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Evaluation of maintenance methods for ASR-damaged structures in Hokuriku district, Japan

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ABSTRACT

River sand and river gravel have for long been used as aggregates for concrete in the Hokuriku district, but some of the volcanic rock types, such as, andesite, rhyolite and tuff have been damaging a lot of structures due to alkali-silica reaction. Damage due to ASR in this region became obvious in the 1980s, and there are many structures that have been repeatedly repaired. Crack injection and surface coating, section repair, concrete jacketing for injury prevention to third parties due to concrete exfoliation and corrosion inhibition of reinforcing bars are common repair methods that have been applied since 2001. This study examines the applicability of these repair methods from the view points of alkali content of concrete, petrological composition of aggregates, and compares the residual expansivity of the structures by Canadian method before repair and 10 years afterwards.

Keywords. alkali-silica reaction, repair, residual expansivity, EPMA, andesite

1. INTRODUCTION

River sand and river gravel have for long been used as aggregates for concrete in the Hokuriku district, but some of the volcanic rock types, such as, andesite, rhyolite and tuff have been damaging a lot of structures due to alkali-silica reaction. Damage due to ASR in this region became obvious in the 1980s. At the time, evaluation of the residual expansivity of cores due to ASR was assessed by JCI-DD2 method (moist-air-cured at 40°C), but most cores did not expand and were judged as having “no residual expansivity”. The repair method used from 1988 was crack injection and surface coating. But cracks and blisters on surface coating almost occurred in a few years after the repairs, and it was evident that the ASR deterioration and the residual expansivity of cores did not match

For this reason, accelerated ASR expansion test (Canadian method, ASTM C1260, saturated 1N NaOH solution at 80°C) that supply alkalis from an external source have been carried out for the past 15 years to evaluate the residual expansivity of concrete cores. Most cores have expanded by this test method, and have been judged as “having residual expansivity”. ASR deterioration on the site and residual expansivity of cores matched, and it was confirmed that the recession and progress of ASR could be determined by periodic Canadian tests.

Crack injection and surface coating, section repair, concrete jacketing for injury prevention to third parties due to concrete exfoliation and corrosion inhibition of reinforcing bars are common repair methods that have been applied since 2001. This study examines the applicability of these repair methods from the view points of alkali content of concrete, petrological composition of aggregates, and compares the residual expansivity of the structures by Canadian method before repair and 10 years afterwards.

2. STRUCTURES SURVEYED IN THE STUDY

The structures surveyed in this study are expressway structures in Toyama Prefecture. These structures were built with aggregates from the same river basins (river sand and river gravel), and have been affected by deicing salts in the winter season. ASR deterioration in this region has a strong relationship to andesite content and alkali content in concrete, i.e. the severity of ASR deterioration is directly proportional to andesite content and alkali content in concrete. Reactive minerals contained in the andesite are opal, cristobalite, trydimite and volcanic glass. The alkali source in concrete is mostly cement, but there are alkalis coming from the aggregate or admixture too. There are also cases of high alkali content on the surface of structures caused by deicer salts. The repair methods and the condition after repair are shown from Tables 1 to 3. The repairs consisted of three types of continuous fiber sheet as surface coating, namely of acrylic, epoxy and urethane types, surface treatment with sodium silicate,

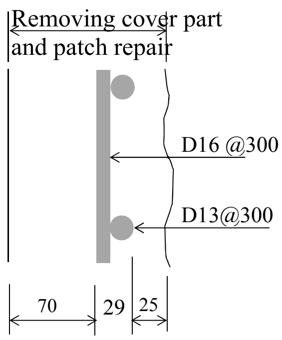
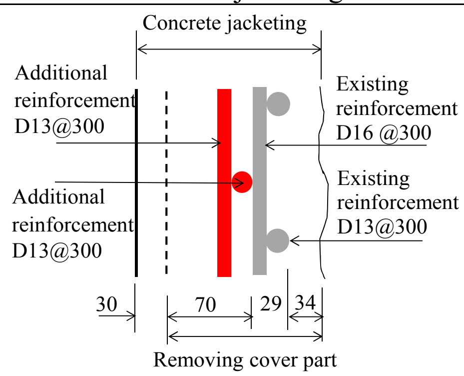
Table 1 Surveyed structure（Surface coating）

