Inspection of the Pathological Manifestations on Janga Bridge

Romildo Alves Berenguer
Catholic University of Pernambuco
templarios_pm@hotmaill.com

Paulo Helene
PhD – Engenharia
Paulo.helene@concretophd.com.br

Eliana Cristina Barreto Monteiro
University of Pernambuco and Catholic University of Pernambuco
eleana@poli.br

Cecilia Silva Lins
Federal Rural University of Pernambuco
cecilia.lins@gmail.com

Analice Lima
Federal University of Pernambuco
analicelima@hotmail.com

ABSTRACT

Located in the metropolitan region of Recife/PE, Janga Bridge is an important element of the highway infrastructure that connects the towns of Olinda and Paulista. Unlike the current situation, the bridge was built in 1974 when the municipality of Paulista had a population of approximately 70,000 inhabitants. Today, 42 years after its construction, the town has a population of over 300,000 inhabitants which entails it has to cater for a daily traffic flow of about 50,000 vehicles. Over the years, it can be verified that there were deficiencies in attending to the maintenance of the bridge which has led to its having noticeable signs of deterioration and consequently this makes its users feel insecure. Besides the lack of maintenance, Janga Bridge is located in an area classified as being of a Very Strong class of environmental aggression, in accordance with NBR 6118: 2014 – A Project of concrete structures - Procedure, implying that there is a high risk of the structure deteriorating. Given the above, this paper sets out to identify the pathologies present in the Special Work of Art, to determine their likely causative agents and to evaluate the degree of weaknesses in the structural elements by using non-destructive tests.

KEYWORDS: Reinforced Concrete. Diagnosis of Pathological Manifestations. Inspection of structures. Janga Bridge.

INTRODUCTION

The Janga Bridge is an important element of the highway infrastructure that connects the towns of Olinda and Paulista. Built in 1974 in reinforced concrete, at a time when the municipality of Paulista had a population of approximately 70.000 inhabitants, today, 42 years after its construction, the town has a population of over 300,000 inhabitants which entails that it has to cater for a daily traffic flow of about 50,000 vehicles.

According to the records of the municipality of Paulista, Janga Bridge underwent structural recoveries during one period and, periodically, inspections are made to detect problems in its structure that may require repairs. However, maintenance has not been carried out adequately and currently the bridge has several pathological manifestations that this research study has identified and now discusses.

In recent years, due to the degree of deterioration presented in works such as bridges, viaducts and vertical buildings, civil engineering has intensified studies of the pathological manifestations in reinforced concrete to ensure a longer service life for these structures.

According to the research study conducted by Pintan *et al*. (2015), this pathological manifestation is one of the factors that make it possible for other pathologies to develop in the structure. When this is so, the leaching of component materials of the cement takes place and consequently the appearance of efflorescence. This also makes the structure liable to being penetrated by aggressive agents, which cause corrosion in steel rebars and the concrete to be weakened.

Experimental Program

The study initially consisted of an analysis of reinforced concrete bridge in the municipality of Paulista / PE, during which a visual inspection of the structure was made and a photographic survey was undertaken in order to record both the symptoms and the nature of the problems found in the bridge. Four types of non-destructive tests were conducted to aid the diagnosis;

History of the Structure

Regarding the history of the structure and using data obtained from the Maintenance Company, the bridge has received periodic maintenance. However, what was found is that it has been thought that maintenance has had to do with the clearing of vegetation, trash, etc., but even this type of maintenance was not noted in the inspections. On the other hand, it was built in 1974 with reinforced concrete on the river Paratibe at a time when the municipality of Paulista had a population of approximately 70,0000 inhabitants. Today, 42 years after its construction, the town has a population of over 300,000 inhabitants which entails there is a daily traffic flow of about 50,000 vehicles. Figures 1 and 2 show the inclined and underside views of Janga bridge, respectively.

Preliminary Inspection

The preliminary inspection of Janga Bridge was made in order to visually detect the pathological manifestations in its reinforced concrete structure as well as to obtain information on the aggressiveness of the environment which surrounds the bridge and on recovery, rehabilitation or restoration services that have been undertaken, thereby checking on the entire history of the structure (PINTAN, BERENGUER, JUST, LINS & MONTEIRO, 2015).

