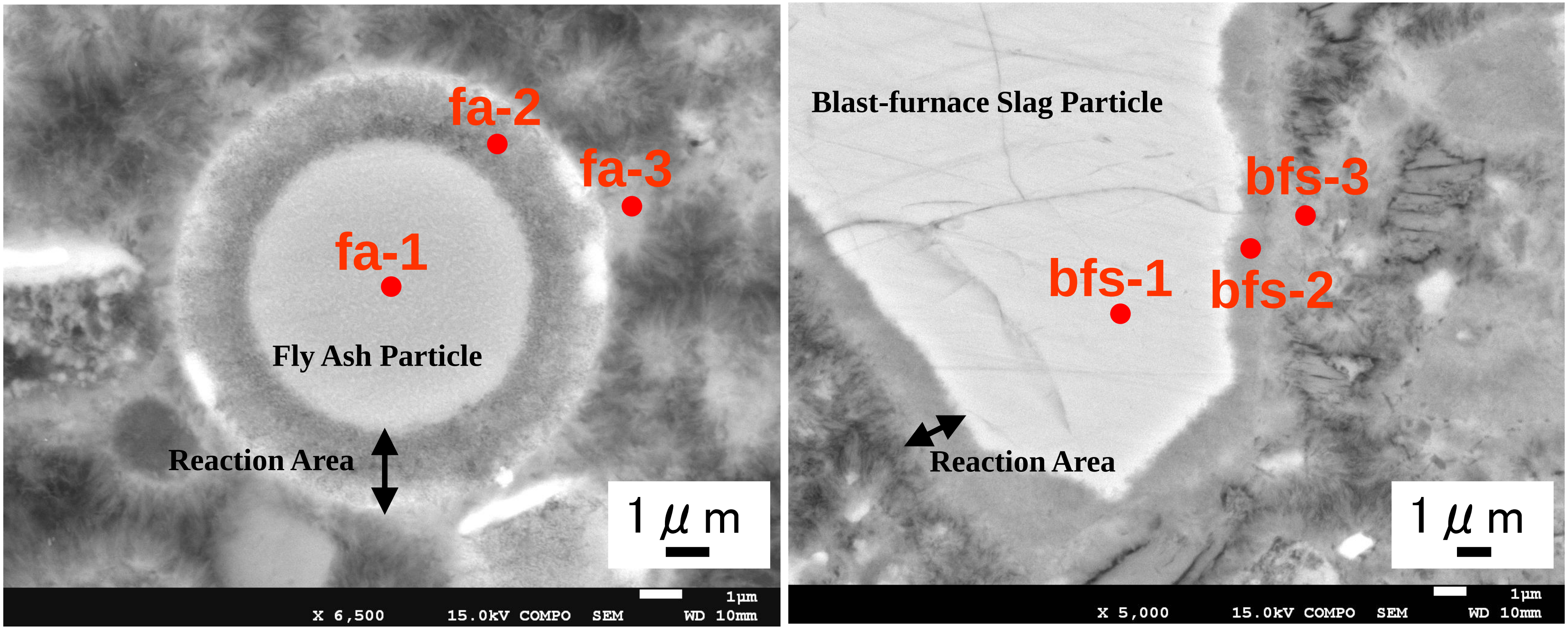
Petrographic observations for thin section of mortars after the JIS A1146 mortar bar test (Polarizing microscope in plane-polarized light)



