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Suppression of ASR Expansion by Pressurized Injection of Lithium Nitrite

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ABSTRACT

Past research shows that lithium ions have a suppressive effect on alkali-silica reaction (ASR) expansion[1), 4), 5)]. A variety of repair methods using lithium ions have been put to practical use, including crack injection, surface coating, and pressurized injection[2),]. Of these methods, pressurized injection, which is able to supply lithium ions over a wide range inside the concrete, is expected to have a particularly high ASR suppression effect[3),]. In this research, first, lithium nitrite was pressure injected into ASR concrete specimens, and it was demonstrated that subsequent ASR expansion was suppressed. Next, follow-up surveys were conducted on actual ASR-deteriorated structures to which pressurized injection of lithium nitrite had been applied. The survey results demonstrated that the ASR suppression effect was maintained for a long period of time.

Keywords: ASR, Lithium nitrite, Pressurized injection, Residual expansion

INTRODUCTION

In recent years, methods using lithium ions to repair concrete structures that have deteriorated as a result of the alkali-silica reaction (ASR) have been attracting attention. Three types of ASR repair methods using lithium ions have been put to practical use: crack injection, surface coating, and pressurized injection. Of these methods, pressurized injection, which is able to supply lithium ions over a wide range inside the concrete, is expected to have a particularly high ASR suppression effect. Pressurized injection suppresses ASR expansion by impregnating the interior of a concrete body with lithium nitrite, which is pressure injected into small-diameter holes drilled into the concrete. Figure 1 shows a schematic diagram of this method.

In this research, first, pressurized injection of lithium nitrite was carried out on concrete specimens with an ASR expansion of approximately 1500 μ, and the suppressive effect on ASR expansion was confirmed. Then, follow-up surveys were carried out on an ASR-deteriorated bridge abutment, bridge pier, and retaining wall that were repaired 4 to 5 years ago by the pressurized injection of lithium nitrite. The survey results demonstrated that the ASR suppression effect was maintained over time.