The visual inspection, with the naked eye, consisted of viewing the exposed underside part of the main structure of each of the spans of the bridge and its supports, excluding the foundations and this was recorded using photographs of all the pathological manifestations found (SOUZA NETO, BERENGUER, BARRETO, LINS & MONTEIRO, 2015).

According to ABNT/NBR 6118 (2014), due to the environment in which the Janga bridge lies, it is categorized as class III of environmental aggressiveness, the structure of which is at high risk of deterioration due to its being in the area affected by sea mist, which means the structure receives a high incidence of salts, which are deposited on the surface of the concrete and may penetrate into the structure, thereby causing various types of pathological manifestations.

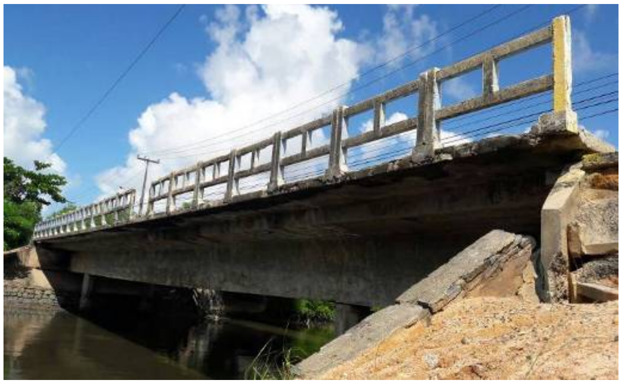


Figure 1: Angled view of Janga Bridge.

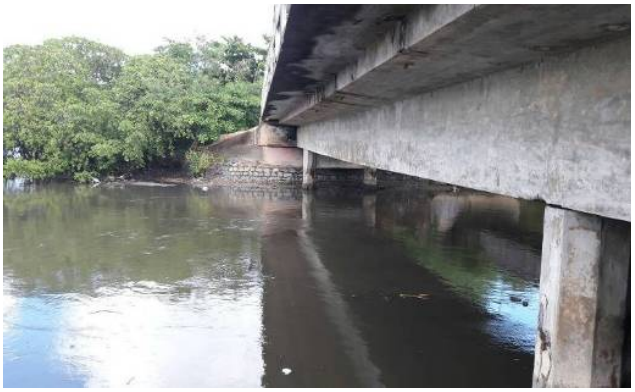


Figure 2: View of the underside of Janga Bridge.

Fissures

According to DNIT (2004), a fissure is a linear fracture in concrete which may extend partially or completely through the element. Fissures can have different origins, arising from materials having been used incorrectly, physical attacks and chemical attacks, and these can progress to the point of causing spalling and even collapse of the structure, depending on the extent of wear and tear.

In our case study, fissures of various sizes and forms were found in various locations of the structure, these being a cause and consequence of other pathological manifestations. Figures 3 and 4 depict the situation found in the structure of the bridge (BERENGUER, RAMOS, CARNEIRO, MONTEIRO, NOGUEIRA SILVA & ALMEIDA, 2016).

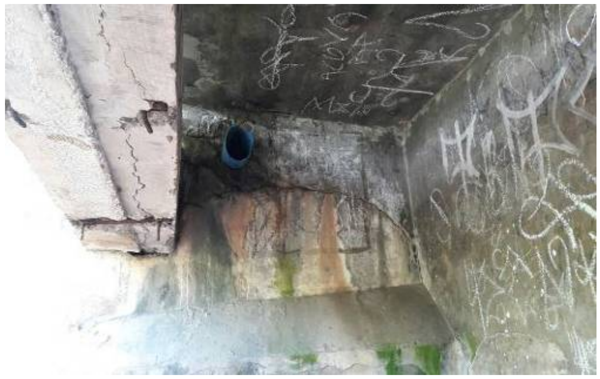


Figure 3: Cracks in beam of the Bridge.

Figure 4: Fissures on the underside of the Bridge.

