8th ICAAR 1989 KYOTO
8th Internationl Conference
on Alkali–Aggregate Reaction

REPAIR OF CONCRETE STRUCTURES DAMAGED BY ALKALI–SILICA REACTIONS AND ITS EFFECTS

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1. INTRODUCTION

In Japan, cracks in concrete have been repaired by injection of epoxy resin or cement mortar into the cracks and cracked concrete slub of bridge has been repaired by adhering steel plate to the bottom surface of the slub by epoxy resin.

This paper reports two test results to confirm the efficiency of such repair methods to be applicable to concrete structures damaged by ASR as well.

Reinforced concrete model beams were used for the first test and reinforced concrete continuous slubs with 2 spans were used for the second test. These ASR models were stored in the room of 40℃ and 100%RH. Strain measurement and crack observation were done periodically. When the expansion reached a certain level and cracks developed widely, the cracks of the beams were repaired by injecting epoxy resin and the slubs were repaired by the steel plate adhering method. After repaired, these models were stored again in the same room. When the expansion of these models almost converged, they were loaded up to failure.

2. EFFECT OF REPAIR BY EPOXY RESIN INJECTION

2.1 Test

2.1.1 Models Eight reinforced concrete beams of 500×500×3150mm were made. Their tensile steel ratio was 0.516% and stirrup ratio was 0.217%.

Figure 1 shows the beams and the cross section. Among 8 beams, 4 ASR beams were repaired by 2 different types of epoxy resin and 2 ASR beams were left unrepaired. The left of 2 beams were normal concrete beams (Table 1).

Table 2 shows the mix proportion of the concrete. Bronzite andesite was used as the reactive aggregate. The sand used was non-reactive. The alkali content was 8.0 kg/m³ and the mix rate of reactive aggregate (GR) to the total aggregate (G) was 50% which is close to the pessimum.

Table 3 shows the property of two different types of epoxy resin injected. The characteristic of these epoxy resin is their ability of large extensibility which is expected to play a role of absorbing strain caused by successive ASR.

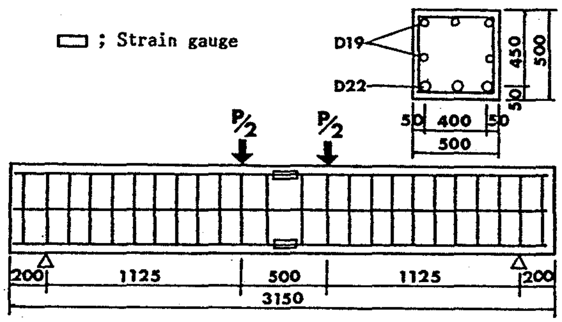

Figure 1 Cross-section of reinforced concrete beam

Table 1 Test beams

Beam NO.	Concrete	Injected epoxy resin	Storing condition
A-1	ASR	Super flexible type	①→②
A-2			①
A-3		Flexible type	①→②
A-4			①
A-5		no repair	①→②
A-6			①
N-1	Normal	no repair	①
N-2			①→②

① In the room of RH 100% and 40℃
② In the atomosphere
Change of storing condition was done at the age of 213 days

Table 2 Mix proportion of the concrete

	Gmax (mm)	Slump (cm)	Air (%)	w/c (%)	s/a (%)	W (kg)	C (kg)	S (kg)	G(kg) GR	G(kg) GN
ASR concrete	20	9.5	3.5	50	44	176	352	778	509	509
Normal concrete	20	9.0	3.6	50	44	176	352	778	—	1018

Table 3 Property of the epoxy resin used

Property	Test values: Super flexible type	Test values: Flexible type
Specific gravity	1.18	1.15
Tensile strength (kgf/㎠)	98	124
Extensibility (%)	190	130
Tensile shearing strength (kgf/㎠)	80	105

2.1.2 <u>Storing and repair</u> The beams were cured for 13 days at 20℃ and 80%RH and then stored in the room of 40℃ and 100%RH for 200 days. Thereafter, the beams A-1, A-3, A-5 and N-2 were exposed to the outdoor and the others were kept in the same room until loading test. At the age of 289 days, cracks of the beams A-1, A-2,A-3 and A-4 were repaired by the epoxy resin.