Material	Acrylic system	Urethane system	Epoxy system
Cross-sectional configuration	Top : Acrylic urethane(300g/m^2) Second : Acrylic rubber (2,000g/m^2) Under : Epoxy (200g/m^2)	Top : Fluorine (300g/m^2) Second : Urethane (2,500g/m^2) Under : Urethane (200g/m^2)	Top : Polyurethane (120g/m^2) Second : Epoxy (700g/m^2) Under : Epoxy (400g/m^2)
Repair	2001	2001	2004
Construction	1975	1975	1975
Structure	A	B	C
Part	Abutment	Abutment	Peer
Present state	Good	Good	Deterioration

Table 2 Surveyed structure（Surface coating）

Material	Continuous fiber sheet		
Cross-sectional configuration	Top : Acrylic ($300g/m^2$) Carbon fiber (Fiber basis weight $317g/m^2$) Adhesive impregnation Epoxy	Top : Acrylic ($300g/m^2$) Aramid fiber (Fiber basis weight $650g/m^2$) Adhesive impregnation Epoxy	Top : Acrylic ($300g/m^2$) Polyethylene fiber (Fiber basis weight $650g/m^2$) Adhesive impregnation Epoxy
Repair	2002		
Construction	1980		
Structure	D		
Part	Abutment		
Present state	Good		

Table 3 Surveyed structure（Patch repair）

Material	Polymer cement mortar		Concrete jacketing	
Cross-sectional configuration				
Repair	2001	2001	2004	2002
Construction	1975	1975	1975	1975
Structure	F	G	H	I
Part	Abutment	Abutment	Abutment	Abutment
Present state	Deterioration	Deterioration	Good	Deterioration

polymer cement for section repair with shotcrete and concrete jacketing. In all these repair methods, the deterioration has reoccurred in the cases of epoxy type of surface coating, section repair with polymer cement and concrete jacketing.

3. SURVEY AND TESTING METHODS

3.1 Lithological composition of gravels

On the surface of concrete cores, all the visible particles exceeding 5mm diameter were lithologicaly classified. Image analysis software provided the tools to determine the overall mineralogical composition, by measuring the surface area of each mineral component.

3.2 Alkali content of concrete

A 10g sample ground to particles with less than 300μm in diameter was added to 100ml of distilled water at 40°C and agitated for 30 min. The mixture was then filtered and the alkali concentration of the filtrate was measured by atomic absorption photometry, to calculate the (Na_2O + 0.658 K_2O) equivalent.

3.3Residual expansion of concrete cores by Canadian method

The time-related changes in the expansion of drilled concrete cores (Ø=55mm, L=150mm, initial depth= 100mm) were measured in accordance with the accelerated mortar method (ASTM C1260-1994). The specimens were immersed in a 1N NaOH solution at 80°C. Referring to the evaluation criteria applied for the Hokuriku Expressway, cores with an expansion ratio exceeding 0.1% at 21 days were judged as having deleterious expansivity, as shown in Figure 1 and Figure 2.

Figure 1 Cores immersed in a 1N-NaOH

Figure 2 Measurement of the expansion of the core

3.4 Elemental mapping by EPMA

Concentration of silicon and calcium were analysed on the surface by “Area analysis method of element distribution in concrete with EPMA (Electron Probe Micro Analyzer)”, in accordance with JSCE-G 574-2005 Japanese Standards, after impregnating a concrete sample (height 50 mm × width 50 mm × thickness 10 mm) with an epoxy resin of low clay content and thoroughly polishing it.

3.5 Reinforcement steel stresses and strains measured in the structure

Strain gauges were set on the rebars, after exposing them by drilling a concrete block with

Figure 3 Setting up of strain gauges

Figure 4 Cutting of reinforcement steel with a grinder

Figure 5 Strain gauges in the reinforcement steel

size averaging 200 X 250mm, as shown in Figure 3. Thereafter, the stresses were measured after cutting the rebars with a grinder, as shown in Figure 4. Strain gauges were set on the cutting points, and the strains developed in the reinforcement steel were therefore monitored (Shown in Figure 5).