Disaggregation of the concrete

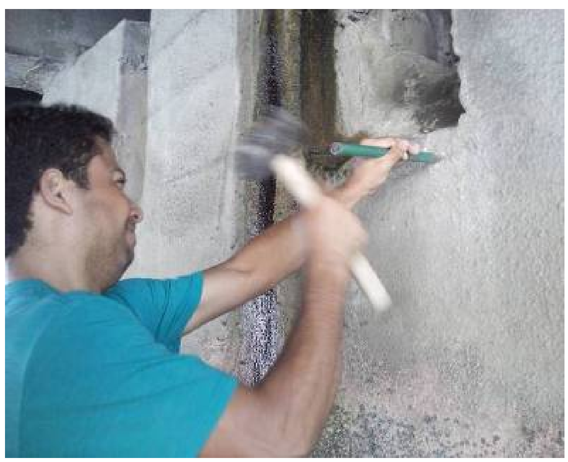
Sites were found throughout the length of the bridge which showed concrete had disaggregated, especially in the regions of the underside face of the beams, in different units. In some situations it was possible to unpick the aggregate of the structure manually, with practically no effort, thus demonstrating the advanced degree of disaggregation of the piece. Figure 5 shows an example of disaggregation verified on site.

Figure 5: Beam section with disaggregation of the piece.

Tests Performed

Evaluation of Free Chlorides

The evaluating free chlorides tests by the silver nitrate spray method, was undertaken on Janga Bridge (bank with reference to upstream of the River Paratibe) on the pillar wall. Part of the concrete of the support of the bridge was fractured and the silver nitrate solution was sprayed in two separate places; the solution was proportionally scaled in a 200 ml container which was wrapped with a paper to prevent light entering it, all in accordance with the standard (UNI, 1978). A photochemical reaction was used to find results and both were positive for the presence of free chloride ions in the structure, represented by a white color. There was no difficulty either in conducting the test, or as to viewing the results, thereby demonstrating how convenient and quick it is to detect the problem. The cost also proved to be quite affordable regarding the tests performed in the laboratory, thereby confirming the reason why its use has become so recurrent. Figures 6 and 7, respectively, demonstrate the process engaged on for the test, with the breaking of the surface of the concrete, spraying the solution and evaluating the coloration that indicates the result coloration, respectively.



Figures 6: Breaking the surface of the concrete

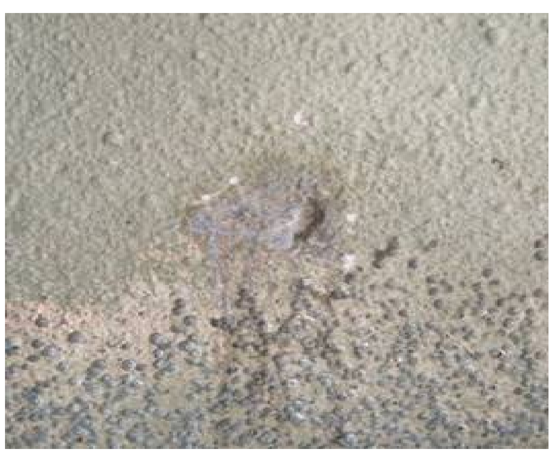


Figure 7: White color which serves as a means by which to evaluate the presence of free chlorides.

Assessment of Carbonation

According to Rilen Recommendation (1988), the test for evaluating carbonation by the method of spraying phenolphthalein solution was performed on the wall of the pillar wall of the last span of the bridge, near the site on which silver nitrate had been sprayed. The concrete was broken in four places and the solution was sprayed immediately after the fracture in order to prevent the carbon dioxide in the atmosphere from contaminating the newly fractured site and thus altering the results of the test. 2 g of phenolphthalein needed to be added to 200 ml of 70% ethanol to form the solution, which was kept in a container which had a sprayer. Immediately after spraying, the coloring of concrete changed to carmine red, thereby demonstrating that a negative result was found for the carbonation of this part of the structure. In all locations where the tests were carried out, they showed the same positive result for the evaluation of carbonation. However, a more detailed analysis is necessary because of the influence of several factors. The test was conducted quickly, conveniently and the cost of doing it was low. Figure 8 below shows how the test was performed.