2.1.3 <u>Loading test</u> The beams were loaded statically up to failure by two-point loading with shear span to effective depth ratio of 2.5. Deflection and steel strain of the beams were measured at the center of span.

2.2 Results

2.2.1 <u>Strength of the concrete</u> Table 4 shows the compressive strength, Young's modulus and bending strength measured at the age of 407 days. The compressive strength and Young's modulus were measured by cylinder specimens of ϕ10×20cm and bending strength were measured by prism specimens of 10×10×40cm.

Table 4 Strength of the concrete

	Compressive strength (kgf/㎠)	Bending strength (kgf/㎠)	Young's modulus ($\times 10^4$ kgf/㎠)
ASR	348	35	21.1
Normal	589	59	40.8

2.2.2 Cracking and expansion due to ASR beams

Cracks of the beams appeared in the axial direction first, then map like cracks developed all over the beams. Maximum crack width reached 0.4mm (Figure 2). The repaired beams did not crack again.

Figure 3 shows the examples of the expansion in the axial direction. The expansion reached 1000 to 1500×10^{-6} and induced compressive stress was estimated to be about 20 kgf/cm².

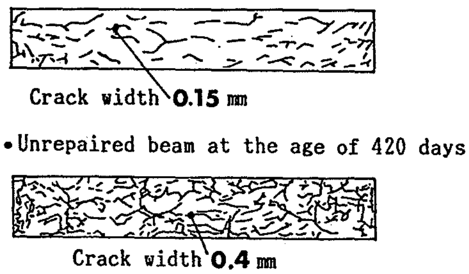

Figure 2 Cracking pattern

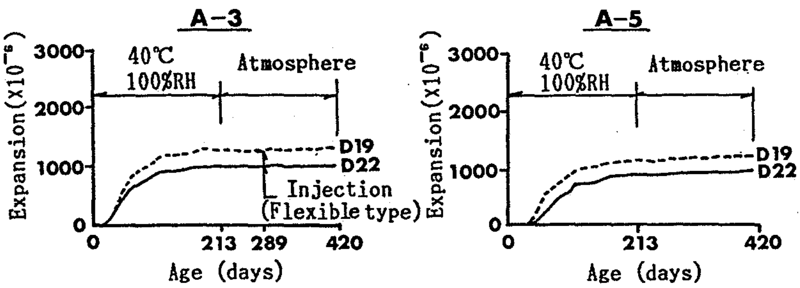

Figure 3 Expansion of the beams

2.2.3 Rigidity and strength of the beams Figure 4 shows the load-deflection curve of the beams. Table 5 shows the ultimate strength of the beams and Figure 5 shows the failure mode.

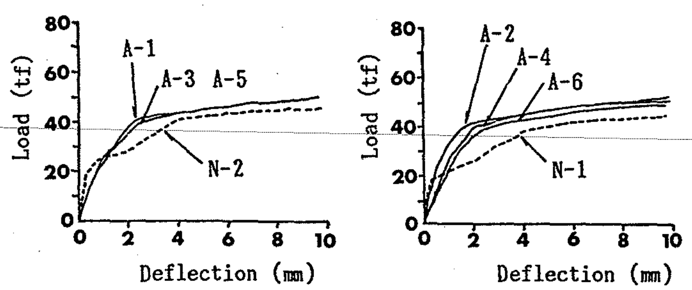

Figure 4 Load-deflection curve

According to these results, rigidity of the ASR beams was lower than that of the corresponding normal concrete beam at the lower load level but it surpassed the rigidity of the normal concrete beam at the higher load level. This is probably due to the existence of the chemical prestress induced into the ASR beams. Repair by the epoxy resin did not improve the rigidity. The ultimate strength of the beams was not affected by ASR and was not improved by the repair.

