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CHARACTERISTICS OF ROAD STRUCTURES DAMAGED BY AAR ON THE HANSHIN EXPRESSWAY DUE TO CONTINUOUS OBSERVATION

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1. INTRODUCTION

Hanshin Expressway, which covers Metropolitan Osaka and Kobe region, is an urban motorway consisted with one-way loop belt in the city of Osaka and eight lines which extend radially to the neighboring cities from the loop. The motorway has constructed almost with the elevated structures of its 99.3% in order to make passing through the existing dense populated area possible. The structure has been built mostly by a prestressed concrete (PC) and reinforced concrete (RC). The rate of PC and RC are 24.4% and 9.8% for superstructures and 16.7% and 72.2% for substructures respectively.

This means that 34.2% of whole superstructures and 88.9% of substructures are built of concrete.[1]

Hanshin Expressway public Corporation (HEPC) is carrying the following periodical inspections to those structures for maintenance management purpose that;

- ... Daily inspection : Once a day (6 times/week)
- ... Periodical inspection: Once every five to seven years
- ... Special inspection : Upon request

In October 1979, a crack was found through those inspections at a beam of T-type concrete pier on Osaka- Matsubara Route before open road. Next March 1980, a repair by means of a resin injection into the cracks was done. Further progress and enlargement on those treated cracks were observed in May 1985 in spite of the treatment.

As shown in Fig. 1, the crack on the beam of Pier-42(P42) and Pier-45(P45) were appeared at upper end of main re-bar of column and surface between both sides of the crack had about 4mm in gap. A series of inspection,

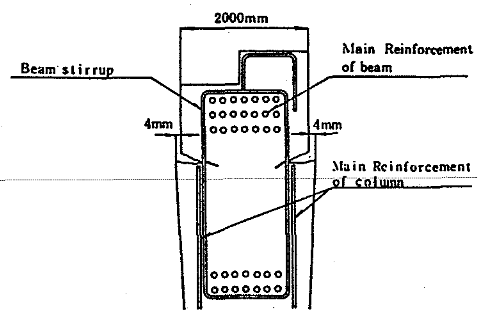

Fig. 1 Detail of Crack in Pier Beam

research of its causes and development of maintenance techniques for those cracks had been started.

The characteristics of those cracks were assumed to be different from the shrinkage and/or heat of hydration, because these were observed the phenomena that the surface level gap between both sides of the crack and an enlargement of structure which was measured using a trace of panel as reference line. This means that those cracks had associated with concrete expansion. In addition, the core samples were taken from adjacent piers on which several cracks were observed. On the cored samples, a reaction rim arround aggregate was observed then transudation of reaction gel was recognised with an elapsed time. From those phenomena, the cause of the structural damamges was caused by Alkari-Aggregate Reaction (AAR). Also, the aggregate consists those concrete structures were clarified as α-Cristobalite and Bronzite Andesite containing some crystal.

Since then, HEPC has carried out a continuous research of AAR phenomenon. A continuous observation on the damaged structures and testings have been performed as well. The purpose of this paper is to report the progress of above activities and results of continuous observations.

2. OUTLINE OF CONTINUOUS OBSERVATION

2.1 Objective Structures to the Observation

Totally 49 piers, 3 spans of prestressed concrete beams and 5 reinforced concrete slab panels are the object of continuous observation. Those have some damages by the reasons considered to be caused by Alkari-Silica Reaction (ASR) of AAR. The 47 piers and 3 spans of PC beams had been maintained among others. So these have been continuously observed for knowing behaviors of the cracks and the effectiveness of maintenance techniques. The specification of observed structures are shown in Table 1.

Table 1 Structure Description under Observations

structure	type	Route Name	No's	Year of built	Damaged area	remarks
Pier	RC	Matsubara	23	1971-76	Beam, column	maintained(21ps)
	RC	East-Osaka	2	1972	Beam, column	ditto
	PC	Sakai	2	1970	Mostly Beam	ditto
	RC	West-Osaka	2	1968	ditto	ditto
	RC	Nishinomiya	1	1974	ditto	ditto
	RC	Ikeda	1	1967	ditto	ditto
	PC	Kobe	18		Beam, column	ditto
Girder	PC	East-Osaka	2	1971	Bottom flange	ditto
	PC	Sakai	1	1969	ditto	ditto
Slab	RC	Matsubara	4	1979	Wholw panel	map-pattern
	RC	Nishinomiya	1	1978	ditto	crack

2.2 Observation Items

Following observations are being carried on the structures listed in Table 1, detail of the above items are;

(1) Width of crack: The tips of measuring point are fixed on both sides of the crack at 100mm interval. By the measurement of distance between tips, a movement of crack width in time lapse can be observed.