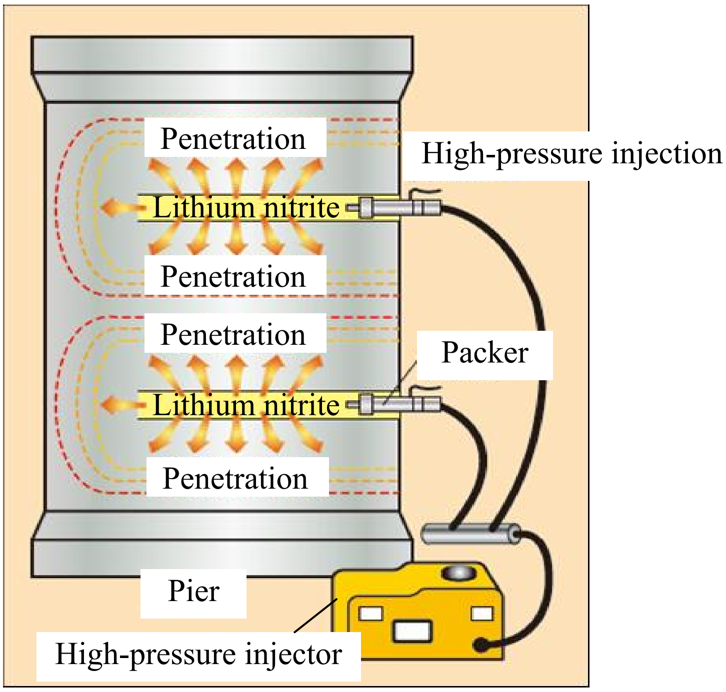

Figure 1 Schematic diagram of pressurized injection of lithium nitrite

SUPPRESSIVE EFFECT ON ASR EXPANSION DUE TO PRESSURIZED INJECTION OF LITHIUM NITRITE

Specimens. The concrete specimen mix used in the experiment is shown in Table 1. Pyroxene andesite from Hokkaido was used for both coarse and fine reactive aggregates. The proportion of reactive aggregate was 70% for fine aggregate and 50% for coarse aggregate, in accordance with the results of the testing of pessimum behavior. The amount of alkali added was 8 kg/m^3 Na_2O equivalent, and this was added to mixing water as NaCl. The lithium compound added as the ASR inhibitor was a 40% aqueous solution of lithium nitrite ($LiNO_2$). Cylindrical specimens of dimensions ∅100 mm × H200 mm were used, and a total of six contact tips were placed on the concrete surfaces (two on the top surface, four on the side surfaces) to measure expansion.

Table 1 Mix proportion of concrete

Gmax (mm)	W/C (%)	s/a (%)	Slump (cm)	Air (%)	Unit content(kg/m^3)					
					W	C	Sand		Gravel	
							Reactive	Non-reactive	Reactive	Non-reactive
20	63	45.7	12±2.5	4.5±1.5	183	290	574	239	493	495

Experimental factors. In this experiment, as shown in Table 2, test cases of premixing and pressure injection of lithium nitrite were set up, and the amount of lithium nitrite added in each case was varied. Three specimens were tested for each case. In the case of premixing, lithium nitrite was added during concrete mixing as an outer percentage corresponding to Li/Na molar ratios 0.4, 0.8, and 1.2. In the case of pressurized injection, at the moment when ASR expansion of specimens placed in an expansion-accelerating environment exceeded 1500 μ and a crack of width 0.2 to 0.4 mm appeared, a 40% aqueous solution of lithium nitrite corresponding to Li/Na molar ratios 0.4, 0.6, and 0.8 was pressure injected. The ASR expansion-accelerating environment was a high-temperature/high-humidity chamber at a temperature of 40°C and humidity of 95%. Specimens were left in the chamber and expansion strain was measured every 2 weeks. The effect of the addition of lithium ions and the effect of the different methods of adding lithium ions on the suppression of ASR expansion were examined.

Table 2 Specimen types of expansion test

Reactive Aggregate	Lithium nitrite ($LiNO_2$)		Number of specimens
	Supply method	Mol ratio (Li/Na)	
Andesite	No addition	—	3
	Premixture	0.4	3
		0.8	3
		1.2	3
	Pressurized injection	0.4	3
		0.6	3
		0.8	3

Experimental results. The relationship between the expansion acceleration period, the average of expansion strain in specimens premixed with lithium nitrite, and the specimens pressure injected with lithium nitrite are shown in Figure 2. The specimens with no added lithium nitrite showed rapid expansion beginning 142 days after the start of expansion acceleration, and the specimens reached an expansion of approximately 5800 μ by the 410th day. Thus, the concrete specimens possessed a huge potential for expansion, but when lithium nitrite (Li/Na molar ratios 0.4, 0.8, and 1.2) was premixed into the specimens before concrete placement, no expansion trend appeared in any of the specimens after 410 days from the start of expansion acceleration. Thus, the suppressive effect of lithium ions on ASR expansion was apparent. No difference according to the amount of lithium nitrite added was found to affect the suppression, and so it was possible to suppress ASR expansion in the specimen conditions by premixing lithium nitrite of Li/Na molar ratio 0.4 or above.

Pressurized injection of lithium nitrite was carried out on the 188th day, when specimen expansion had reached approximately 1500 μ. After injection was complete, the drill holes were immediately filled with non-shrink grout, and the specimen was returned to the expansion-accelerating environment. Immediately before the pressurized injection of lithium nitrite, the specimens showed rapid expansion; however, after pressurized injection of lithium nitrite, the expansion leveled off in all specimens (molar ratios 0.4, 0.6, and 0.8).

This shows that the ASR expansion property was greatly reduced after pressurized injection was carried out. In the expansion during the 222 days after pressurized injection, no difference due to the amount of lithium nitrite added was found to affect the suppression, and so it was possible to suppress ASR expansion in the specimen conditions by pressurized injection of lithium nitrite of Li/Na molar ratio 0.4 or above.