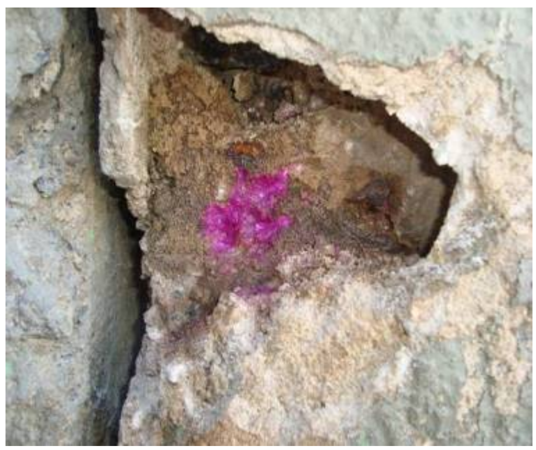


Figure 8: Phenolphthalein solution applied to the newly fractured areas of the structure of the bridge.

Sclerometry

The sclerometry test was conducted at two locations by boring sixteen holes at positive angles of ninety degrees and zero degrees in the support structure and in one of the beams of the underside of the bridge. In order to make the holes, sites were selected that had regular surfaces so there would be no interference in the final result. The places chosen for conducting the tests formed with a positive ninety degree plane, and in the second choice it was at zero degrees.

The readings obtained from the rebound of the hammer were listed in columns, noting the corresponding averages, where values that are 10% distant from the average were excluded. The whole procedure to find the value of the Scleromertric rebound index rebound hammer was carried out as stated in ABNT/NBR 7584 (2012). Tables 1 and 2 show the results of rough workpiece resistance.

Table 1: Result of Sclerometric Index (IE).

Values	Slope angle of the Sclerometer	
	0º	90º
SCLEROMETRIC INDEX AVERAGE	23.78	26.33
ESTIMATED RESISTANCE – ABACUS	24	21
CORRECTION CO-EFFIFICIENT	+/- 3.0	+/- 3.5
VARIATION OF RESISTANCE	21 to 27	17.5 to 24.5

Table 2: Results of the sclerometry tests

Nº. of order	Slope angle of the sclerometer		Nº. of order	Slope angle of the sclerometer		Nº. of order	Slope angle of the sclerometer	
	0º	90º		0º	90º		0º	90º
1	22	25	1	22	25	1	22	25
2	21	26	2	**21**	26	2	24	26
3	20	30	3	**20**	**30**	3	25	27
4	24	31	4	24	**31**	4	26	27
5	25	27	5	25	27	5	22	27
6	28	31	6	**28**	**31**	6	25	26
7	26	33	7	26	**33**	7	25	
8	21	27	8	**21**	27	8	23	
9	29	27	9	**29**	27	9	22	
10	21	22	10	**21**	**22**	10		
11	22	23	11	22	**23**	11		
12	25	26	12	25	26	12		
13	25	23	13	25	**23**	13		
14	23	23	14	23	**23**	14		
15	22	22	15	22	**22**	15		
16	28	21	16	**28**	**21**	16		
AVERAGE	23.88	26.06	-10%	21.49	23.45	AVERAGE	23.78	26.33
			AVERAGE	23.88	26.06			
			+10%	26.27	28.67			

The result of the quality of the covering of the structural concrete for the beam inspected (90° tilt angle) showed that the surface was bad, the value of the Sclerometric Index being 26.33, as for support (Tilt angle 0º), the result showed the quality was poor, as it the SI value was IE 23.78. Table 3 lists the values of the Sclerometric Index with the quality of the concrete which are important data from which the final result was obtained.

Table 3: Parameters for assessing the quality of the concrete (Pitan *et al.*, 2015).

