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LONG-TERM BEHAVIOR OF AAR BRIDGE PIER AND THE INTERNAL DETERIORATION

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ABSTRACT

This paper reports on the results from 11 years of monitoring of an AAR RC bridge pier. This pier was constructed in 1977. The monitoring commenced in 1984 and it was continued until the pier was demolished in 1995. The column of the pier was 2.5 meters in diameter and 7.2 meters in height. The expansion and the compressive strength of the concrete cores taken from the pier were measured periodically. The expansion of the pier itself and the ultrasonic wave velocity through the pier were also measured. The propagation of cracks into the inside of the pier was confirmed both by the concrete core and by direct observation of the cut face of the pier when it was demolished.

The results show the following points;

1. Expansion of the pier by AAR continued for a long period
2. The compressive strength of the concrete decreased with time and it became even lower than the design value.
3. Drop of ultrasonic wave velocity with time was also observed.
4. AAR cracks propagated well into the inside of the pier and decreased the effective cross-section area of the column.

Keywords:Alkali-aggregate reactions, bridge pier, cracking, compressive strength, expansion, ultrasonic wave velocity.

INTRODUCTION

Alkali aggregate reaction (AAR) was determined to be a serious problem for the first time in Japan in 1982 even though AAR was already well known. Since that time, tremendous efforts have been put into the investigation of AAR itself, identifying reactive aggregates, surveying damaged structures by AAR, safety assessment and countermeasures for damaged structures. Specifications to ban the use of reactive aggregates have been established by various organizations.

There is an argument in Japan that the influence of AAR is not so serious in terms of safety and serviceability of concrete structures since AAR would converge within a relatively short period and the cracking would be limited to the surface of the concrete. This argument probably came from the results of relatively short period of monitoring. The authors had a chance to monitor an AAR damaged pier for over 10 years and to observe the internal sections when it was demolished. This paper presents these results.

SURVEY OF AAR BRIDGE PIER

The AAR bridge pier under survey was constructed in 1977 and repaired once in 1984 by urethane resin coating. In 1994, the pier was again repaired by gummy resin coating after injection of epoxy resign into the developed cracks. The pier was demolished in 1995 after the Kobe earthquake. The pier type was a single T shape and the diameter and height of the column were 2.5 m and 7.2 m, respectively. Fig.1 shows a photograph of the pier taken in 1993. Since the repair in 1984, the pier had been monitored.

Fig.1: The monitored pier (in 1993)

The cores drilled from the pier measured the compressive strength of the concrete and the expansion. The size of each core was 10 cm in diameter and 20 cm in height. The ultrasonic wave velocity was measured through the pier. The hoop expansion of the column was measured by a contact gauge periodically for about 11 years. The identified reactive aggregate used in this pier was Bronzite andesite and the content was 39% of the total coarse aggregate. The hoop expansion of a sound pier near the AAR pier was also measured for comparison. Observation of crack patterns at the surface of the beam and column was done when the pier was demolished. Observation of the footing surface was also done. Table 1 shows the mix proportion of the concrete.

TABLE 1: Mix Proportion of the Concrete

slump	water	cement	W/C	sand	gravel	AE agent
12 cm	191	345	0.55	745	1070	0.1

unit for the materials: kg/m^3
maximum size of gravel: 20 mm
cement: normal portland cement (alkali content 0.79 % of cement weight)
estimated alkali content in the concrete: 6.18 kg (1.80 % of cement weight)

RESULTS

Table 2 shows expansion and compressive strengths of the cores taken from the pier. Ultrasonic wave velocity through the pier is also shown in the table. Fig.2 shows the expansion of the column. The ambient temperature was also recorded when the expansion measurement was performed.

TABLE 2: Expansion, Compressive Strength, Young's modulus and Ultrasonic Wave Velocity of the Pier

	Expansion of core ($\times 10^{-6}$)				Compressive strength (N/mm^2)	Ultrasonic wave velocity (m/sec)	Young's Modulus (kN/mm^2)
	Year	Released	Residual	Total			
Beam	1984					3635	
	1991					3575	
	1995	113	60	118~239	22.4~29.7		10.2~17.8
				average 172	average 26.2		average 13.4
Column	1984	130	590	544~1005	20.3~28.0	3510	7.9~11.4
				average 649	average 22.5		average 10.1
	1991	180	240	200~680	20.1~25.9	3470	6.2~10.2
				average 420	average 22.1		average 8.0
	1995	103	43	118~182	17.2~22.3		9.1~10.4
				average 146	average 19.6		average 9.7