BFS 42%



FA 15%



Reaction Area and CSH Products（SEM–BEI）

Points	fa-1	fa-2	fa-3
Ca/Si Ratio	0.05	0.88	1.64

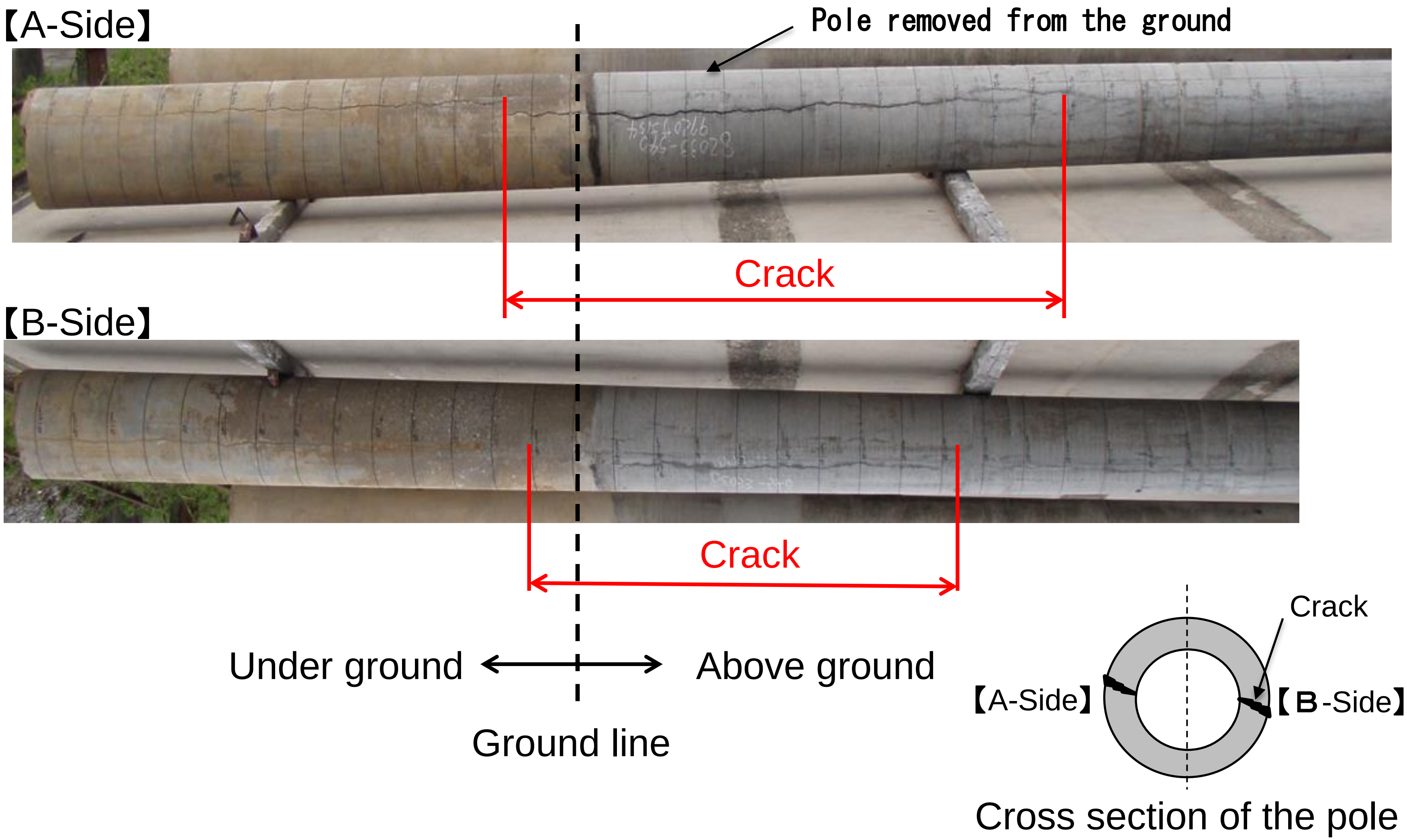
Points	bfs-1	bfs-2	bfs-3
Ca/Si Ratio	1.39	1.47	1.58

4. Successful Case of Fly Ash Concrete in PCa PC Concrete Electrical Poles as Mitigation Method

#【Background of the Research】

・Recently in the Hokuriku district, it has been found that large vertical cracks occurred on the surfaces of the electrical concrete poles. However, the cause of the cracks has not been clarified.

【Characteristics of the vertical cracks of Electrical Poles】

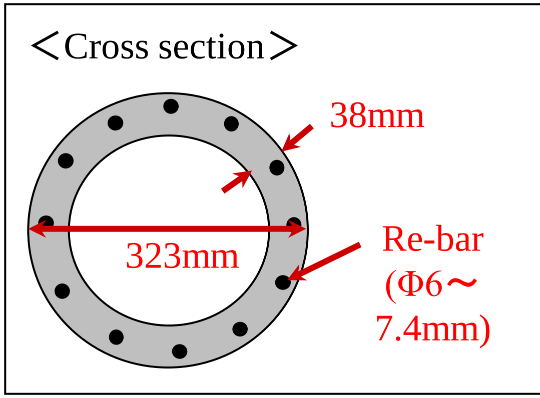


The cracks are progressing from near the ground. In many cases, vertical cracks occur in pairs in a diagonal configuration on the circumference.

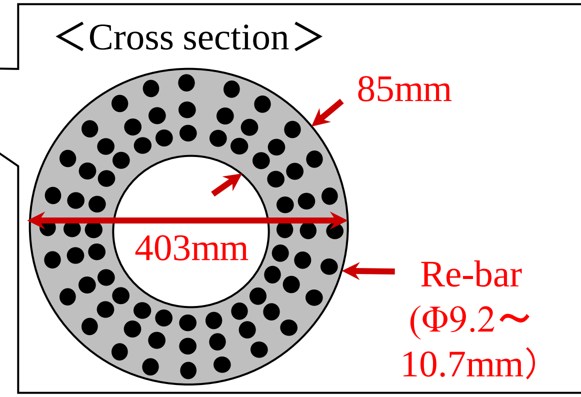
【Structure of the Pole】

Standard type

Special type



Standard type   Special type



	Length (m)	Thickness of the concrete (mm)	Number of the re-bar	Design load (kgf)
Standard type	10	38	12	350
	16	50	24	700
Special type	10	85	72	3000
	16	70	64	2000