(2) Depth of crack: It is measured by Ultrasonic pulse.

(3) Expansion volume of concrete body: It is measured as follows. The

tips, which are same one used for the crack width measurement, are aligned at 300mm interval as a measurement line which is extended from one end of the beam to other end holizontally and/or from top of column to bottom vertically. A movement of those course of measurement line give a concrete mass expansion behaviors.

(4) Measurement of compressive strength: Young's modulus and Ultrasonic pulse velocity, those are performed on the concrete samples taken from the structures. A coring was carefully done after confirmation of reinforcement position in order to avoid cutting re-bars.

(5) ASR tests: For prediction the ASR potentiality, Mortar-Bar Test (ASTM C227) and Chemical Analysis according to ASTM C289 are performed using the aggregates taken from the core samples.

(6) Ultrasonic Pulse Velocity measurement on the structure: A degree of damages and its progress condition are predicted from measured velocity of Ultrasonic pulse.

The data from above observations has been an elapse time.

3. RESULT OF CONTINUOUS OBSERVATIONS

3.1 Width of Crack

28 piers, 3 spans of PC girders and 5 slab panels are employed the crack width observation. Annual change value of crack width as a simplification to adjust time of observation is shown in Fig. 2. As shown in Fig. 2, the most of cracks are growing in time. Particularly the cracks appeared on Matsubara Route show remarkable growth even after treatment by the resin injection and coating.

In addition, newly created cracks other than the treated one are also found.

The measuring results of crack width show a remarkable growth at P42 on Matsubara Route which is shown in Fig. 3.

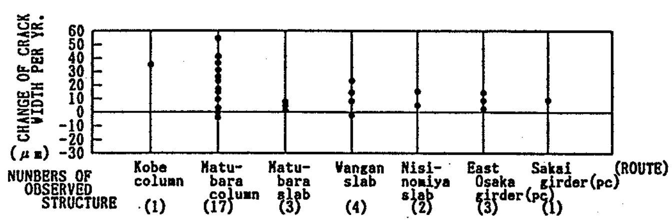

Fig. 2 Changed Width of Cracks per Annual

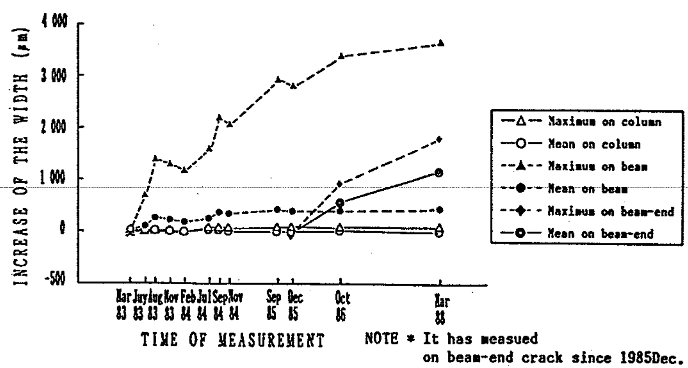

Fig. 3 The Width of Crack

3.2 Depth of Cracks

The observation of crack depth has carried on 5 slab panels. A rate of measured depth versus slab thickness and the progress of crack depth are shown in Table 2 and Fig. 4 respectively. It is clear that the all observed cracks are concluded to reach to the re-bars. The crack depth definitely reaches to the half way of slab thickness particulary 112-slab at Osaka-Nishinomiya Route and 583-slab at Matsubara Route. The increase of depth and of width are clear on Fig. 4 respectively.