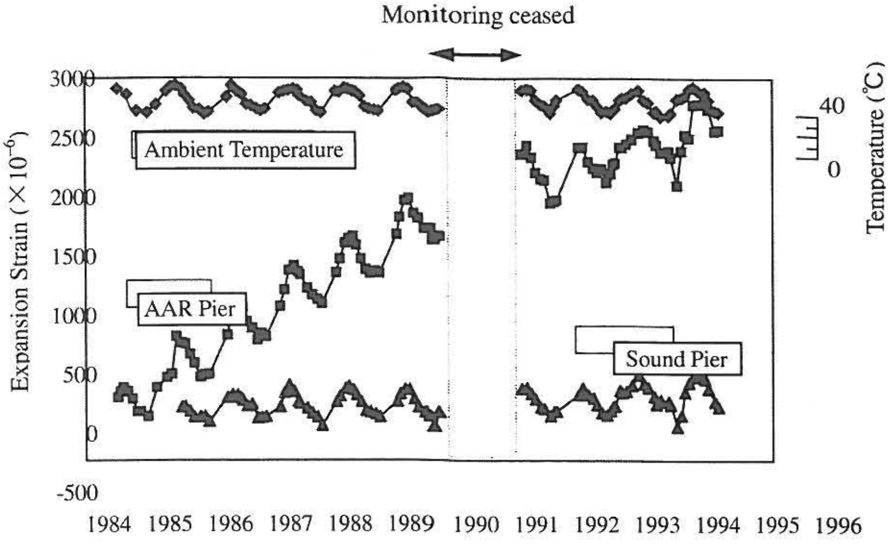


Fig.2: Hoop expansion of the column

The total expansion of the drilled core reached about 1000μ (0.001)after 7 years (in 1984) but it became less than 200μ after 18 years (in 1995). The expansion of the column also continued even after 18 years although the rate of the expansion decreased gradually. The total cumulative expansion for 18 years is estimated to have reached more than 5000μ considering the data that the cumulative expansion in the last 10 years reached about 2500μ. The compressive strength of the concrete decreased gradually with time and the minimum value measured in 1995 was 17.2 N/mm^2 which was significantly lower than the design value of 21.0 N/mm^2. There was a tendency that the ultrasonic wave velocity also dropped slightly for the period from 1984 to 1991. The measured Young's modulus was significantly lower.

It should always be recognized that any core used for the compressive test, for example, is normally taken from the uncracked good part of the concrete. In fact, all the cores drilled from the pier for the testing had no visible cracking. The loss of the compressive strength of the pier as a whole would therefore have been more although it is difficult to define concrete strength itself. In any case, it is evident that the concrete strength becomes significantly lower by AAR and that the stiffness of the pier also decreases probably due to the development of internal cracking. Fig. 3 shows a core drilled from the surface to the center of the column. The length of the core is 140 cm, which is a little longer than the radius of the column. It is evident that the cracks are propagating well into the section.