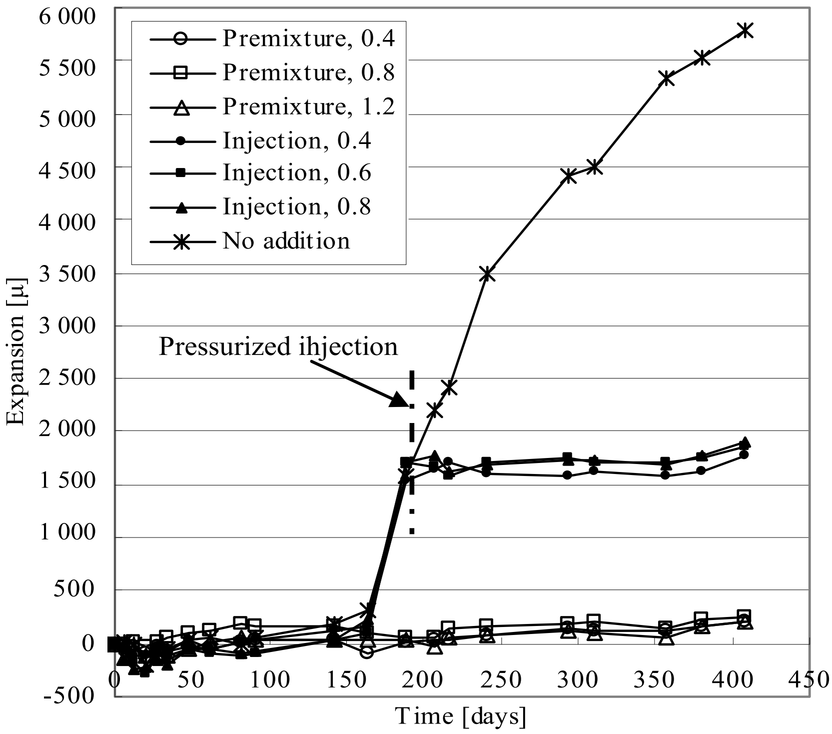

Figure 2 Expansion of concrete specimens

Lithium ions are distributed evenly within the concrete when premixed. In contrast, in the case of pressurized injection, the movement of lithium ions is considered to vary according to the width and density of cracks inside the concrete and achieving uniform distribution is considered difficult. Therefore, the supply efficiency of pressurized injection is assumed to be inferior to premixing, and it was predicted at the outset of the experiment that the amount of lithium nitrite required would be higher in the case of pressurized injection. However, the results of the experiment showed that ASR expansion was suppressed at a molar ratio of 0.4 or above in both cases, and no difference in the required amount of lithium nitrite was found. The reason is thought to be that the supply efficiency was not significantly reduced in the pressurized injection method because the specimen sizes were small (∅100 × H200 mm) and highly accurate injection control was possible in the laboratory. A loss resulting from deterioration in supply efficiency due to the pressurized injection method must be adequately taken into account when the method is actually applied onsite.

FOLLOW-UP SURVEY AFTER PRESSURIZED INJECTION

Surveyed structures. The structures targeted by the follow-up survey were a bridge abutment, a bridge pier, and a retaining wall, all of which were completed approximately 30 years previously and were still in service at the time of the survey. Pressurized injection of lithium nitrite was carried out during 2004 to 2005. Based on the results of testing to find the total alkali content of the concrete, lithium nitrite of Li/Na molar ratio 1.0 was injected into each of the structures at a pressure of 0.5 to 1.2 MPa. Table 3 shows an overview of the surveyed structures and examination items.

