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

Tateyama Mountains

Hokuriku Shin-kansen Line (JR)

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1. ASR problems in Japan
Map of ASR Affected Bridges in Japan

Past 40 years ago
Classical ASR such as Andesite
* Hokuriku, Kansai, Kyushu etc.

Last 20 years
Late Expansive ASR such as
Chert, Silicious Slate
New Findings ; Okinawa, Tokyo,
Tohoku, Hokkaido etc.

Now, ASR is a common problem everywhere all over Japan!

* 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$_2$Oeq

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

- Depending on conditions, ASR is still sometimes observed.

How can we counter ASR?
Why should we start using fly ash concretes?

Applied most often. These measures are not enough.
Not applied.
2. ASR Problems in Hokuriku District
Located on Green-tuff Area in Japan
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.
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.
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 pessimunm 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 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.
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

- **Boiler**
- **Electrostatic precipitator**
- **Chimney**
- **Centrifugal machine**
- **Filter**

**Added device**

**Silo (Original raw fly ash)**

- **Fan**
- **Original raw fly ash**

**Silo (Coarse Powder)**

**Silo (Fine Powder)**

**Classified fly ash**

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

<table>
<thead>
<tr>
<th>Fly ash type</th>
<th>Physical properties</th>
<th>Mineralogical properties(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Density (g/cm³)</td>
<td>Blaine fineness (cm²/g)</td>
</tr>
<tr>
<td>Original</td>
<td>2.36</td>
<td>3390</td>
</tr>
<tr>
<td>Classified fine fly ash</td>
<td>2.43</td>
<td>4780</td>
</tr>
</tbody>
</table>

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)
### Reaction Area and CSH Products (SEM–BEI)

<table>
<thead>
<tr>
<th>Points</th>
<th>fa-1</th>
<th>fa-2</th>
<th>fa-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca/Si  Ratio</td>
<td>0.05</td>
<td>0.88</td>
<td>1.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Points</th>
<th>bfs-1</th>
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<th>bfs-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca/Si  Ratio</td>
<td>1.39</td>
<td>1.47</td>
<td>1.58</td>
</tr>
</tbody>
</table>
4. Successful Case of Fly Ash Concrete in PCa PC Concrete Electrical Poles as Mitigation Method
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.
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

<table>
<thead>
<tr>
<th></th>
<th>Length (m)</th>
<th>Thickness of the concrete (mm)</th>
<th>Number of the re-bar</th>
<th>Design load (kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard type</strong></td>
<td>10</td>
<td>38</td>
<td>12</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>50</td>
<td>24</td>
<td>700</td>
</tr>
<tr>
<td><strong>Special type</strong></td>
<td>10</td>
<td>85</td>
<td>72</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>70</td>
<td>64</td>
<td>2000</td>
</tr>
</tbody>
</table>

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

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

* Gel Fluorescence Test
The area where ASR is present shows a characteristic greenish yellow fluorescence.
The andesite and rhyolitic tuffs contained in fine aggregates generated ASR.
Example of cracks occurred in fine aggregate

Especially, numerous cracks developed from fine aggregates.
Example of ettringite generated at the aggregate interface

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.
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/mm² (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.

<table>
<thead>
<tr>
<th>Case</th>
<th>Unit content(kg/m³)</th>
<th></th>
<th></th>
<th>Sand</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water</td>
<td>Powder volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cement</td>
<td>High-strength admixture</td>
<td>Fly ash</td>
<td></td>
</tr>
<tr>
<td>FA 0%</td>
<td>155</td>
<td>500</td>
<td>50.0</td>
<td>0</td>
<td>642</td>
</tr>
<tr>
<td>FA 5% cement substitution +11% sand substitution</td>
<td>155</td>
<td>475</td>
<td>47.5</td>
<td>100</td>
<td>552</td>
</tr>
<tr>
<td>FA 10% cement substitution +6% sand substitution</td>
<td>155</td>
<td>450</td>
<td>45.0</td>
<td>95</td>
<td>581</td>
</tr>
<tr>
<td>FA 10% cement substitution +11% sand substitution</td>
<td>155</td>
<td>450</td>
<td>45.0</td>
<td>132</td>
<td>539</td>
</tr>
</tbody>
</table>
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

![Graph showing the quantity and cumulative quantity of fly ash concrete use in different fiscal years.]

- **Quantity (thousand m³/year):**
  - 2011: 0
  - 2012: 4
  - 2013: 9
  - 2014: 24
  - 2015: 60
  - 2016: 91
  - 2017: 125
  - 2018: (increasing trend)

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  - 2011: 0
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  - 2017: 125
  - 2018: (increasing trend)

(Fiscal year)
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”.

[Images of construction sites included]
Thank you very much for your kind attention!