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AAR in Brazilian Bridge Foundations Tests and Rehabilitation Procedures

RAA em Fundações de Pontes Brasileiras – Ensaios e Procedimentos de Reabilitação

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Abstract

Alkali-aggregate reaction (AAR) affects many structures worldwide. Unfortunately, traditional and available chemical tests like Test Method for Potential Alkali Reactivity of Aggregates–Mortar-Bar Method (ASTM C 1260) and Test Method for Potential Alkali-Silica Reactivity of Aggregates Chemical Method (ASTM C 289) require some time to verify inspections and suspects. However, substitution of these traditional tests by others like hammer test, elasticity modulus and ultrasonic pulse could be more useful always when the AAR action mechanism and its microscopy visual manifestation is known. These tests are easier to interpret and this paper shows a case study where that mechanical tests as well as petrography, X-Ray diffraction and microscopy were used to verify AAR existence instead of the traditional ASTM C 1260 and C 289 methods. A reasonable corrective action is proposed to rehabilitation the bridge based on some durability criteria.

Keywords: AAR, bridge, concrete expansion, concrete durability.

Resumo

A reação álcali-agregado (RAA) afeta várias estruturas no mundo. Infelizmente, alguns ensaios tradicionais e químicos disponíveis como o método das barras para avaliar o potencial de reatividade de agregados (ASTM C 1260) e o método químico de avaliação da reação álcali-sílica (ASTM C 289) necessitam de ser melhor avaliados. Entretanto, o emprego de outros ensaios em substituição aos citados como ensaios ultra-sônicos, determinação do módulo de elasticidade além de investigações visuais e microscópicas podem ser bastante úteis na presença da RAA. Estes ensaios são de fácil interpretação, sendo apresentado neste trabalho um estudo de caso onde foram empregadas as técnicas de petrografia, difração de Raios X e microscopia na investigação da RAA ao invés dos métodos tradicionais. Uma ação corretiva é proposta na reabilitação da ponte baseando-se em critérios de durabilidade.

Palavras-chave: RAA, ponte, expansão do concreto, durabilidade do concreto.

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Figure 1 – PGB view, emphasizing some deteriorated parts

1 Introduction

The Paulo Guerra Bridge (PGB) on Recife, Brazil was constructed during 1977. 25 years later, it shows evident deterioration signs on the deck, superstructure and sub-structure, which are caused not only by the surrounding atmosphere but also by wrong materials selection and poor supervision during construction. Damages on deck and super-structure have been inspected and the results published elsewhere [1]. This paper will deal with the inspection of the foundation blocks that are part of the sub-structure.

A general view of the PGB can be seen on Fig. 1. It is surrounded by a marine atmosphere according to the classification provided by MICAT [2], which is characterized by the presence of marine spray as well as wet and dry cycles.

The foundation blocks were constructed following an innovative technique which included the positioning of pre-cast reinforced concrete boxes on the piles, which served as permanent forms for the concrete blocks, as illustrated on Fig. 2. After 25 years of service, the concrete blocks and boxes showed evident deterioration through durability cracks and corrosion stains. The objective of this paper is to show that mechanical techniques together with others different than ASTM C 1260 and C 289 can help to verify the AAR. Then, rehabilitation can be proposed based on durability criteria.

