The Deterioration by Alkali-Silica Reaction of Hanshin Expressway Concrete Structures—Investigation and Repair

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ABSTRACT

This paper deals with the structural behavior of the reinforced concrete structures deteriorated by alkali silica reaction and the repair method by using synthetic resin in Hanshin Expressway.

1. INTRODUCTION

In 1979, small cracks were found on the reinforced concrete piers of Hanshin Expressway at the age of four years after construction. Many severe cracks were found in May 1982 as shown in Figs. 1 and 2. The alkali aggregate reaction had not been realized in Japan untill this case. This reaction was identified as alkali silica reaction (ASR) caused by bronzite andesite containing a-cristobalite (Mizumoto et al. 1986).

Table 1 shows the typical ultrasonic pulse velocities of the damaged and sound pier concretes. The pulse velocity of damaged concrete decreased, with increasing cracking due to ASR, down to about 2000m/sec. The measured crack depth using the pulse velocity method was about 10cm which was almost equal to the clear cover of reinforcing steel.

Table - 1 Examples of ultrasonic pulse velocity (m/sec)

Pier (No.)	max.	min.	mean.
Damaged pier (P-42)	3150	1920	2740
Sound pier (P-44)	4420	4200	4280

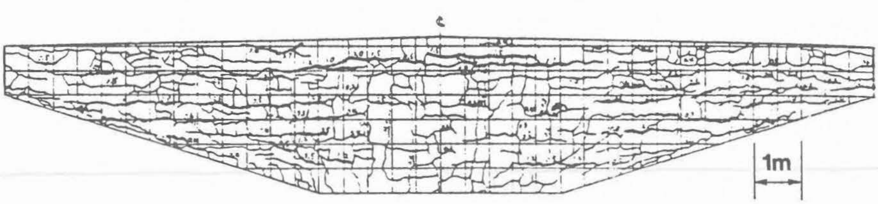


Fig.—1 Crack pattern of pier deteriorated by ASR

Table-2 Typical properties of concrete cores

Pier (No.)	Pulse velocity (m/sec)	Compressive strength (kgf/cm²)	Young's modulus (kgf/cm²)
Damaged pier (P-42)	2630	233	0.62×10^5
Sound pier (P-44)	3860	357	2.80×10^5

2. PROPERTIES OF PIER CONCRETE

The reinforced pier was made of the flyash cement concrete ($C=278kg/m^3$, $F=61kg/m^3$), and the design compressive strength was $270kgf/cm^2$. The compressive strength of the test cylinder was $332kgf/cm^2$ at construction.

The pulse velocity, compressive strength and Young's modulus of drilled concrete cores are listed in Table 2. The compressive strength and the Young's modulus of cores obtained from deteriorated piers were about 65% and about 20% of those of cores from the sound ones respectively. The maximum amount of alkali silica expansion in a damaged concrete core exceeded 1% at 28 days under the accelerated condition of 40°C and R.H. 100%.

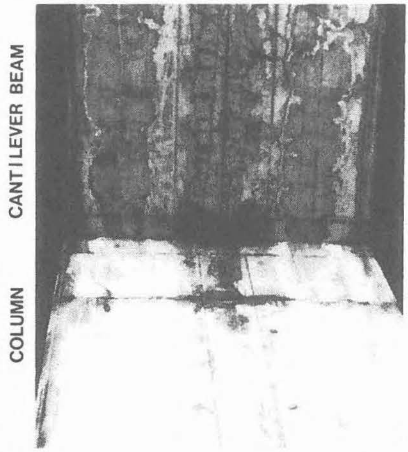


Fig.—2 Cracks of deteriorated pier

It was thought that these properties of concrete core might indicate a reduction of load carrying capacity and the progress of alkali silica expansion.

3. FIELD LOADING TEST

In order to assess the structural performance of the severely damaged T-shaped cantilever reinforced concrete piers, the field loading tests were carried out in 1984. Fig. 3 shows the loading method and the deflection measurement points. Trucks, each of about 28ton, were placed on the deck slab and the deflections of the beam were measured by using electric dial gages. In the first series of tests, the three trucks were placed on the both sides of the outer lanes. In the second series of tests, the three trucks were placed only on the one side of the outer lane. The maximum test load (six trucks) was about 80% of the design live load.