Table 3 Overview of surveyed structures and examination items

Viaduct K pier	Bridge S abutment	Facility A retaining wall
		
•Amount of lithium nitrite injected: 24.8 kg/m^3 •Reactive aggregate: Andesite •No. of years elapsed since injection: 5 •Examination item: External distortion follow-up survey	•Amount of lithium nitrite injected: 19.7 kg/m^3 •Reactive aggregate: Andesite •No. of years elapsed since injection: 4 •Examination item: External distortion follow-up survey	•Amount of lithium nitrite injected: 23.5 kg/m^3 •Reactive aggregate: Bronzite andesite •No. of years elapsed since injection: 4 •Examination item: Residual expansion (JCI-DD2 method)

Examination methods. Residual expansion testing indicates the possibility of future ASR expansion. So, residual expansion should be reduced in concrete in which ASR expansion has been suppressed by pressurized injection of lithium nitrite. To confirm quantitatively the ASR suppression effect resulting from the pressurized injection method, residual expansion testing was carried out on the Facility A retaining wall shown in Figure 3 before and after pressurized injection.

The method of residual expansion testing used was the JCI-DD2 method in which the conditions of the expansion-accelerating environment were 40°C, 95% RH. The cores used were of size ∅100 × L250 mm and were extracted from the surveyed structure using a diamond core drill. The core extraction period prior to pressurized injection was 2 to 4 weeks before pressurized injection was carried out, and the core extraction period after pressurized injection was 1 to 2 weeks after the completion of pressurized injection.

After measuring the core base length, standard curing was conducted for approximately 2 weeks under the conditions of temperature 20°C, relative humidity 95%, during which time the expansion strain was measured and taken as free expansion. Then, accelerated curing was conducted for 13 weeks under the conditions of temperature 40°C and relative humidity 95%, in accordance with the JCI-DD2 method, during which time the expansion strain was measured and taken as the residual expansion.

To confirm the presence or absence of external distortion, signs of redeterioration due to ASR, etc., a follow-up survey of external distortion were carried out on the Viaduct K pier and Bridge S abutment 4 to 5 years after pressurized injection of lithium nitrite. Because surface protection using flexible polyurethane resin had been applied to the surface of

Viaduct K, the presence of distortion in the surface of the surface protective material was confirmed. However, because surface protection had not been applied to the concrete surface of Bridge S, the condition of the concrete surface was confirmed directly.

Results of residual expansion testing. Using the core specimens collected before and after pressurized injection of the Facility A retaining wall, residual expansion testing was conducted in accordance with the JCI-DD2 method, and the ASR suppression effect of pressurized injection of lithium nitrite was confirmed. Figure 3 shows the results of the residual expansion testing (JCI-DD2 method) before, directly after, and 4 years after the pressurized injection method was applied to the Facility A retaining wall.