Figure 2 – Schematic details of one representative concrete foundation block

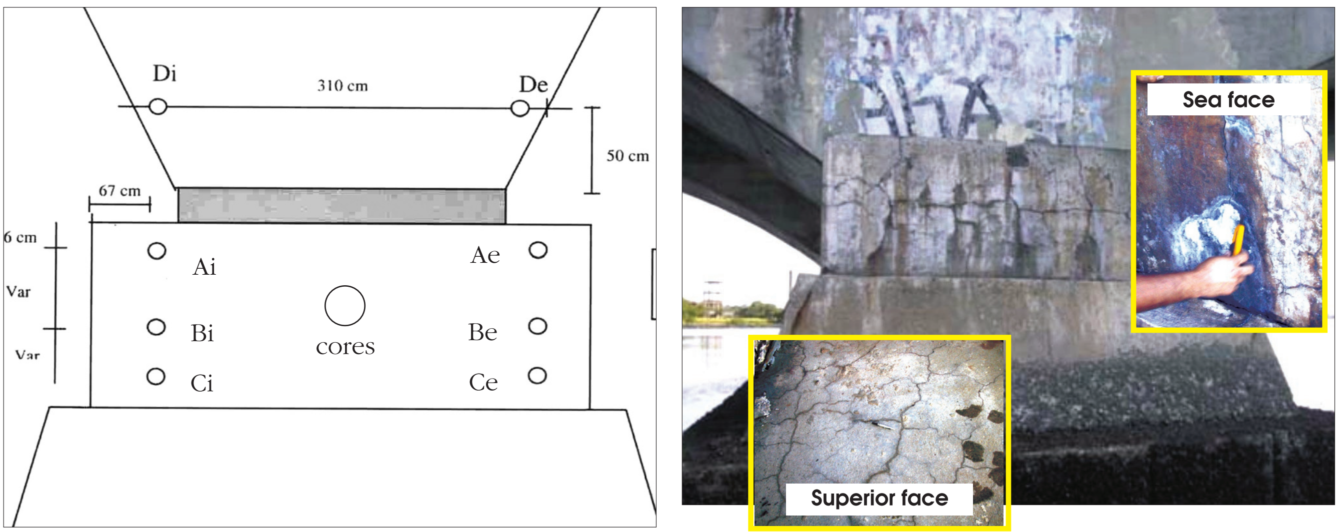
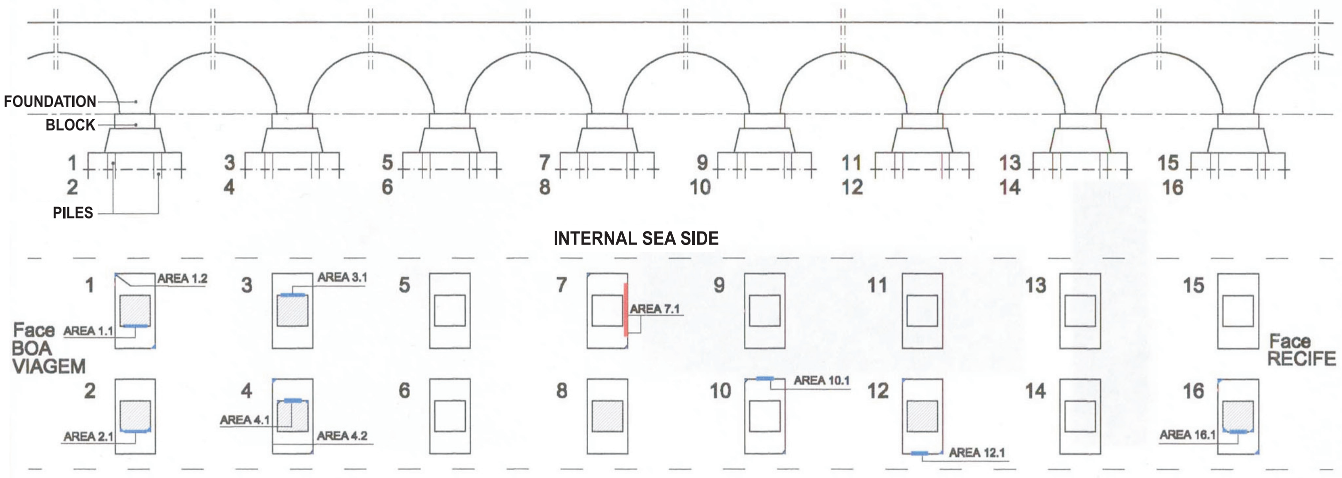