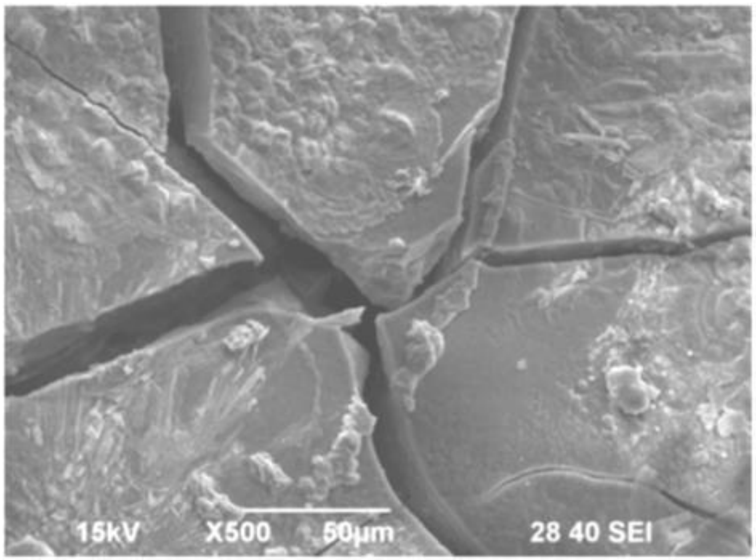
Designed strength of special type poles has a higher strength of 50 N/mm2.

In many cases, severe cracks occur in this special type poles.

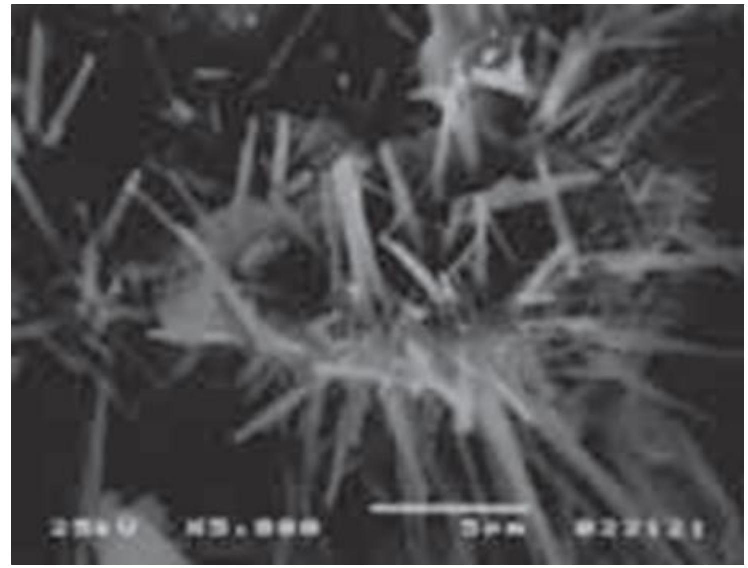
【Investigation and Identification of the Cause of Vertical Cracks】

Which is the cause of the cracks? ASR and/or DEF

ASR (ASR gel)



DEF (Ettringite)



Two possibilities of ASR and/or DEF were suspected,

Because high-strength type poles with high cement content ⇒ASR

Because manufactured by steam curing. ⇒ DEF

We decided a further research for cores from deteriorated concrete.

【Research of the Poles】

Sliced the poles at 10cm intervals and checked the situation inside the cracks.
And then, taken out concrete pieces to investigate the cause of the cracks.

【Observation of ASR gel (Gel Fluorescence Test)*】

* Gel Fluorescence Test

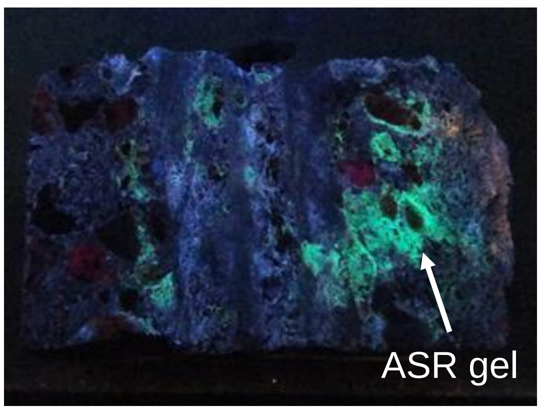
The area where ASR is present shows a characteristic greenish yellow fluorescence.