4. SURVEY RESULTS OF SURFACE COATING REPAIR METHOD

The structures deteriorated by ASR in the Hokuriku district have tended to crack in the cases were the andesite content was approximately 4% or more and the alkali content was more than 2 kg/m^3. With the increase of both, a wider ASR cracking network occurs and ASR deterioration becomes severe. Figure 6 shows the relationship between the andesite content and the alkali content of each structure. Figure 7 shows the comparison of Canadian method results (expansion ratio at 21 days) before repair works and 10 years after repair was completed.

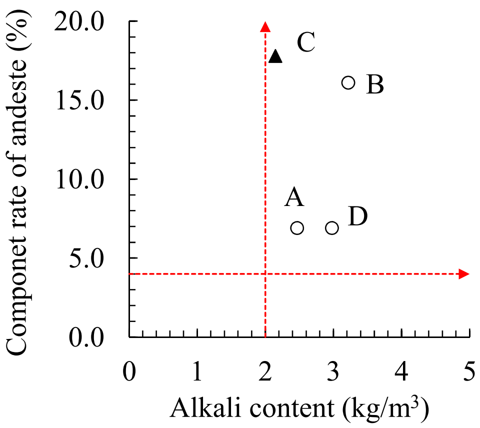


Figure 6 Relationship between the alkali content and the andesite ratio

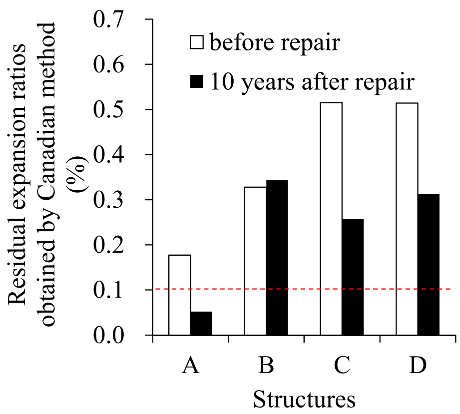


Figure 7 Comparison of expansion ratios determined Canadian method

The potential of ASR progress in the structure A was small due to the lower andesite ratio and lower alkali content. Also, the residual expansion determined by Canadian method was 0.2% (at 21days) before repair, but the residual expansion 10 years later was less than 0.1%, showing that ASR was in recession. This trend shows that acrylic type of fiber sheet coating suppressed the progression of ASR.

The potential of ASR in the structure B was big because the andesite ratio and alkali content were both high. The residual expansion by Canadian method did not decrease since the repair period. Although the ASR potential of this structure was high, the urethane type of fiber sheet coating performed very well.

In structure C, the andesite ratio was high, but the alkali content was relatively low. In this case, it was considered that ASR would continue for prolonged periods. On the other hand, the residual expansion determined by Canadian method was as high as 0.5% in the repair period, but decreased to 0.25% in the course of 10 years after repair. Although there was no risk that structure C could be affected by water leaking from the backfill into the abutment, ASR showed a recession pattern, but it was difficult to apply the epoxy type of fiber sheet coating and cracks occurred in the cases where the residual expansion was more than 0.2%, as shown in Figure 8

Figure 8 Cracks occurred on the repaired in Structure C

Structure D had a low andesite ratio and high alkali content. In this case, it was considered that ASR recession would be relatively fast. The residual expansion by Canadian method decreased to 0.3%, corresponding to approximately 60%, in the period of 10 years after repair. Although the decreasing of ASR expansion was relatively slow in the beginning, for about five years' time ASR began to recess faster than other structures, but the ASR potential was still considered high. Nonetheless the ASR potential was high, the 3 types of fiber sheet coating have performed well.

The good practice shows that soon after diagnosing ASR, the structure should not be rashly repaired before correctly understanding the alkali content of concrete, the lithological composition of aggregates and the continued evaluation of residual expansivity of cores by Canadian method. This study has shown that the selection of the repair method can be adapted to the potential of ASR progress.