Figure 3 – PGB schematic view including zones where test were performed



2 Methodology

Visual inspection was performed according to well-established procedures [3]. Typical corrosion and concrete leaching stains were detected, as well as cracks with defined paths, possibly attributed to corrosion products, expansive reactions (AAR or sulphates), or late hydration of magnesium or calcium oxides. These manifestations can be partially observed in Fig. 1. Fig. 3 shows a schematic view of the bridge where sites for performing different tests are specified. A commercially available rebar locator was used to detect bars in the concrete boxes and blocks. Several measurements like hammer test [4] and Ultrasonic Pulse [5] were performed on site together with chemical carbonation [6], chloride determination [7], electrochemical resistivity [8], and corrosion potential [9] tests. Corrosion rate was not possible to measure due to the concrete thickness that made difficult the measurements on the selected sites. Concrete cores were obtained on several places of the different blocks. Compressive strength [10] and modulus of elasticity [11] results were obtained from them.
Part of the concrete cores was used to obtain samples for tests of petrography [12] and aggregates [13]. Coarse aggregates were classified according to well-known criteria [14][15]. Concrete blocks were evaluated and following are the representative tests results of them.

3 Results

Table 1 shows the tests results for hammer test, concrete cover, carbonation and corrosion potential for each of the evaluated blocks. Designed concrete cover was 10 cm on the top part, 15 cm at the bottom and 12.5 cm on the lateral surface. These values were verified during the inspection, where the minimum cover was closed to 8 cm. Superficial concrete hardness through hammer test showed a value of about 20 that corresponds to a concrete of approximately 20 MPa, according to [4], in cylinders. This means that this concrete is enough from the structural point of view.
Carbonation [6] showed an insignificant advance, as expected, and mainly due to the marine environment. Corrosion potential varied between +60 mV and –150 mV vs $Cu/CuSO_4$ [9] which indicates low corrosion probability in foundation blocks.
On the other hand, Table 2 shows total chloride concentration profiles [7] on selected zones of the blocks, which indicate that threshold for corrosion [16, 17] has not been reached. In the case of the blocks, cracking produced by possible AAR allowed the entrance of chloride and that is the reason of the high concentrations close to the surface.
Table 3 shows the results of ultrasonic pulse velocity [5] for all the tested blocks. The bigger the concrete cover from the surface, the higher the ultrasonic pulse velocity. Table 4 shows the results of compressive and tensile strength, as well as those of modulus of elasticity. The bigger the concrete depth from the surface, the higher the values of elasticity modulus as well as compressive and tensile strength.

4 Discussion

Evaluating the durability behavior of a structure is not easy if the right equipment and techniques are not available. Most of the times, the only available techniques are those very common and well known by the engineers. These techniques can be used in an adequate form, as in this case, to verify specific problems. In this case, there was evidence that corrosion problems had been the effect and not the cause of the PGB deterioration, because presented cracks were previous to detected corrosion and chlorides lower than expected. On the other hand, modulus of elasticity is a mechanical parameter that indicates concrete integrity and, according to the observed deterioration symptoms, it showed that the more cracking, the

less the modulus of elasticity value. Therefore, this shows if the reaction has proceeded at all or not which is not possible to know with the visual inspection only. On the other hand compressive strength and tensile strength are other two parameters that indicate concrete deterioration as observed here, and they are in accordance with the results of modulus of elasticity.
Confirmed AAR deleterious reaction many correctives alternatives were studied like induced carbonation and lithium salts injection. Considering the local conditions and the advanced concrete blocks deterioration the confinement of blocks were appeared as the best alternative. Once it was impossible to keep the concrete dry and the continuity of the reaction was expected, the designed confinement must have enough strength to resist the AAR forces of expansion. After some finite elements method simulation and considering others lab test results and the deformations induced by the AAR expansion it was decided to use

Table 1 – Results of hammer test (4) concrete cover (Pachometer), carbonation (6) and corrosion potential (9) for the evaluated concrete blocks