Table 2 Measured Crack Depth Versus Slab Thickness

	slab-112(O)	slab-433(M)	slab-434(M)	slab-583(M)	slab-584(M)
slab thickness(cm)	21.0	22.0	22.0	19.0	19.0
crack depth(cm)	10.1	6.4	6.4	6.9	8.7
ratio (%)	47.6	29.1	29.1	36.3	45.8

NOTE 1:(O)=Osaka-Nisinomiya Route 3:ratio=slab thickness/crack depth X 100
2:(M)=Matubara Route 4:Crack depth is a mean value in ten samples

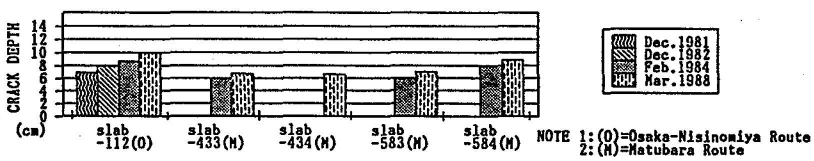

Fig. 4 Result of Crack Depth Observation

Continuous progress of the cracks are predictable. Moreover, an analysis of crack density by means of a grid density method indicates increase of cracks at 433, 583 and 584-slabs on Matsubara Route as well. From those results, it can be said that it is not damaged by a particular crack but whole slab is seriously damaged by the cracks.

A slab deflection was measured on 583-slab on Matsubara Route by the loading test using a 20 tons vehicle. Figure 5 indicates an increase of deflection of the slab and decrease of slab stiffness contrarily. This deflection of the slab and decrease of slab stiffness contrarily. This means that a progress of crack-width, depth and an increase of crack density have worked decrease of slab stiffness.

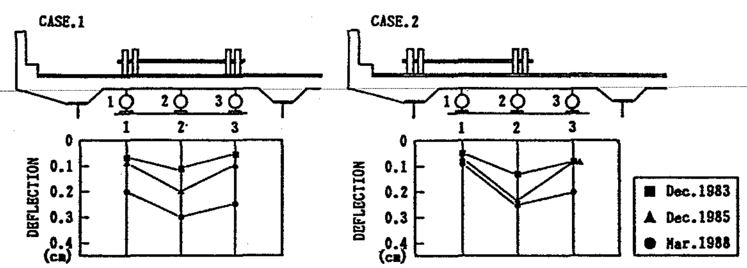

Fig. 5 Result of Slab Deflection

3.3 Expansion of Concrete Body

The mass expansion are measured for 35 piers. The average results on each route are shown in Fig. 6.

Excepting the column on Kobe and Sakai Routes, all results show a tendency of concrete expansion. In addition, even after repaired by the resin sealing and coating treatment, all expansion at each route results on Matsubara Route show same tendency as well. This means that those structures are having a certain structural damages caused by ASR and the concrete expansion is still going on even waterproof coating has been made.

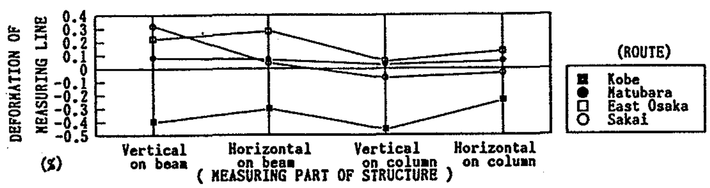

Fig. 6 Structure Concrete

3.4 Young's Modulus, Compression Strength and Ultrasonic Pulse Velocity

On the samples had taken from 14 numbers of structures during the series of observations in 1987, several testings in connection with ASR such as Young's modulus, Compressive strength and Ultrasonic pulse velocity measurement have been performed. The results are shown on Table 3.