Average (SI) Quality of the covering of the concrete
> 40 Good, hard surface
30 - 40 Satisfactory
20 - 30 Poor
< 20 Fissures/loose concrete on the surface

Regarding the estimated resistance of the structures tested, there was a change from 21 to 27 MPa for the support beam inspected, from 17.5 to 24.5 MPa. In accordance with the degree of aggressiveness of the environment in which Janga Bridge lies, and according to ABNT/NBR 6118 (2014), the resistance values should be at least 30 MPa, and thus, the support lies outside the standard.

Velocity of Propagation of Ultrasonic Wave

According to ABNT/NBR 8802 (2013) the concrete was tested by the semi-direct transmission method, with a length of 29.7 cm, on one of the supports located on the banks upstream of the Capibaribe river. Prior to measuring the propagation velocity of the ultrasonic wave, the apparatus had to be calibrated. Moreover, the concrete surface of the structure needed to undergo adjustment so that the value found would be as consistent as possible, thus minimizing errors. After the initial process of calibrating the apparatus, measurements began to be taken, as shown in Figure 9. The apparatus reached the result 178.6, with a pulse of ten Hz, as shown in Figure 10.

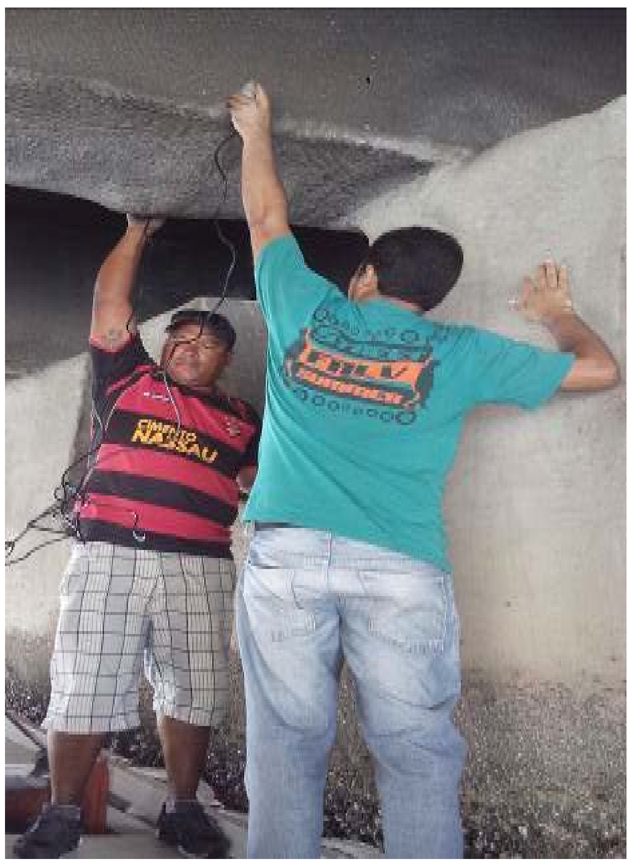


Figure 9: Start of the ultrasound test of the concrete structure of the bridge.

Figure 10: Result of the ultrasound test of the concrete structure of the bridge.

If one knows the space between the measurement and the time required to obtain it, by making calculations one can find the value of the propagation velocity of the ultrasonic wave, which reached 1,664.72 m/s. The quality of the concrete was considered poor because it achieved a result of less than 2,000 m/s, showing that it is not homogeneous, or this characteristic shows there are faults and fissures. Table 4 below lists the condition of the concrete with the velocity that was found of the propagation of the ultrasonic wave.

Table 4: Condition of the concrete tested by ultrasound equipment (Pitan *et al*., 2015)

VELOCITY OF CONDITIONS OF THE PROPAGATION (m/s)	CONDITIONS OF THE CONCRETE
Above 4,500	Excellent
3,500-4,500	Good
3,000-3,500	Satisfactory (questinable)
2,000-3,000	Generally poor
Under 2,000	Poor

Despite the negative result, the test method has several variables that can influence the result, so it is recommended that more elaborate tests be carried out that certify the condition of the concrete.