Outside

Inside

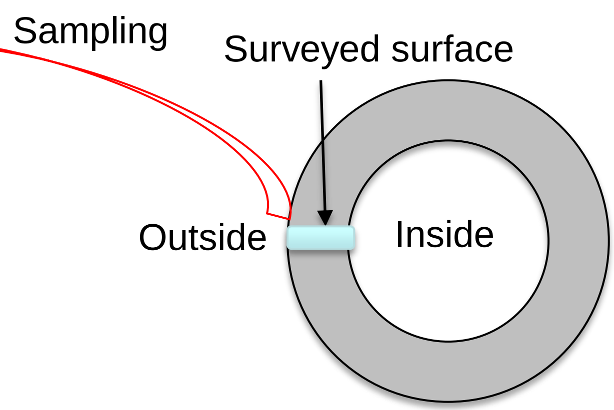
Under visible illumination

Outside



Inside

Under UV light

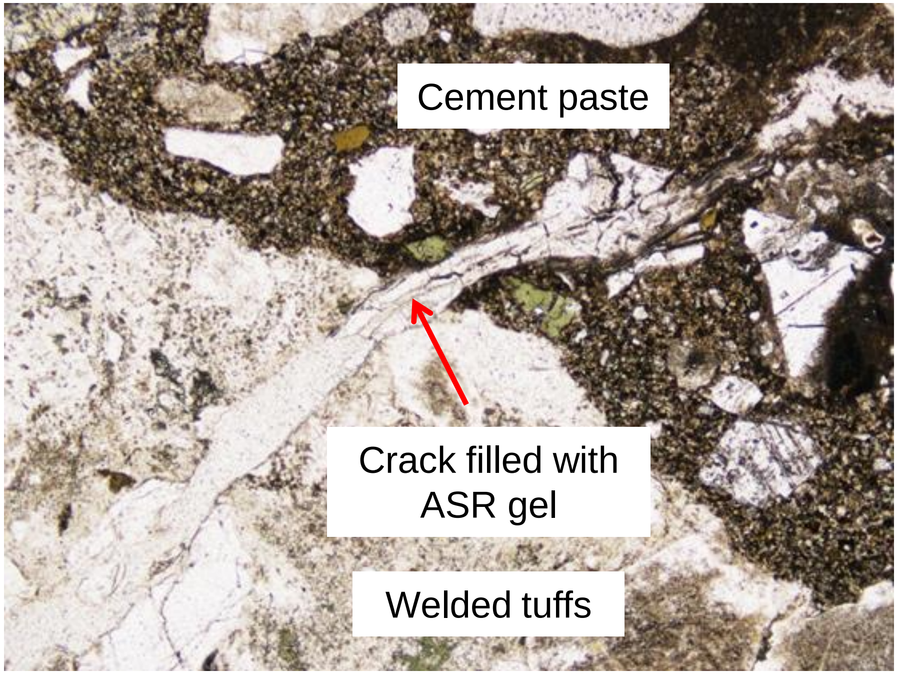


Cross section of the pole

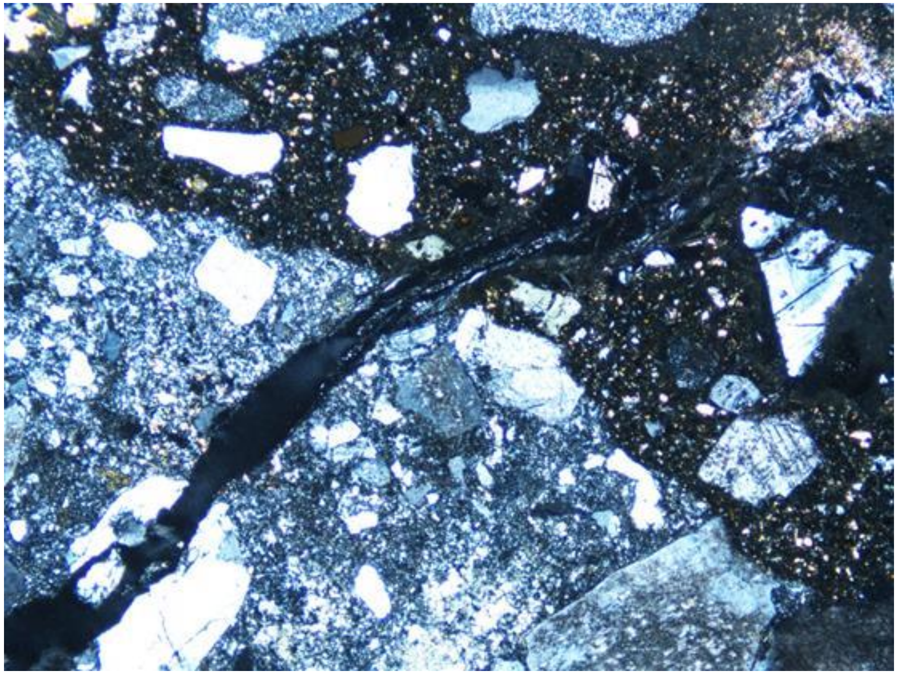
The fine aggregates of some volcanic rocks were intensely generating ASR especially in the interior of PC pole columns in the hollow cross sections.

【Observation of thin sections of concrete slices using a polarized light microscope】