5. SURVEY RESULTS OF SURFACE TREATMENT REPAIR METHOD

In structure E, surface treatment with sodium silicate was applied as ASR repair method in 1995, but cracks occurred after a few years, as shown in Figure 9. The characteristics of this material composed mainly of magnesium compound, suppress the ASR progress by densifying the concrete, while penetrating into the concrete depths and promoting the

Figure 9 Deterioration due to ASR in Structure E

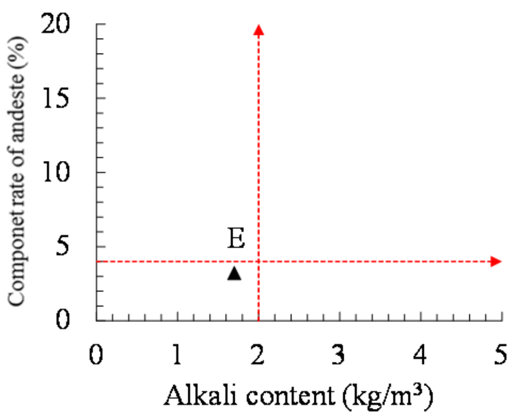
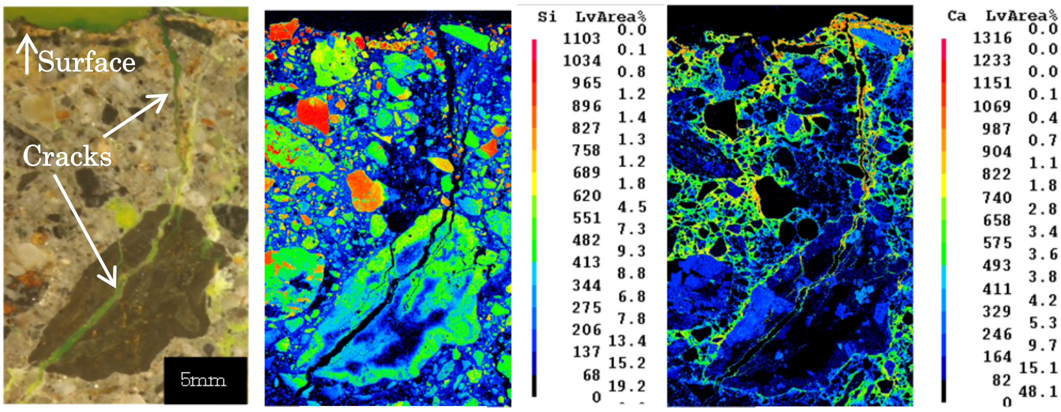


Figure 10 Relationship between the alkali content and andesite ratio



Real image Si mapping Ca mapping

Figure 11 Results of EPMA(WDS) mapping at the cracks point

formation of new cement crystals that grow in the capillary pores, transition zone and microcracks. The Figure 10 shows the relationship between the andesite ratio and alkali content, and it is understandable that the ASR potential is very low. The concrete core was drilled from a cracked point of the structure and Figure 11 shows the results of element analysis distribution in concrete using EPMA. Crack width of approximately 0.5 mm that occurred through the coarse aggregate from the surface were observed. But these results could not confirm the presence of silica and calcium as the main cement crystals. This surface treatment has not been able to fill the cracks even 17 years after repair, so this method was not effective for suppressing ASR progress.

6. SURVEY RESULTS OF PATCH REPAIR METHOD

6.1 Patch repair with polymer cement mortar

After removing the concrete cover, patch repair with polymer cement mortar was executed in Structures F and G. The polymer cement mortar used in both cases was a product of the same company. These mortars contain about 1.5 to 2% short fibers in order to prevent cracking in the material. However, ASR progress of the structure inside continued after repair, and cracks with less than 0.2 mm width have reoccurred, as show in Figures 12 and 13. Figure 14 shows the relationship between andesite ratio and alkali content of each structure. Figure 15 shows the comparison of expansion ratios at 21 days determined by Canadian method before repair and 10 years after repair. It can be understood that the andesite ratio and the alkali content of structure F are higher than those of structure G. In addition, the residual expansivity trended toward convergence in structure F, but it was clearly progressing in structure G. The changes in the extension and pattern of cracks that occurred in the patch repair have been better in structure G than F, and it became reflective of the potential of ASR. It is also important to note that, in the structures with patch repair where no residual expansivity was observed, the residual expansivity obtained by Canadian method was less than 0.1% at 21 days. From the economic rationality point of view, in the cases where a large number of cracks occurred, the possibility of re-damage was higher when patch repair was applied instead of crack injection. Therefore, the option of patch repair has to be carefully reviewed and judged in accordance with the results of the residual expansivity determined by Canadian method.