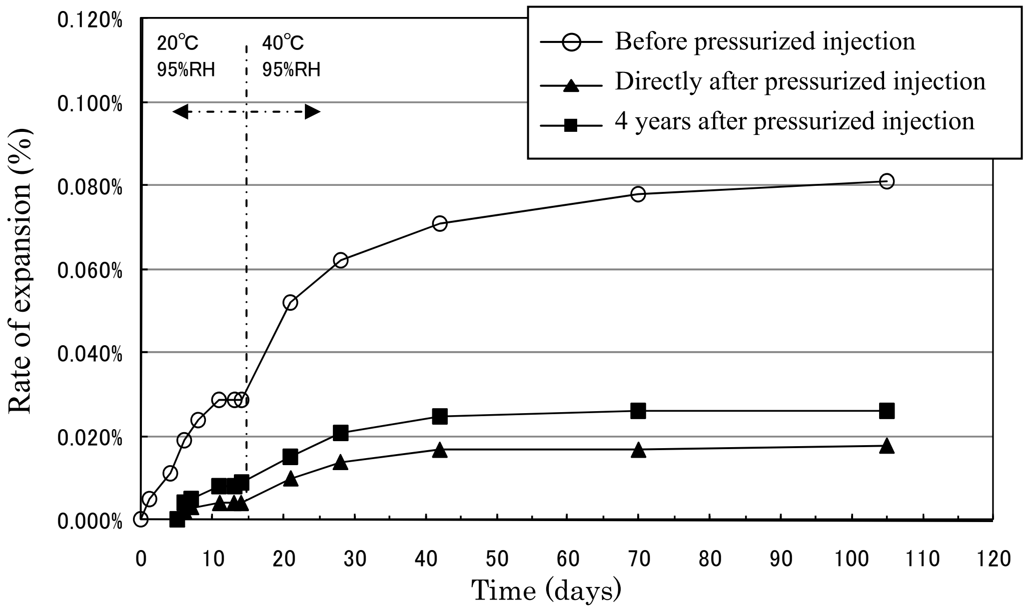

Figure 3 Residual expansion testing of Facility A retaining wall (JCI-DD2 method)

The results prior to and directly after pressurized injection are compared as follows. In Figure 3, 0.081% total expansion is shown prior to pressurized injection, but after pressurized injection this drops to 0.018%, which is 22.2% of the former amount. Prior to pressurized injection, residual expansion is 0.052%, while afterward it falls to 0.014%, which is 26.9% of the former amount. Residual expansion, which indicates the possibility of future expansion, drops to 26.9% after pressurized injection and is below 0.05%, which is one of the evaluation criteria of the JCI-DD2 method. Therefore, it can be judged that an ASR suppression effect is obtained directly after pressurized injection of lithium nitrite.

Next, expansion trends directly after and 4 years after pressurized injection are compared. For total expansion, 0.018% is shown directly after pressurized injection, and this amount becomes slightly higher (0.026%) 4 years after pressurized injection. However, this amount is well below the reference value of 0.05% at 13 weeks, as given in the JCI-DD2 method and, even after 4 years, the total expansion is still reduced to 32.1% of the value prior to pressurized injection (0.081%). Therefore, it can be judged that the high reduction of ASR expansion is maintained.

The reduction in residual expansion after pressurized injection of lithium nitrite is considered to indicate that the alkali-silica gel inside the concrete becomes non-expansive by the addition of lithium ions and thus reduces the possibility of future ASR expansion. It is assumed that once the gel has been made non-expansive by lithium ions, the gel will not acquire the property of expansion again unless a drastic change occurs in the balance between equivalent Na^+ and Li^+ ions. Therefore, the possibility of ASR causing redeterioration in structures that have had pressurized injection of lithium nitrite applied is considered to be low.

Results of external distortion survey. The condition of Viaduct K pier before pressurized injection (May 2004) and 5 years after pressurized injection (May 2009) is shown in Figure 4. Before pressurized injection, numerous cracks of width 0.5 to 5.0 mm were found in the pier's beam section, and rebar breakage was found in the bent sections of rebar at the upper and lower edges of the beam. The external appearance 5 years after pressurized injection shows no external distortion that could be regarded as ASR redeterioration or as a sign of ASR redeterioration, such as bulges or cracks in the surface of the flexible polyurethane resin applied as surface protection material to the concrete surface.