Table 5 Ultimate strength of the beams

Beam NO.	Ultimate load (tf)
A-1	55.5
A-2	53.4
A-3	56.7
A-4	54.8
A-5	54.9
A-6	52.0
N-1	51.2
N-2	53.8

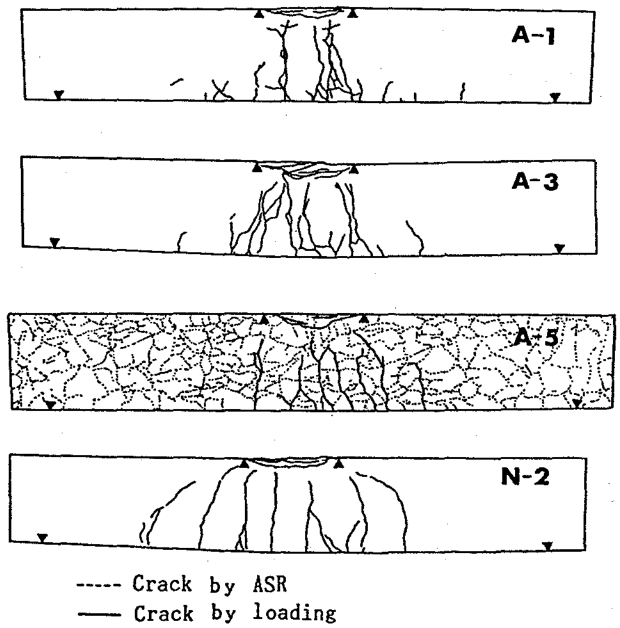

Figure 5 Failure mode

3. EFFECT OF REPAIR BY STEEL PLATE ADHESION

3.1 Test

3.1.1 Models Figure 6 shows the test model. The size and the amount of steel are same as the slub of a highway bridge in Japan. Two ASR models and one normal concrete model were made. One of the ASR model was repaired by steel plate (Table 6). Table 7 shows the mix proportion of the concrete.

3.1.2 Storing and repair The models were cured for 15 days at 20℃ and 80%RH and the ASR slubs were stored in the room of 40℃ and 100%RH for 196 days. The normal concrete slub was exposed to the atmosphere . One of the ASR slubs was repaired by steel plate at the age of 123 days and stored again in the same room.

3.1.3 Loading test The slubs were loaded statically up to failure by two-point line load as shown in Figure 6. The test was carried out at the age of 196 days after the conversion of the slub expansion.

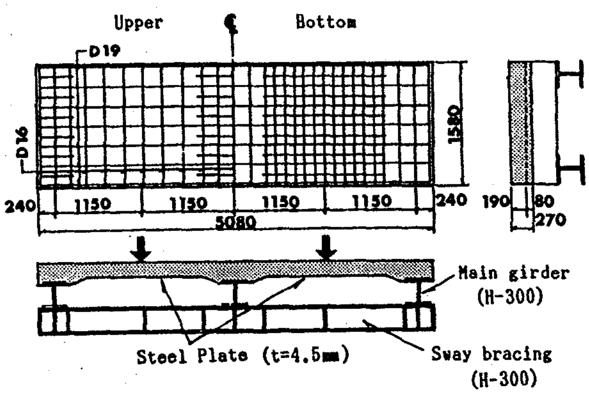

Figure 6 Test slub

Table 6 Test slubs

Slub NO.	Concrete	
A	ASR	not repaired
R	ASR	repaired
N	Normal	—

Table 7 Mix proportion of concrete

	Gmax (mm)	Slump (cm)	Air (%)	w/c (%)	s/a (%)	W (kg)	C (kg)	S (kg)	G(kg) GR	G(kg) GN	Alkali content (kg)	GR/G (%)	Reactive aggregate
ASR concrete	20	7	4	50	43.8	170	340	768	391	622	6.8	40	Bronzite andesite
Normal concrete	20	6.6	4	50	43.8	170	340	768	—	1036	—	—	—

3.2 Results

3.2.1 Cracking and expansion Figure 7 shows ASR cracking of the slub A before loading. These cracks reached the concrete cover of 3cm.