Figure 12 Cracks occurred on the patch repair in Structure F

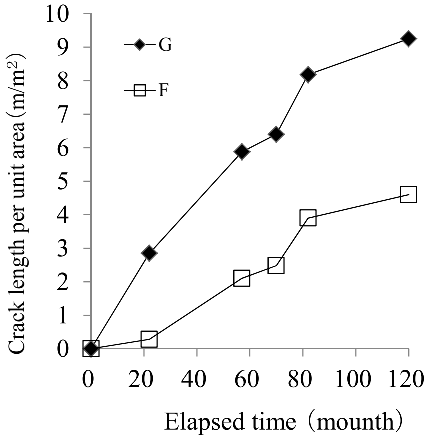


Figure 13 Crack density progress occurred on the patch repair

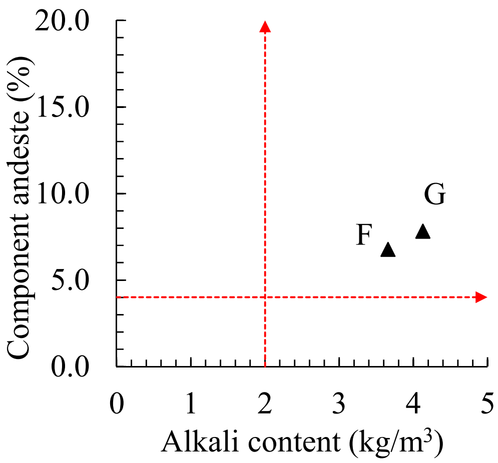


Figure 14 Relationship between the alkali content and andesite ratio

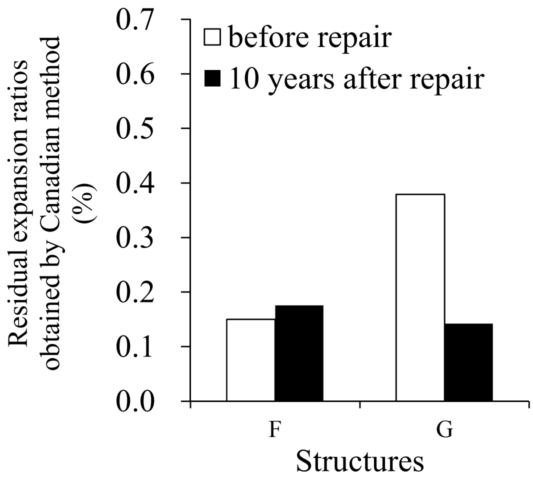


Figure 15 Comparison of expansion ratios determined by Canadian method

6.2 Concrete jacketing

Concrete cover was removed and concrete jacketing was executed in Structures H and I, after placing the reinforcement steel. Table 4 shows mixing proportions of the concrete used. In addition, short fibers in the proportion of 0.5% of cement were included for crack prevention in the concrete, expansive agents and superplasticizer were added as admixtures. Figure 16 shows the relationship between the andesite ratio and the alkali content on each structure. Figure 17 shows the comparison between the expansion ratios at 21 days determined by Canadian method before repair and 10 years after repair. Both structures showed high potential trend of ASR. In addition, structure H had an high residual expansivity at the repair time, but the residual expansivity was less than half after 10 years period. It was suggested that ASR trend in structure H was towards convergence. On the other hand, the trend of residual expansivity has been constant in structure I, and it was suggested that ASR was not trending towards convergence. Figure 18 shows the cracks ithat occurred in the structure I. Since ASR was not trending toward convergence, it was considered that concrete jacketing was not that effective in ASR suppression.