ANALYIS AND RESULTS

Preliminary inspection

Visual inspection of Janga Bridge pointed to an advanced state of deterioration of its reinforced concrete structure. In it, various pathological manifestations that corrode the structure of the bridge were observed, the most worrying being the constant presence of localized areas of concrete with exposed rebars in an advanced state of corrosion, especially in the beams. Secondly, the aggressiveness of the environment in which the concrete structure is exposed acts on it adversely, thereby causing its elements to corrode. According to the National Department for the Infrastructure of Transport DNIT (2004), the bridge ought to undergo periodic inspections that allow the diagnosis of abnormalities every two years at most. As no one knows when the last one was done, it is likely that the period since the final date of the last inspection has already passed. As a result of the state of degradation found on the bridge, one can identify that these inspections are not made periodically and that they have not been adequately maintained. This s because the information gathered at the site reveals that the maintenance that is done is only that of removing overgrown vegetation. Currently, the structures of the bridge need to be heavily repaired and restored.

In the preliminary inspection, several fissures were found. These may have been caused for several reasons, among which the most likely are because they have been pitted by, among other acids, chlorides but another possible one is because of tidal waters that are in constant contact with it and their tidal variations. This takes place in the cycle of being made wet and dry, which is always present in the structure. As a result of leaching, due to the environment in which the bridge is located, cases of efflorescence may have occurred, which together with the fissures and concentration of free chlorides and the decrease in pH of the structure, have begun to corrode the rebars, thereby justifying the current situation in which the bridge is now in.

Tests undertaken

On using the silver nitrate spray test, the presence of free chloride ions was identified, thus explaining the occurrence of numerous points of corrosion on the rebars which are present in the whole structure of Janga Bridge;

The test of assessing carbonation was positive for the place where it was performed, but this does not mean that this is not to be found in other places;

The evaluation of the hardness of the surface of the concrete for which the sclerometry test was used showed the result was poor, a bad surface for the beam and another considered bad for the support assessed, but it is worth noting that the test is influenced by several factors, including carbonation.

And with regard to the estimated resistance of the structure, the support was found to be outside the standard because the result for this was lower than that established by the standard in that structure situated in the zone of local aggressiveness in addition to which the beam presented a result that lay outside what is laid down in the standard.

The propagation of the velocity of a ultrasonic wave in the concrete showed a poor result for the support on which the test was run. However, this result may not match reality, due to the constant errors obtained by this method, so it is recommended a further evaluation be made elsewhere in the structure or by using another type of test.

All the tests carried out have their limitations as to obtaining an accurate result. The ideal is to extract specimens on which to conduct laboratory tests. Table 5 shows the summary of the results of the tests.

Table 5: Summary of the tests

Tests	Places Tested Indicators/values	References	Results in the Places Tested
Free Chlorides	Whitened	UNI (1978)	Presençe of Free Chlorides
Carbonation	Partially Carmine Red	RILEM RECOMMENDATION (1988)	Displayed Carbonation
Sclerometry	(Hole 1) = 23.78 (Hole 2) = 26.33	ABNT NBR 7584 (2012)	Displayed partially Satisfactory
Ultrasound	1664.72 m/s	ABNT NBR 8802 (2013)	Displayed Unsatisfactory

FINAL REMARKS

According to the studies conducted, it is concluded that in addition to all the pathological manifestations visibly detected, the Sclerometry test of Janga Bridge revealed a resistance of the concrete of the beams lower than that required by the degree of aggressiveness in the bridge, thereby demonstrating its incompatibility to meet the requirements of the standard. However, what must be taken into account is when the bridge was designed as it is probable that there were no such parameters in the standard at that time.

It could be observed that the structure is in a greatly deteriorated state and has an advanced degree of rebar corrosion at several points, thus adversely affecting the structural function of the elements in question. The most aggressive corrosion is that caused by the chlorides and was detected in the test of the method of spraying silver nitrate.

The study reveals that if there is no immediate maintenance intervention, recovery and strengthening of the bridge structure, the tendencies for pathological manifestations to advance will be maintained, and may make the structure completely lose its functionality and collapse, and cause harm to the city as a whole, because Janga Bridge is a key access road that connects the town of Olinda to Paulista and vice versa, as well as being a hallmark of the municipality.

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