	Block	max	min	μ	δ	units
SCLEROMETRY (NBR 7584 ASTM C 803)	B 04*	n.a	n.a	n.a	n.a	IE
	B 07 *	54	48	52	2.38	IE
	B 10*	58	52	55.2	2.2	IE
	B 12*	55	52	54.3	2.2	IE
CONCRETE COVER Horizontal "PACHOMETER"	B 04*	n.a	n.a	n.a	n.a	mm
	B 07*	n.a	n.a	n.a	n.a	mm
	B 10*	44	34	39	5	mm
	B 12*	n.a	n.a	n.a	n.a	mm
CONCRETE COVER Vertical "PACHOMETER"	B 04*	n.a	n.a	n.a	n.a	mm
	B 07*	99	21	79	16.6	mm
	B 10*	34	17	25	7.1	mm
	B 12*	n.a	n.a	n.a	n.a	mm
CARBONATION RILEM CPC 18	B 04*	8	1	4	5	mm
	B 07*	16	5	11.3	3.8	mm
	B 10*	30	2	12	12.6	mm
	B 12*		1	1.8	0.8	mm
CORROSION POTENTIAL (E_{corr} superior) ASTM C 876	B 04*	n.a	n.a	n.a	n.a	mV
	B 07*	100	-1	39	59	mV
	B 10*	-98	-182	-138	35.8	mV
	B 12*	n.a	n.a	n.a	n.a	mV
CORROSION POTENTIAL (E_{corr} inferior) ASTM C 876	B 04*	n.a	n.a	n.a	n.a	mV
	B 07*	100	-5	21	31	mV
	B 10*	90	-1	45	35.6	mV
	B 12*	n.a	n.a	n.a	n.a	mV

*Indicated the block side
B = Block
B 04* Boa Viagem-Recife Side
B 07* Recife Side
B 10* Internal Side
B12* Sea Side (OO - Open Ocean)

Table 2 – Results of total chloride measurements (7) for the evaluated concrete blocks

	REBAR Diameter (cm)		CHLORIDES PROFILE Depth (cm)					Chlorides
	Horiz.	Vertical	0.5	1.0	2.0	3.0	Nucleus	
Block 07 - Recife side	1.2	1.2	0.518	0.385	0.590	0.342	0.202	% Per Concrete mass
Block 10 - Internal side	1.2	1.2	0.479	0.545	0.529	0.527	0.198	
Block 12 - Sea side *	1.2	1.2	0.673	0.198	0.673	0.532	0.422	

* (OO) = Open Ocean

Table 3 – Results of ultrasonic pulse velocity measurements (5) for the evaluated concrete blocks

BLOCK	POSITION (cm)	SIDE	MEASUREMENTS (φs)	VELOCITY (m/s)
BLOCK 04	Ai (67; 6)	Internal	1700	1,882
	Bi (67;20)		1050	3,048
	Ae (67;6)	External	1920	1,667
	Be (67; 20)		1020	3,137
BLOCK 07	Ai (67; 6)	Internal	1024	3,125
	Bi (67; 50)		831	3,851
	Ci (67; 80)		828	3,865
BLOCK 08	Ai (67; 6)	Internal	1908	1,616
	Bi (67; 50)		1260	2,540
	Ci (67; 80)		938	3,411
	Ae (67;6,0)	External	2355	1,359
	Be (67; 50)		933	3,430
	Ce (67; 80)		968	3,306
BLOCK 10	Ai (67; 6)	Internal	3480	919
	Bi (67; 50)		970	3,299
	Ci (67; 80)		860	3,721
	Ae (67; 6)	External	1100	2,909
	Be (67; 50)		847	3,778
	Ce (67; 80)		1045	3,062
BLOCK 12	Ai (67; 6)	Internal	1740	1,839
	Bi (67; 35)		795	4,025
	Ae (67; 6)	External	1400	2,286
	Be (67; 35)		820	3,902

Table 4 – Results of compressive strength (10), tensile by splitting test (18) and modulus of elasticity (11)