Furthermore, the reinforcement steel strains were measured at the repair time in the structure I, and they varied from 850μ to 1300μ. The reinforcement steel strains have been monitored by strain gauges after concrete jacketing was applied. Figure 19 shows the results of reinforcement steel strains. The expansion due to ASR has continued after repair, and the steel stresses have also increase. In particular, the strain of D13 reinforcement steel was more than 2000μ and reached the plastic area. Therefore, if concrete jacketing is aplied to suppress ASR progress in the structure, the margin of reinforcement steel diameter has to be increased.

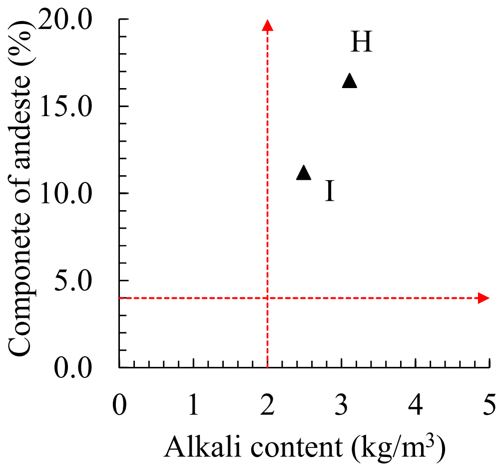


Figure 16 Relationship between the alkali content and component rate of andesite

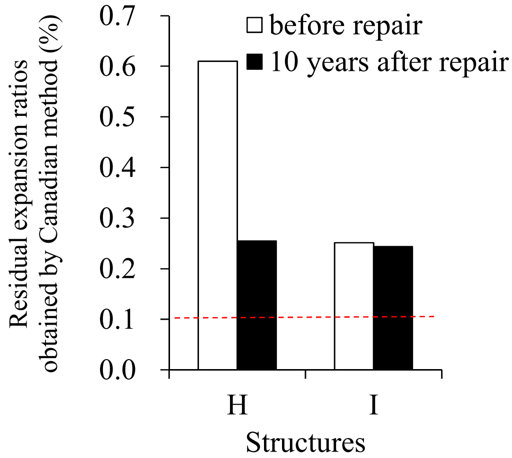


Figure 17 Comparison of expansion ratios determined due Canadian method

Figure 18 Cracks occurred on the patch repair Structure H

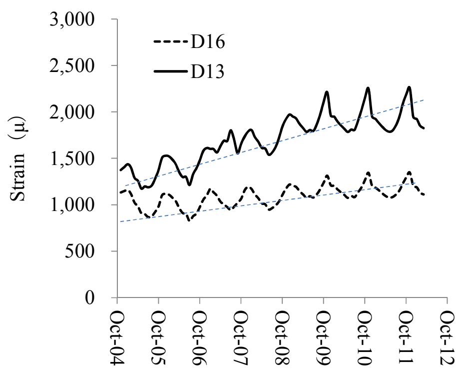


Figure 19 Strain of steel reinforcement due to ASR progress in Structure H

7. CONCLUSIONS

This study examined the praticability of repair methods and the long-term results of residual expansivity tests of the structures, determined by Canadian method. The main concluding remarks drawn from this study are as follows:

(1) Some surface coatings have performed well, according to the ASR potencial of the structure. In the case of low ASR potential, the acrylic type of fiber sheet coating was effective, while the urethane type of continuous fiber sheet performed well in the case of high ASR potential.

(2) The applicability of epoxy type of continuous fiber sheet coating was difficult in the case of high ASR potential.

(3) The sodium silicate-based materials targeted in this study were not able attain the expected results, and deterioration due to ASR has progressed.

(4) The patch repair with polymer cement mortar could not suppress ASR-induced expansion, and the cracks reoccurred on the surface of the repaired patch. The occurrence of crack was a concern if comparing the options of patch repair and crack injection, from the economic point of view. The application of patch repair helped to assess the trend of residual expansivity in the structure.

(5) The repair with concrete jacketing was a good measure to suppress the residual expansion, despite high ASR potential of the structure. However, in the cases where the residual expansivity did not trend towards convergence, high stresses developed in the reinforcement steel. Therefore, when concrete jacketing is applied, the diameter of the reinforcement steel has to be considered with a margin.

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