Figure 8 shows the distribution of the axial expansion and estimated axial deformation of the slub.

According to these results, repair by steel plate did not yield abnormal behavior of the slub compared to the unrepaired plate.

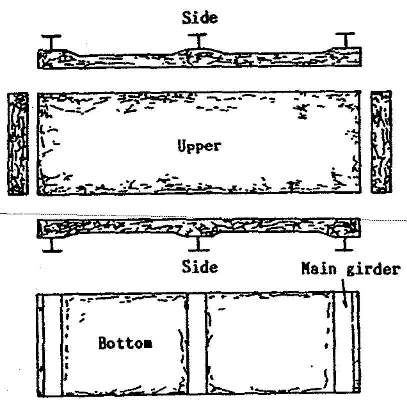

Figure 7 Cracking before repair

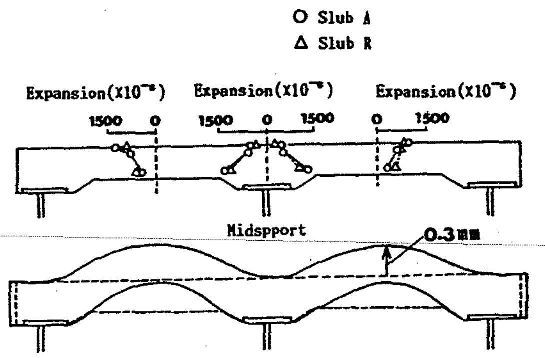

Figure 8 Distribution of axial expansion and estimated axial deformation of the Slub

3.2.2 Rigidity and strength Figure 9 shows the load-deflection curves. Rigidity of the slub was not affected by ASR but repair by steel plate almost doubled the rigidity of the slub.

Table 8 shows the ultimate load of the slubs and Figure 10 shows their failure mode. Failure of each slub occurred by shear. The repair looks improved the strength of damaged slubs. However, in this test, the ASR damaged slub showed higher strength than the normal slub.

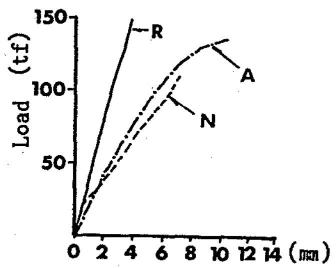

Figure 9 Load-deflection curve

Table 8 Results of loading test

Slub NO.	Flexural cracking load (tf)	Ultimate load (tf)	Failure mode
A (ASR)	30.0	144.1	shear
R (ASR)	28.0	157.8	shear
N(Normal)	26.0	114.8	shear

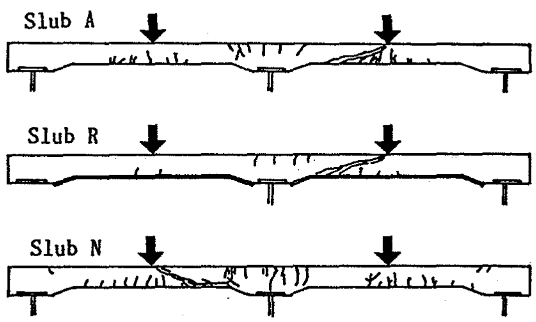

Figure 10 Failure mode

4. CONCLUDING REMARKS

From these tests, following results were found.

(1) Injection of the epoxy resin into the ASR cracks did not slow down the expansion of the beam and did not improve the rigidity and strength but protected new cracking.
(2) The ultimate strength of the beam was not affected by ASR.
(3) Concrete slub repaired by steel plate did not show abnormal behavior such as bending or warping during the successive reaction.
(4) The repair by steel plate improved the ultimate strength of the ASR damaged slub.