TESTS	Nº CP	B 01	B 04	B 07	B 09	B 10	B 12
Compressive Strength (MPa)	01	19.1	22.5	12.9	29.4	13.1	40.1
	02	23.6	29.4	32.5	35.4	23.6	49.2
	03	35.4	31.8	32.5	44.4	28.6	44.7
Tensile Brazilian Test Stress (MPa)	01	3.34	3.58	2.15	3.22	2.86	3.40
	02	5.49	4.47	2.89	3.46	3.16	3.94
Modulus of Elasticity (GPa)	01	10.4	n.a	n.a	n.a	8.0	n.a
	02	17.2	n.a	n.a	n.a	13.2	n.a
	03	24.4	n.a	n.a	n.a	6.6	n.a

a confining force enough to support 8 MPa as expansion tensile forces. That solution could avoid demolition and bridge substitution what was initially programmed, saving money and inconvenience for the people.
The AAR is usually verified through specific standards like ASTM C 1260 and ASTM C 289 but they are expensive and time consuming. The AAR was verified here through X ray diffraction and microscopy. The microphotography sequence from Fig. 4 shows the existence of the typical AAR gel which surrounds the paste-aggregate interface, which coincides with the low compressive tensile strength results and typical cracks and morphologies of the AAR. Also always when the lowest compressive and tensile strength were detected was possible to find typical gel salts on the edge of aggregates and in the transition zone between cement paste and aggregates. These behaviors were founded more expressive in the concrete block surface, around 40 cm comparing to the concrete block bulk.

5 Conclusions

Traditional mechanical tests like hammer test, ultrasonic pulse and elasticity modulus helped to verify the existence of AAR on the analyzed foundation blocks of the Brazilian bridge.
Damage by AAR in the blocks foundation is significant and affects their structural resistance.
Based on the obtained results, reinforced concrete jackets are a reasonable proposal for rehabilitation.

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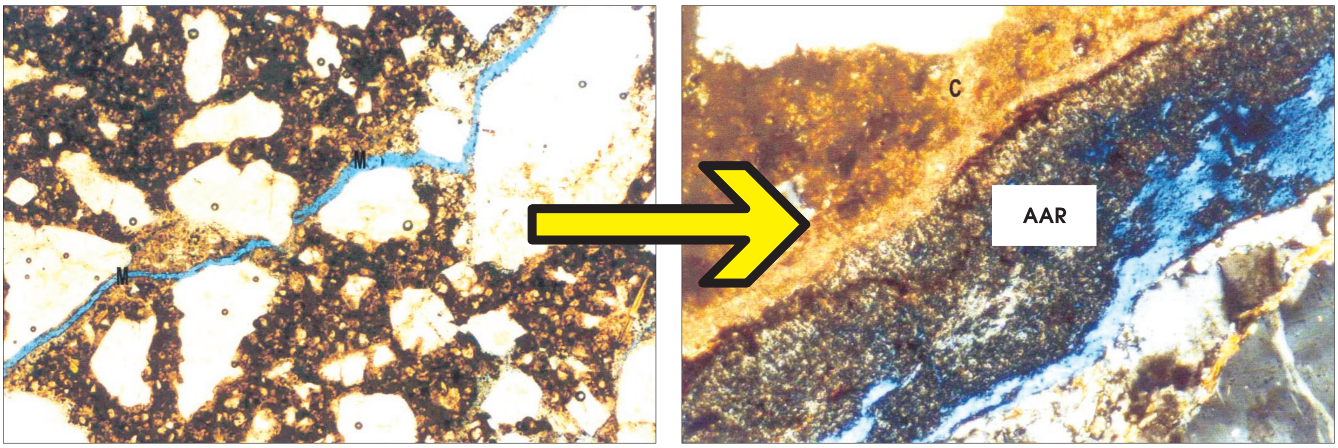
Figure 4 – Microphotography sequence showing details of the AAR identification



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