Example of cracks occurred in coarse aggregate



Plane polarized light



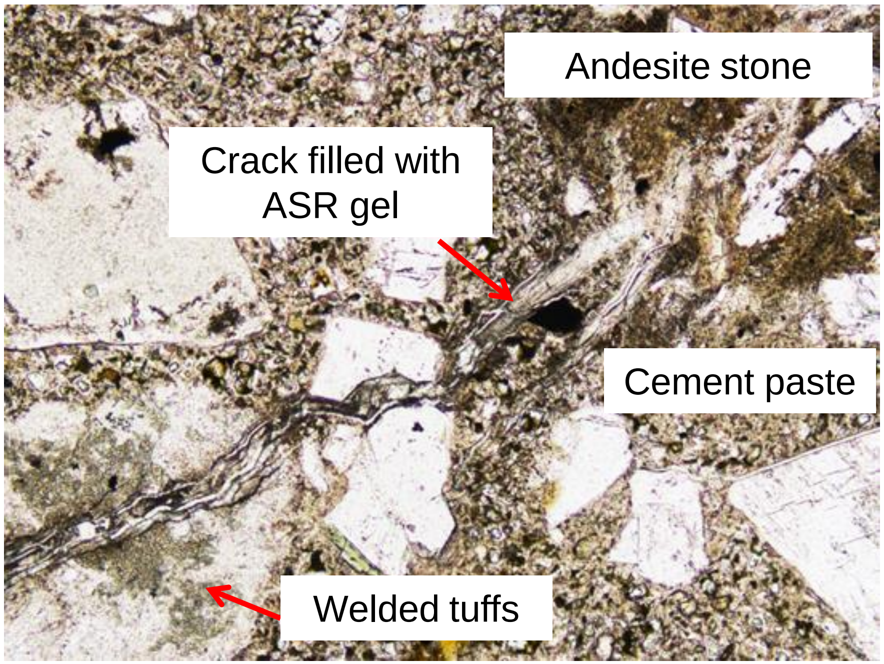
Crossed polarized light

1mm

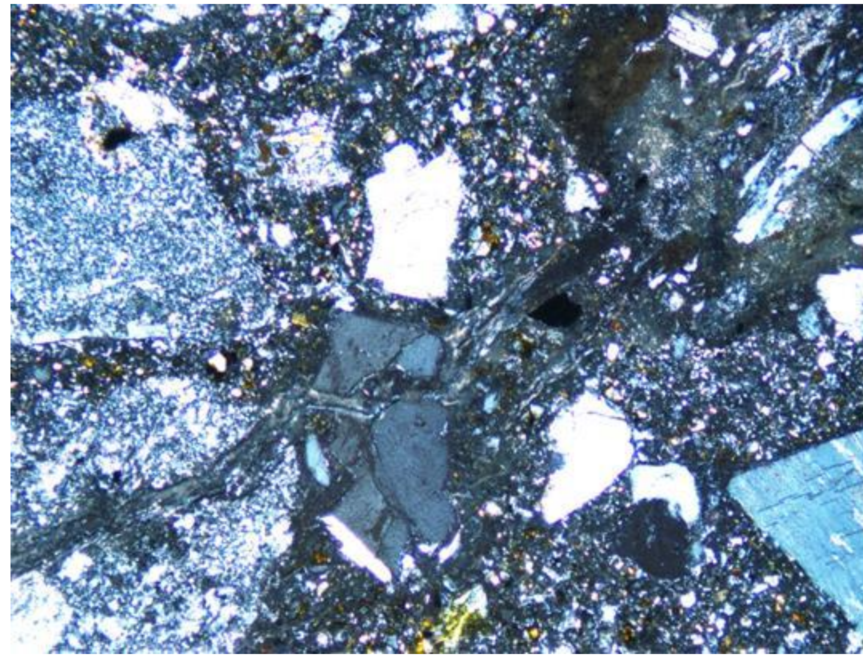
The andesite and rhyolitic tuffs contained in fine aggregates generated ASR.

【Observation of thin sections of concrete slices using a polarized light microscope】