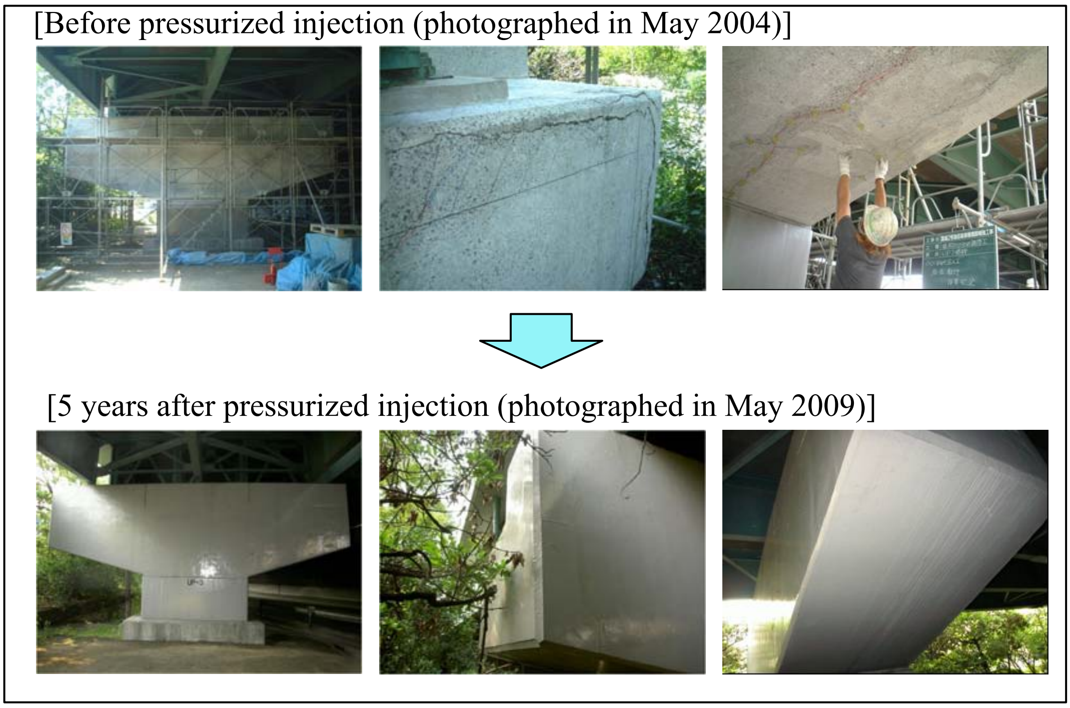

Figure 4 Viaduct K pier: condition before pressurized injection and 5 years after pressurized injection

ASR repair work using a surface protection method had been carried out on this pier in the past, but redeterioration due to ASR occurred within just a few years of the repair. Thus, the concrete of this pier demonstrated fast progression of ASR expansion. However, 5 years after pressurized injection of lithium nitrite, ASR suppression was maintained.

The condition of the Bridge S abutment prior to pressurized injection (September 2005) and 4 years after pressurized injection (August 2009) is shown in Figure 5. Prior to pressurized injection, distortion was found in the form of a large amount of map cracking, and water was leaking from some of the cracks. Also, it was found that water was seeping through the cracks and inside the concrete from the bearing and back surfaces of the abutment to the front surface of the abutment.