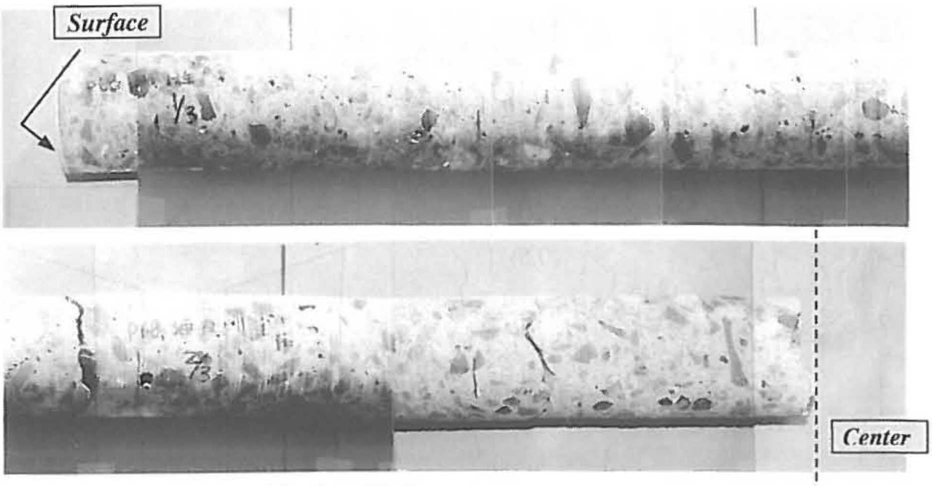
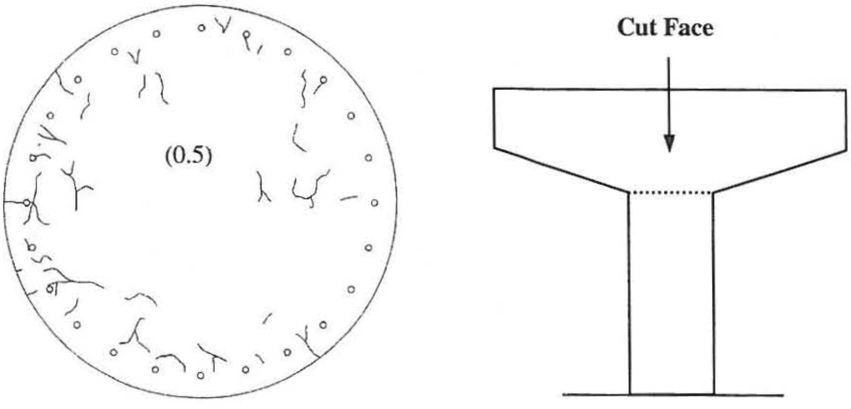


Fig. 3: Drilled core from the column

Fig. 4 and Fig. 5 show a crack pattern at the cut surface of the column and beam, respectively and their close-up photographs. It is normally not easy for AAR cracks to develop near these sections due to the higher level of restriction. On the other hand, these cracks are considered to have obtained less effect from the Kobe earthquake since the direction of those cracks differs from that of bending cracks both in the beam and column. Nevertheless, it can be seen that the cracks are developing well inside of the beam and column even at such confined sections.



The number in each parenthesis represents the crack width in mm.