Example of cracks occurred in fine aggregate



Plane polarized light



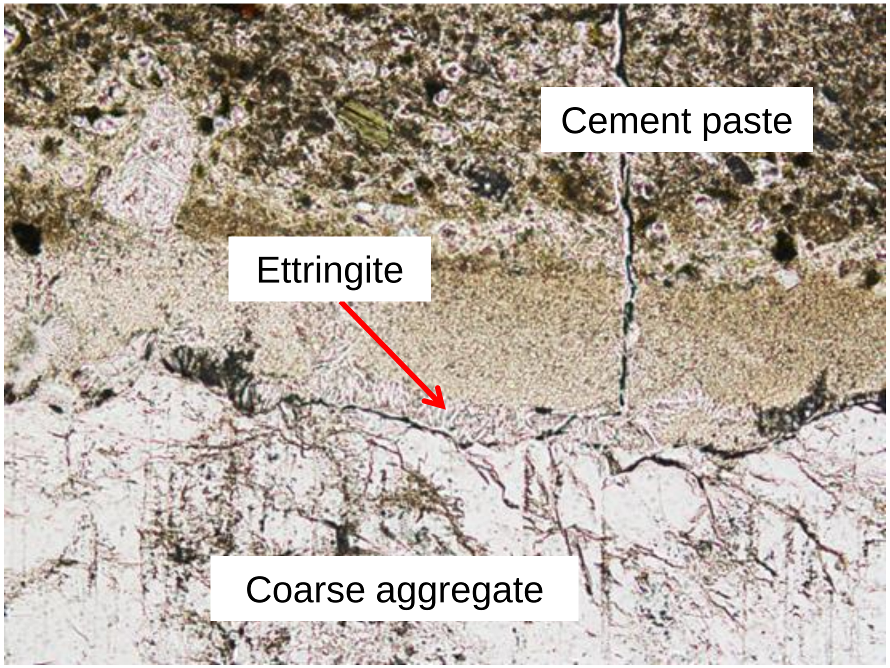
Crossed polarized light

0.2mm

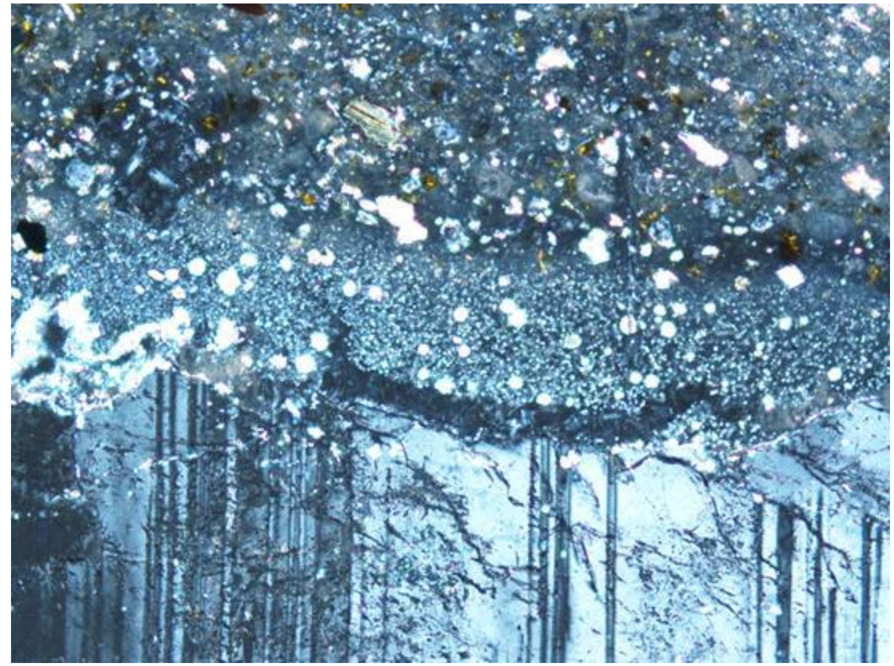
Especially, numerous cracks developed from fine aggregates.

【Observation of thin sections of concrete slices using a polarized light microscope】

Example of ettringite generated at the aggregate interface



Plane polarized light



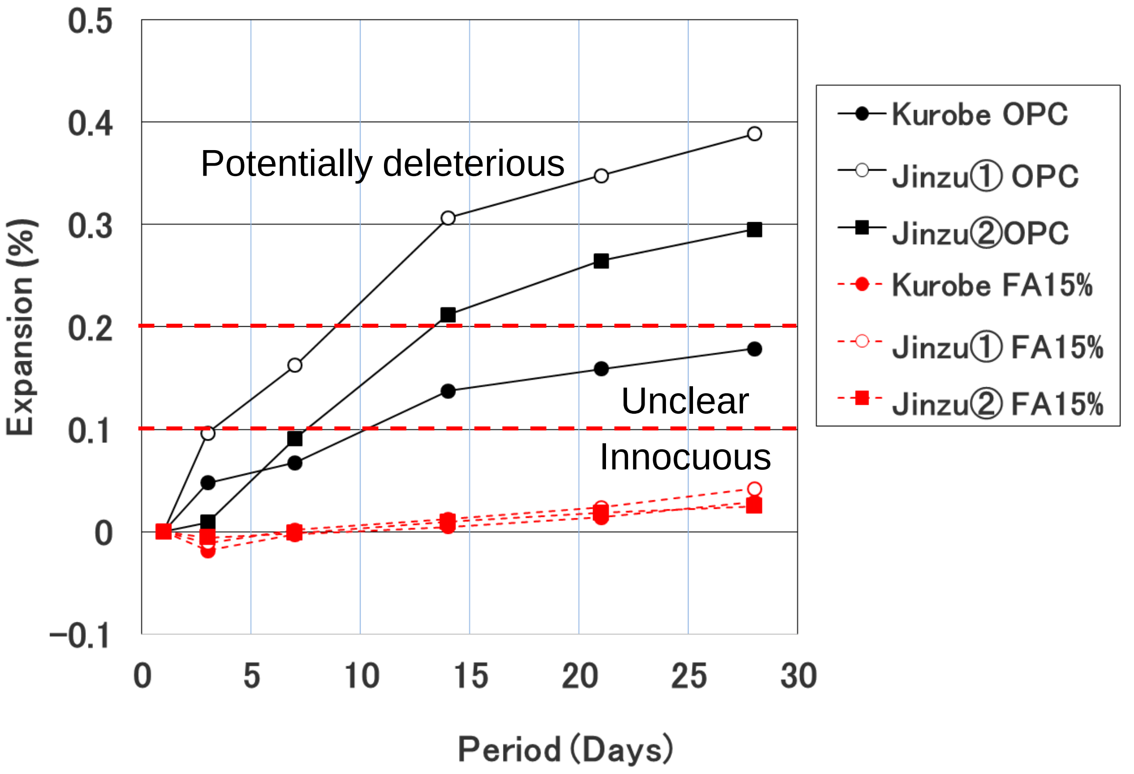
Crossed polarized light

Although some cracks and air voids filled with needle-type ettringite in the cement paste portion indicated the possibility of DEF, however typical feature of DEF was not confirmed. Importantly, Fly ash is effective for ASR and/or DEF.