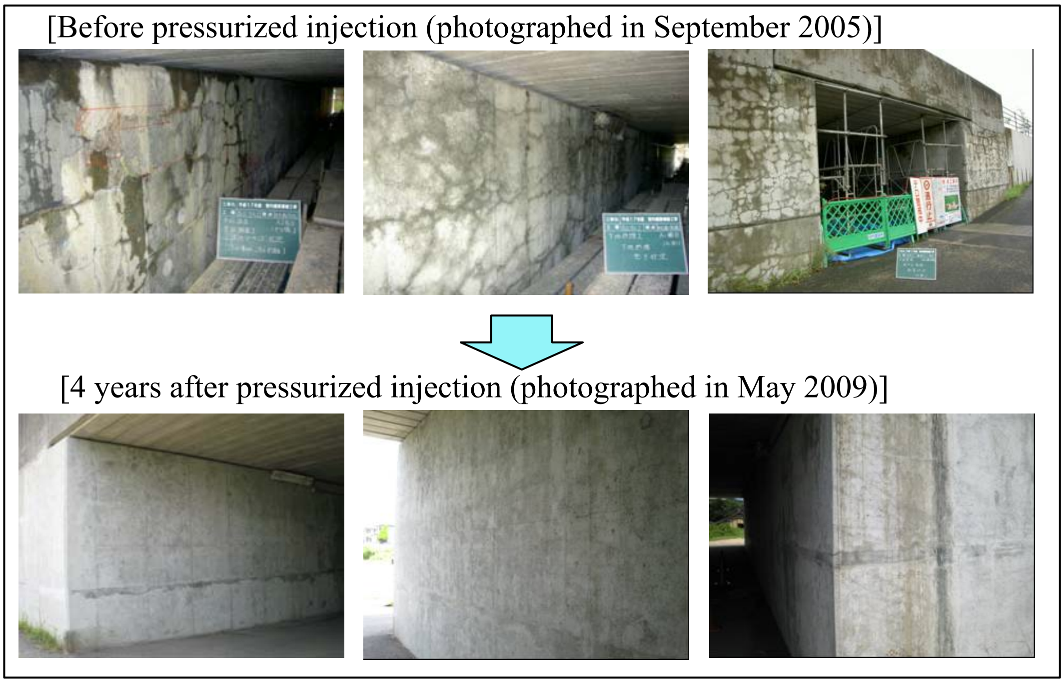

Figure 5 Bridge S abutment: condition before pressurized injection and 4 years after pressurized injection

No surface protection repair had been applied to the concrete surfaces of the abutment after pressurized injection of lithium nitrite. Thus, it was possible to confirm the condition of the concrete surface directly 4 years later. A careful, close visual inspection of the concrete surfaces of the abutment found no external distortion that could be regarded as ASR rederioration or a sign of ASR redeterioration.

Figure 6 shows the trace of an injected crack on the front surface of the abutment. This crack trace, which was wider than 0.2 mm, was injected with crack injection material of ultra-fine cement as pretreatment prior to pressurized injection of lithium nitrite. This injection material does not possess crack-bridging properties, but a sound condition was maintained around the crack injection trace. Figure 7 shows the condition near the boundary between a section where pressurized injection was carried out and a section on the side surface of the abutment where pressurized injection was not carried out. Cracks approximately 2.0 mm wide were found in the section where pressurized injection was not carried out, whereas no new cracks or other distortion were found in the section where pressurized injection was carried out. These results show that no distortion suggestive of ASR progress or any sign of ASR progress was found during the 4 years period from the application of pressurized injection up to the current time, and the lithium nitrite maintained the ASR suppression.

Figure 6 Condition of injected crack trace

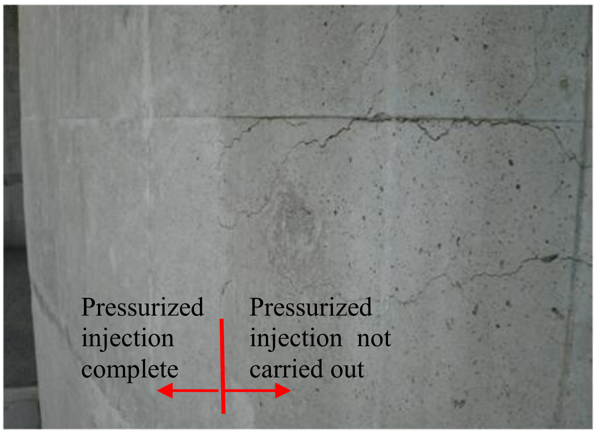

Figure 7 Condition near boundary between sections with and without Pressurized injection applied

CONCLUSION

(1) Suppression of ASR expansion was achieved by premixing lithium nitrite of Li/Na molar ratio 0.4 or above into ASR concrete specimens containing reactive aggregate. Also, suppression of ASR expansion was achieved after pressurized injection of lithium nitrite of Li/Na molar ratio 0.4 or above into ASR-deteriorated concrete specimens.

(2) External visual inspections of the abutment and the pier 4 to 5 years after pressurized injection found no distortion suggestive of ASR redeterioration or any sign of ASR redeterioration.

(3) As a result of carrying out residual expansion testing according to the JCI-DD2 method on a retaining wall prior to, directly after, and 4 years after pressurized injection, it was shown that residual expansion 4 years after pressurized injection was maintained at almost the same level as that directly after pressurized injection (i.e., a value lower than that before pressurized injection).

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