The degree of deterioration was evaluated by comparing the measured deflections of deteriorated piers, with those of sound piers of the same dimensions and also with the calculated deflections using the finite element method. The finite element analysis was based on the elastic stress strain relationship of concrete using the measured Young's modulus from concrete cores. In the first case of analysis, the load distribution was not

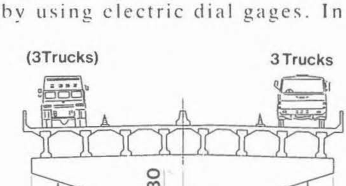


Fig.— 3 Schematic view of loading test

considered. In the second case, it was considered on account of the influence of the rubber bearing plates and the concrete end beams. The assumption of load distributions are shown in Fig. 4.

Figs. 5 and 6 show the examples of measured and calculated deflections. And the profile of measured and calculated deflections of the most severely damaged pier are shown in Fig. 7. These three Figures indicate that the measured deflections of both deteriorated and sound piers were almost same as the calculated ones. Those test results imply that the stiffness of deteriorated piers due to ASR was not significantly reduced from the original value. Thus, it could be concluded that the tested piers had a sufficient load carrying capacity. This conclusion was also demonstrated in the model test (Fujii et al. 1986).

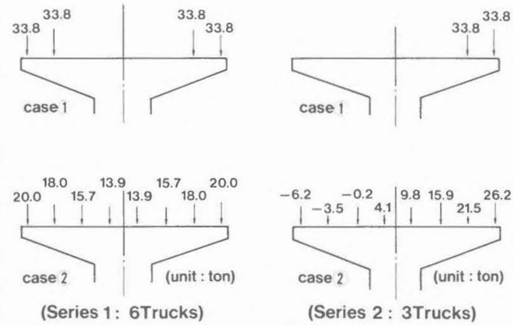


Fig.— 4 Assumption of load distribution for numerical analysis

4. REPAIR

4.1 Laboratory Test

The safety of damaged piers appeared not to be a problem, but, there was a high possibility that reinforcing steel corrosion at cracks was occurring and concrete expansion was proceeding. Laboratory tests were conducted on various repair methods. The repair methods examined were

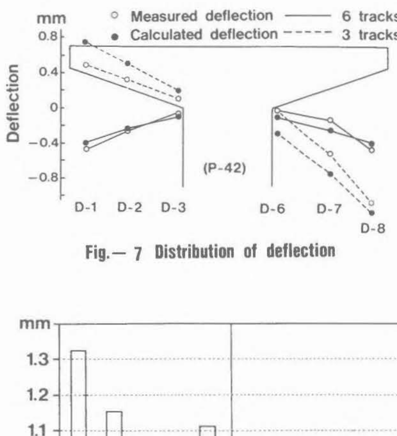


Fig.— 7 Distribution of deflection

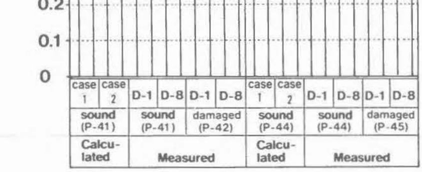


Fig.— 5 Examples of measured and calculated deflections (Series 1 : 6 trucks)

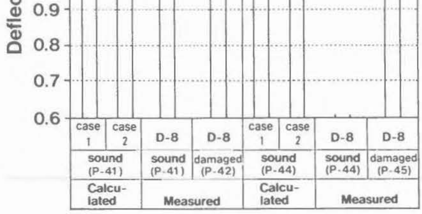


Fig.— 6 Examples of measured and calculated deflections (Series 2 : 3 trucks)

as follows.

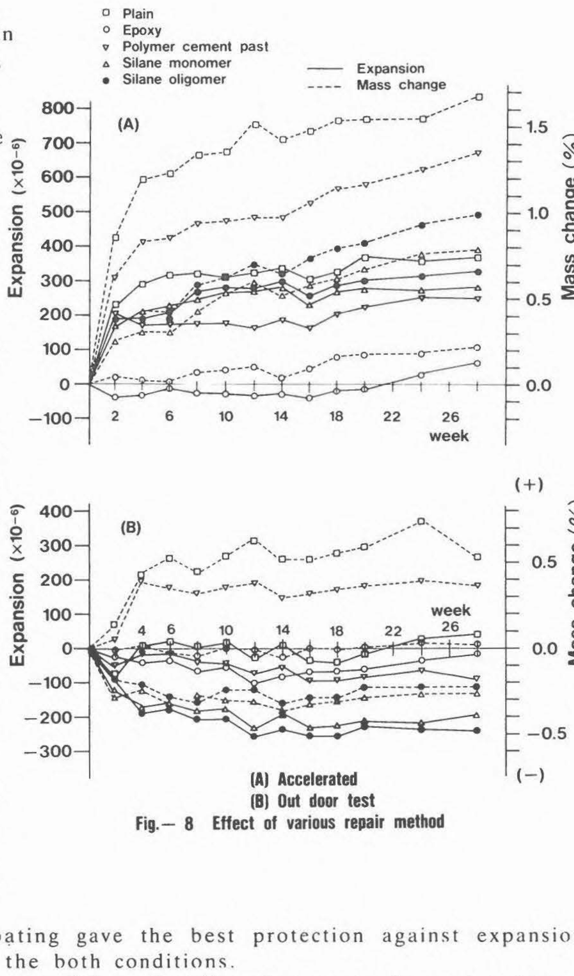
(1) Epoxy resin coating (Primer: Epoxy, Main coat: Epoxy=250μm, Top coat: Acrylic urethane=30μm)