【Verification of ASR Suppression Effect by Fine Fly Ashes】

A mortar bar test was conducted for a total of six cases with mixtures of 15% cement substitution of fine fly ash

Aggregate actually used at the factory was used.



Accelerated mortar bar test result in accordance with ASTM C1260 shows a sufficient ASR mitigation effect.

【Test using the Concrete Mixtures to Confirm Applicability of Fine Fly Ashes in Centrifugal Molded Precast Concrete Products】

The conditions of the mix design were set to a control strength of 94 N/mm^2 (nominal strength class 85), a slump of 180±30 cm, and an air volume of 2±1%.

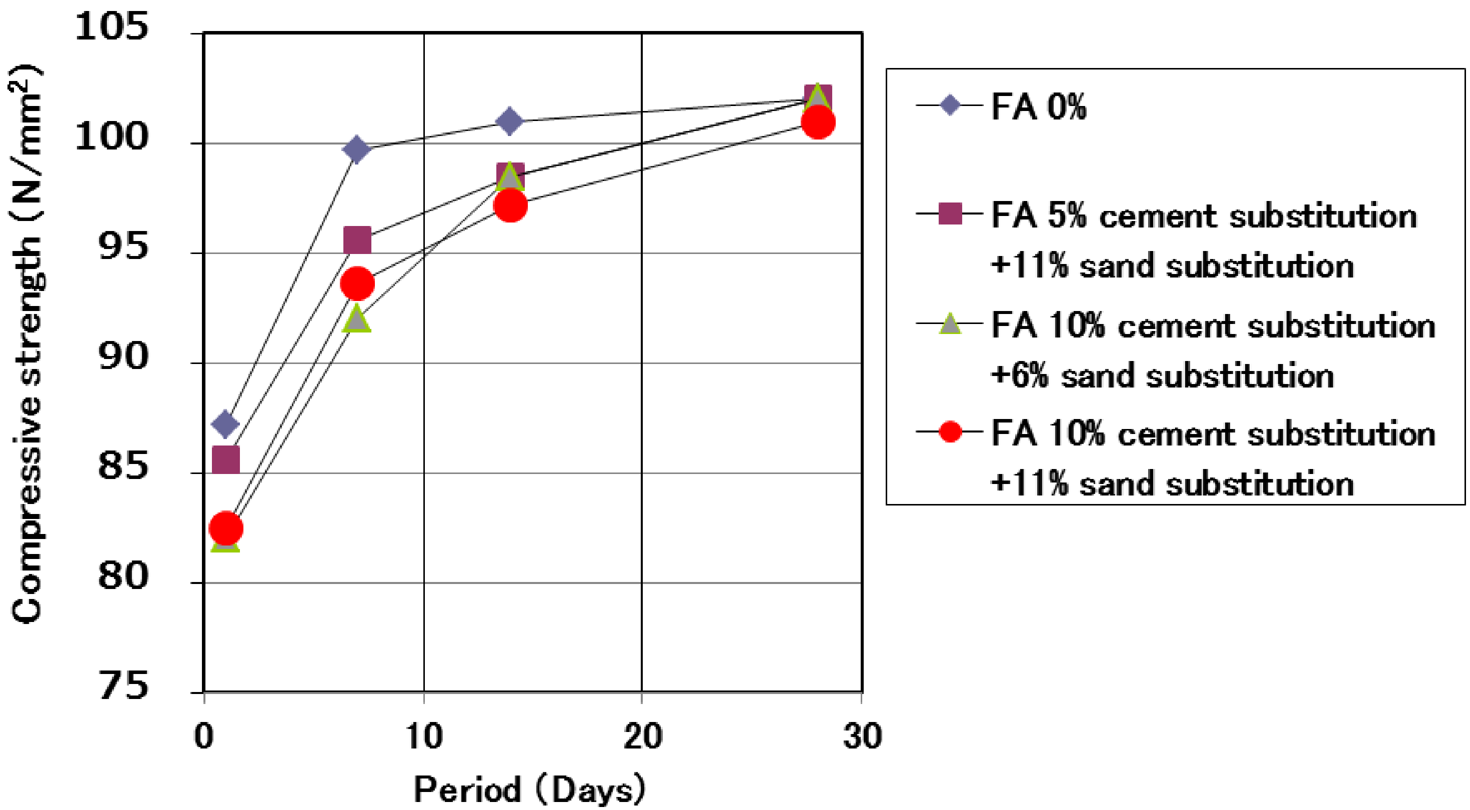
The mixing method of fly ash was a combination of sand and cement substitution.

As for the amount of fly ash used to exert an ASR suppressing effect, it was set to a level equivalent to or greater than 15% in the case of cement substitution.