Fig. 4: Crack pattern at the cut surface of the column

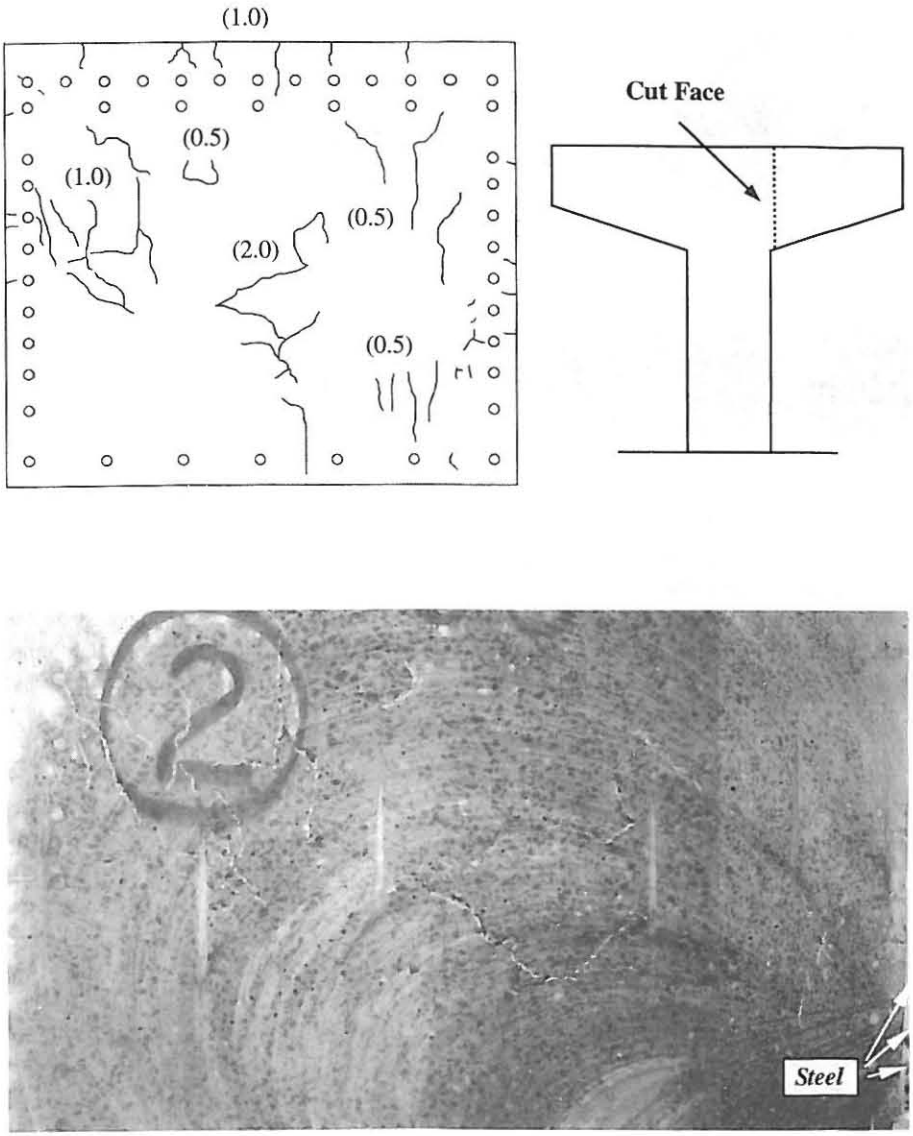


Fig. 5: Crack pattern at the cut surface of the beam

Fig. 6 shows crack pattern at the horizontal cut surface of 3 different columns. In the column of Fig. 6 (a), most of the cracks stop at the re-bar and are limited within the concrete cover. In the column shown in Fig. 6 (b), the cracks are propagating beyond the re-bars. It can be seen in Fig. 6 (c), that cracks are propagating and join together adjacent to the re-bar. It is evident that the cross-section of the pier is less than the original value at least by the concrete cover.

(a)

(b)

(c)

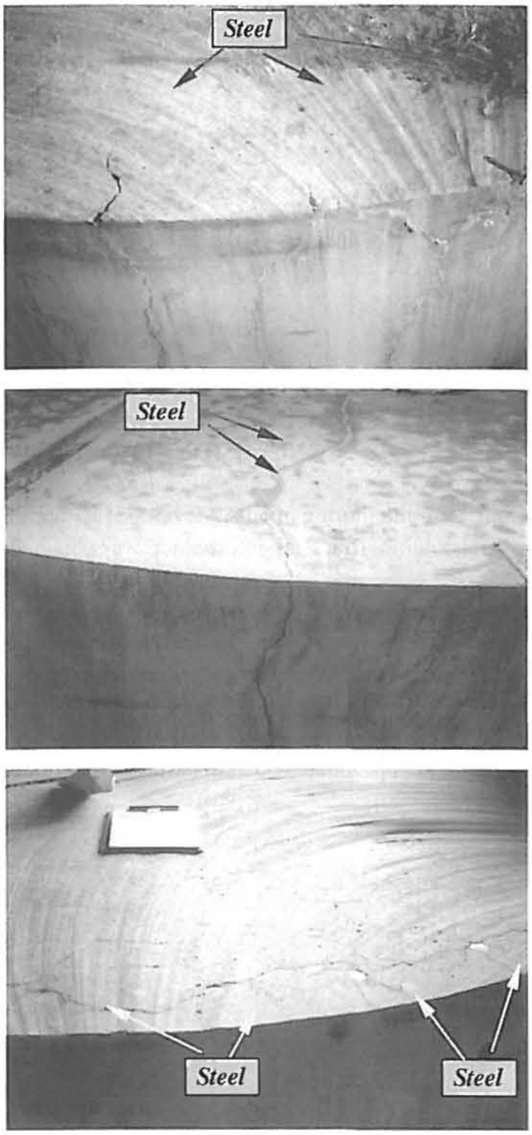


Fig. 6: Crack pattern at the horizontal cut surface of 3 different columns

Fig. 7 shows the surface of the footing of the pier after cutting off the column. It can be seen that many major cracks are developing in the footing as well although some of these cracks might have been widened by the earthquake.

Fig. 7: Cracking at the surface of the footing

CONCLUSION

From the relatively long term monitoring of an AAR bridge pier and the observation of the cut faces in the beam and column, following information was obtained:

(1)Expansion of a concrete pier by AAR continues for a long period.
(2)The loss of compressive strength and Young's modulus becomes significant with time.
(3)AAR cracks propagate deep into the section and reduce the effective cross-section area.
(4)Crack propagation in a concrete column by AAR would result in scaling off of the concrete cover.
(5)Long term monitoring and appropriate countermeasures are required for AAR concrete structures.