(2) Polymer cement Paste lining (Primer: Epoxy, Main coat: W/C=0.58, Polymer/C=0.20, 0.7mm)

(3) Silane monomer impregnation(400g/m^2)

(4) Silane oligomer impregnation(300g/m^2)

Test concrete specimens (10×10×40cm: Prism) were repaired according to the above mentioned methods after some hair cracks were observed under the accelerated storage conditions of 40°C and R.H. 100%. After the repair, half of the repaired specimens were placed out doors, and the others were continuously stored under the accelerated condition. The examples of expansion and weight change of test specimens after repair are shown in Fig. 8.



(A) Accelerated
(B) Out door test
Fig.— 8 Effect of various repair method

The epoxy resin coating gave the best protection against expansion and water absorption in the both conditions.

However, in out door conditions the silane impregnated samples showed remarkable reduction in expansions considering their relatively high water vapor transmission ability.

4.2 Field Repair

After the deteriorated piers were dried (Concrete surface moisture ratio <8%), the repairs were carried out. At the first stage of repair, the cracks of concrete were filled with an epoxy resin injected under pressure. At the

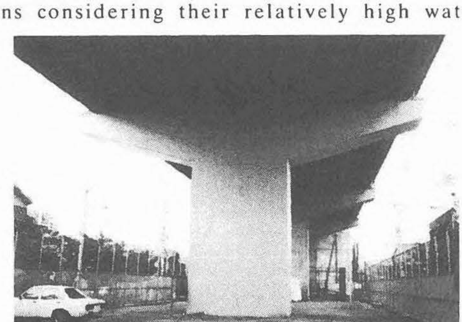


Fig.—9 Coated pier

second stage, two types of repair method were used. One was epoxy resin coating (Fig. 9), the other method was silane impregnation followed by painting with a polymer cement for surface decoration.

After the repairs, the pulse velocity was restored up to 3000m/sec, and has not decreased in three years, and expansion of pier concrete has scarcely been observed.

Examples of growth in crack width after repairs are shown in Fig.10. The rate of crack opening was controled by the repair.

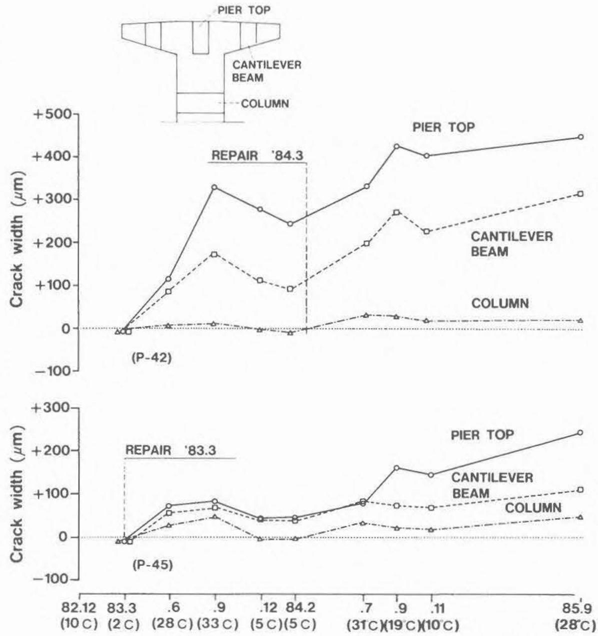


Fig.— 10 Typical effect of epoxy repair on crack width

5. CONCLUSIONS

The conclusions are summarized as follows:

(1) The stiffness and load carrying capacity of deteriorated T-shaped cantilever reinforced concrete piers due to ASR were almost the same as those of sound piers.

(2) Filling cracks with an epoxy injected under pressure, and epoxy coating or silane impregnation were found to be very effective for controlling the reinforcement corrosion and expansion of piers.

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