Test Concrete Mixtures

Case	Unit content(kg/m^3)					
	Water	Powder volume			Sand	Gravel
		Cement	High-strength admixture	Fly ash		
FA 0%	155	500	50.0	0	642	1088
FA 5% cement substitution +11% sand substitution	155	475	47.5	100	552	1088
FA 10% cement substitution +6% sand substitution	155	450	45.0	95	581	1088
FA 10% cement substitution +11% sand substitution	155	450	45.0	132	539	1088

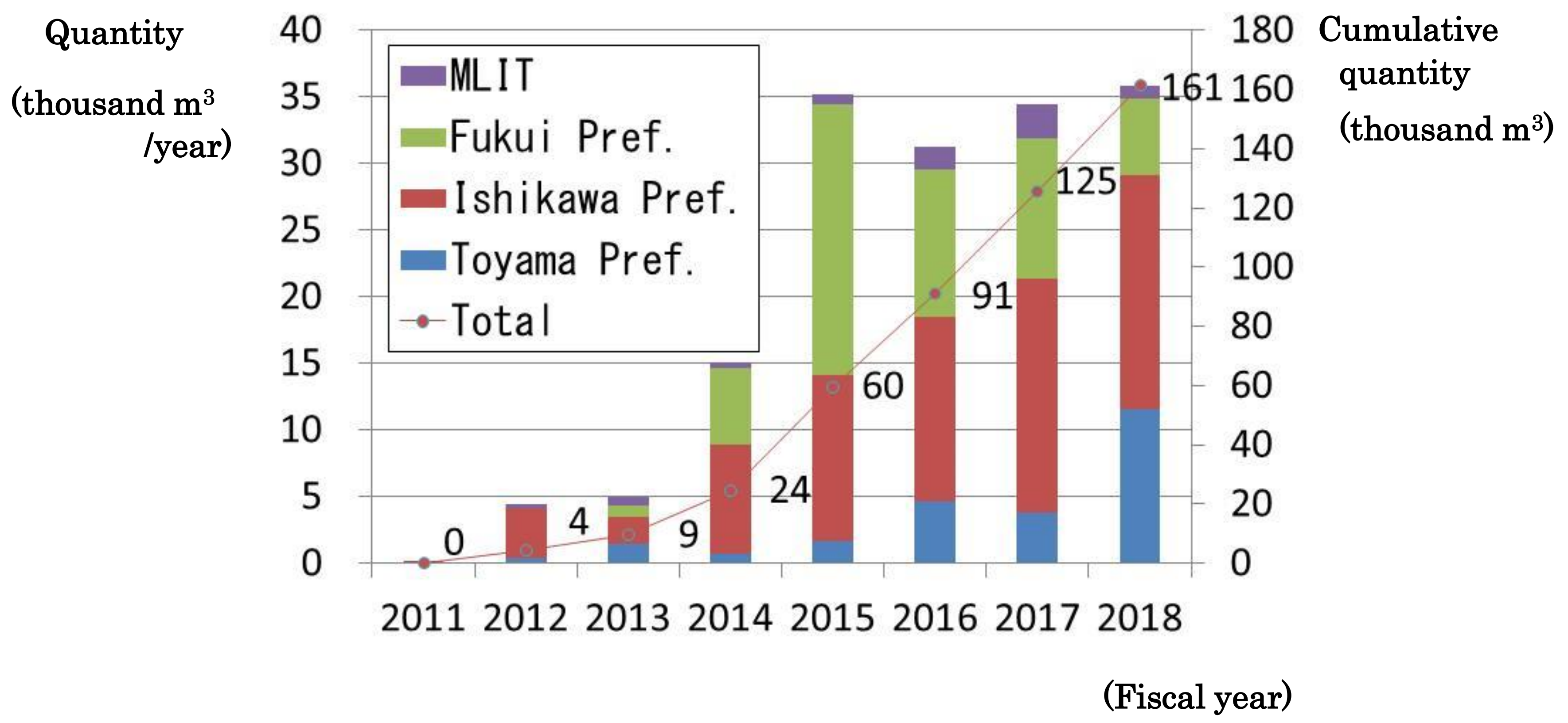
【Test Result of Compressive Strength of Precast Concrete 】



Compressive strength test results

The compressive strength of the fly ash mixture was about 5% lower than the portland cement formulation up to 14 days, but from 14 days to 28 days, the fly ash mixtures showed a strength enhancement higher than the OPC concrete. Furthermore, it was confirmed that the compressive strength of fly ash mixtures at 28 days was equal to that of the reference formulation.

Concrete volume of structures using fly ash concrete in public works in the Hokuriku district



Concluding remarks

In January 2011, a joint-collaborative industry-academia-government research committee on the "promotion of effective utilization of fly ash concrete in the Hokuriku district" was set up.






At present, a lot of candidates for the actual use of fly ash concrete in bridge, culvert and dam structures are being actively investigated.

We would like to propose the know-how for a further effective utilization of fly ash concrete in the Hokuriku District and other districts, based on the strong ethic . That is "Local Production for Local Consumption" .

Thank you very much for your kind attention！