Table 3 Analysis Results of Core Sample

No. (Route)	ASTM C289	X-Ray Analyzing (%)	core Expansion (%)	Ingredient Analyzing (%)	compressive strength Young's modulus	Ultrasonic Pulse Velocity (km/sec)
Median (Mastubara)	deleterious	quartzite	0.015-0.06 (13w)		162-465 kgf/cm^2 4.67-25.2 $\times 10^4 kgf/cm^2$	2.92-4.44
Median (East Osaka)	potentially deleterious		0.01-0.022 (10w)		328-373 kgf/cm^2 19.1-27.6 $\times 10^4 kgf/cm^2$	4.30-4.51
Pier-189 (Ikeda)	deleterious	quartzite	0.023 (13w)	R_2O 0.12 Cl 0.014	333-512 kgf/cm^2 19.5-30.0 $\times 10^4 kgf/cm^2$	2.92-4.44
Pier-109 (Nishinomiya)	deleterious		0.035-0.041 (8w)	R_2O 0.20 Cl 0.014	314-377 kgf/cm^2 12.7-23.7 $\times 10^4 kgf/cm^2$	3.78-4.11
Pier-2 (West Osaka)	deleterious		0.063 (13w)	R_2O 0.20 Cl 0.024	209-408 kgf/cm^2 8.60-30.5 $\times 10^4 kgf/cm^2$	3.27-4.39
Pier-4 (West Osaka)	deleterious		0.036-0.082 (12w)	R_2O 0.20 Cl 0.048	297-353 kgf/cm^2 11.8-25.9 $\times 10^4 kgf/cm^2$	3.63-4.36
Pier-379 (East Osaka)	deleterious	quartzite	0.012-0.032 (13w)	R_2O 0.17 Cl 0.002	332-485 kgf/cm^2 22.8-30.7 $\times 10^4 kgf/cm^2$	4.36-4.61
Pier-9 (East Osaka)	potentially deleterious	quartzite	0.01-0.013 (13w)	R_2O 0.15 Cl 0.001	346-414 kgf/cm^2 24.2-4.76 $\times 10^4 kgf/cm^2$	4.52-4.76
Pier-3 (Kobe)		Bronzite Anadesite α-Cristobalite	0.103-0.1345 (19w)	R_2O 0.16 Cl 0.059	307-379 kgf/cm^2 24.1-32.5 $\times 10^4 kgf/cm^2$	3.96-4.01
Pier-326 (Kobe)		Bronzite Anadesite α-Cristobalite	0.131-0.1405 (19w)	R_2O 0.16 Cl 0.053	259 kgf/cm^2 1.56 $\times 10^4 kgf/cm^2$	3.71-3.96
Pier-329 (Kobe)		Bronzite Anadesite α-Cristobalite	0.54-0.083 (19w)	R_2O 0.16 Cl 0.052	293 kgf/cm^2 10.9 $\times 10^4 kgf/cm^2$	3.75-3.76
Pier-335 (Kobe)		Bronzite Anadesite α-Cristobalite	0.04-0.07 (19w)	R_2O 0.12 Cl 0.051	438 kgf/cm^2 27.0 $\times 10^4 kgf/cm^2$	4.14-4.27

* note: R_2O=Eguivalent Alkari content
Cl =Chlorine content

3.5 ASR Tests on the Cored Sample

The results of Chemical Analysis in accordance with ASTM C289 are shown in Fig. 7. It indicates that all aggregates of observed structures have considered deleterious and/or potentially deleterious.

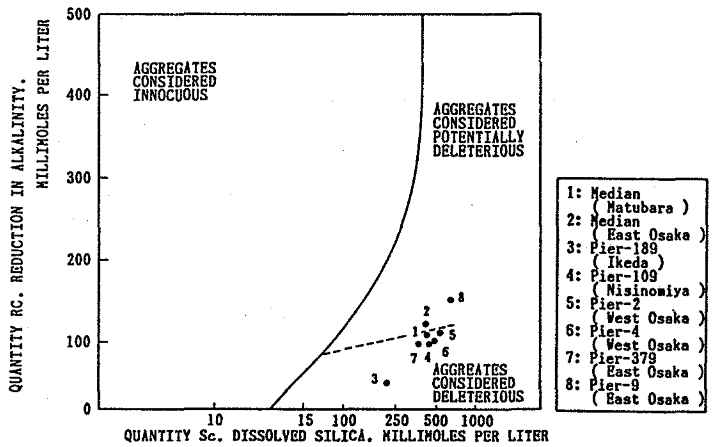

Fig. 7 Result of Chemical Test C289

The material age versus expansion rate of Mortar-Bar Test in accordance with ASTM C227 is shown in Fig. 8. Some of test results indicates that a large expansion is introduced with an elapse of time. This means that some structures have possibility of ASR problems even any structural damages have not been recognised so far. A continuous observation and attention are required.

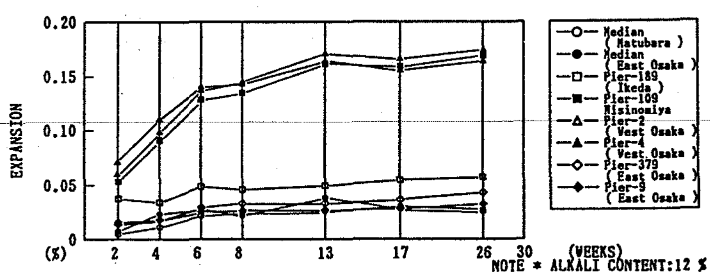

Fig. 8 Result of Mortar-Bar Testing

3.6 Ultrasonic Pulse Velocity of the Structure Concrete

The measurements of Ultrasonic pulse velocity on the structure concrete have been performed on 38 piers and PC girders of 3 spans. The results are compiled in each route on Fig. 9.

In Matsubara Route, extremely low velocity was observed at the beams of P42 and P45 on which a remarkable increase of the crack width was also observed.

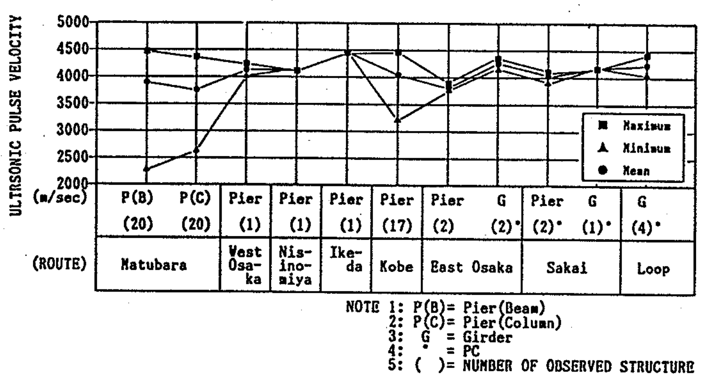

Fig. 9 Result of USP Velocity Measurement at Each Route

Particularly low velocities on P42, P43 and P45 among other piers of Matsubara Route are shown on Fig. 10. The beams of P42 and P45 and the column of P43 are evaluated to be seriously damaged because of the large crack widths and expansion values of concrete structures.

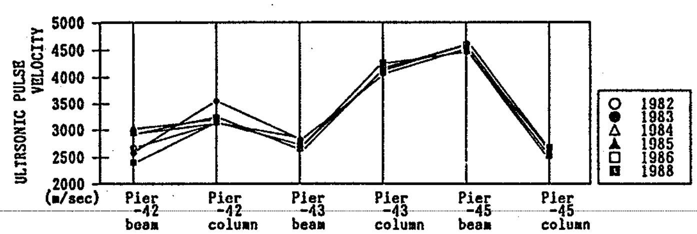

Fig. 10 Result of USP Velocity Measurement

4. CONCLUSIONS

As results of those continuous observations and several testings, the followings can be obtained:

a) Decrease of structural stiffness has been observed on dense cracked panels of slabs.
b) Concrete expansion phenomenon is progressing even after the waterproof-treatments such as injection and coating to the damaged structures.
c) From Mortar-Bar Test results, a large expansion may occur with an elapsed time even its small in young aged.
d) From observations and Mortar-Bar Tests results, the damaged structures for ASR have a potentiality of strength decrease infered from increase of concrete expansion and crack width, and decrease of Ultrasonic Pulse Velocity.

As conclusions, structural damages by ASR is still in progress. It will be extremely difficult to hold further progress by the present treatment techniques which HEPC have emploied so far. The most of observed structures are being utilised so that a lot of attentions on decrease of structural strength, falling of pop out concrete fragments for the growth of cracks. HEPC schedules a continuous observation of the damaged and doubtful structures by ASR of AAR from now on.

5. ACKNOWLEDGEMENT

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REFERENCE

[1] Deterioration and Repair of Bridge Structure in Hanshin Expressway, P.113, Hanshin Expressway Administration and Technology Center, Mar. 1987., Japanese Edition (for books)