Paper No:
RCC24

CORCON
17-20 September 2017
Mumbai, India

Case studies on corrosion testing in concrete structures

Dr. V.V.L. Kanta Rao

Senior Principal Scientist,
Bridge Engineering and Structures Division,
CSIR-Central Road Research Institute
Mathura Road, New Delhi – 110025
vvlkrao.crri@nic.in

Dr. Lakshmy Parameswaran

Chief Scientist,
Bridge Engineering and Structures Division,
CSIR-Central Road Research Institute
Mathura Road, New Delhi - 110025
lakshmy.crri@nic.in

ABSTRACT

The case studies of non-destructive / semi-destructive investigations carried out on a RCC/PSC bridge and a RCC silo in the state of Kerala, India are presented in this paper. Both the structures were built during 1984-85. The substructure of the 12 span bridge had RCC piers and, its superstructure was built in PSC girders and RCC deck slab. The accessible piers of the bridge were tested non-destructively / semi-destructively using rebound hammer, UPV, concrete resistivity meter and core cutting. In-situ carbonation test was carried out and the chloride content of concrete was determined from powder samples. The RCC silo was in use for storage of water based slurry of thorium hydroxide. The walls of the silo were tested for rebar corrosion using Galvapulse, and concrete carbonation.

The results show that there has been no corrosion of reinforcement or concrete carbonation of both structures despite of the fact that these were exposed to aggressive environment for about 30 years. The possible reasons for no corrosion were attributed to good quality of construction and high / adequate concrete cover. The study highlights the importance of the above two factors which are essential for any durable concrete structure.

Key words: Field investigation, RCC/PSC Bridge, RCC Silo, NDT, Corrosion of Steel, Carbonation of concrete, Chloride profile.

Paper No:
RCC24

17-20 September
Mumbai, India
2017

INTRODUCTION

Investigation and determination of the causes of structural failures of buildings, bridges and other constructed facilities, assumes immense importance before planning and executing any repair / rehabilitation measures. Non-destructive testing (NDT) is a vital component of the forensic investigation which makes it possible to determine the causes of deterioration and take decisions with regard to repair / rehabilitation of the distressed structures, and also assess the present structural condition of the concrete structures.

Non-destructive test methods such as rebound hammer[1] and ultrasonic pulse velocity[2], and semi-destructive method such as core extraction (IS:1199-1959) and testing[4] are in wide use in India for assessment of concrete in structures. Help from relevant ASTM / EU or other codes is often taken for evaluation of steel corrosion, concrete resistivity, chloride permeability, etc.

This paper presents the results of NDT of more than 30 year old concrete structures, namely a RCC/PSC bridge, and a RCC silo, carried out to assess the quality of concrete and condition of steel with respect to corrosion. The structures are located in the coastal state of India, i.e. Kerala.

NON-DESTRUCTIVE TESTING OF STRUCTURES

CHETTUVA BRIDGE

The salient features of the bridge (Fig. 1), built across the backwaters, are presented in Table 1. The non-destructive testing of the bridge was carried out during July 2011with an objective to assess the condition of the concrete. As, barring the piers 1, 2 and 11, the other piers were surrounded with water, the testing were carried out on these accessible piers only. The numbering of the piers was reckoned from its Northern side. The design strength of concrete was not known.

Figure 1: Chetuva Bridge

Table 1: Salient features of the Bridge

1.	Total Length (m)	319.9
2.	No. of spans	12
3.	Type of Foundation	Well
4.	Type of substructure	RCC Piers
5.	Type of super-structure	PSC girders and RCC deck slab
6.	Year of construction	Approx. 1985

The list of the tests carried out and, method adopted / equipment used for the same are presented in Table 2. Figures 2 and 3, respectively, show the test for resistivity, and concrete core extraction.

Table 2: Tests carried out on the selected piers of the bridge

S. No.	Tests carried out	Test method / equipment used
1.	Rebound Hammer	Ref. 1
2.	Ultrasonic Pulse Velocity	Ref.2
3.	Concrete Cover	Cover meter
4.	Concrete resistivity	Resistivity meter
5.	Concrete carbonation	Phenolphthalein indicator
6.	Concrete core extraction for testing of Concrete density, water absorption and compressive strength	Refs. 3, 4

7.	Concrete powder collection for Determination of chloride content	Ref. 5

Figure 2: Concrete Resistivity Test

Figure 3: Concrete Core Extraction

RCC SILO

The size of the silo was 15600 x 35600 mm. It was constructed in 1984 using a M 25 grade concrete. OPC of Grade 33 grade was used for the purpose. Ribbed bars of different diameters were used as reinforcement. This silo was in use for storage of water based slurry of thorium hydroxide which was in direct contact with the inside surface of the concrete

CORCON
17-20 September 2017
Mumbai, India

walls of the silo. The slurry was still inside the silo at the time of testing, and hence not all areas of the inside faces of the wall were accessible for testing. Also, as thorium hydroxide contains minute quantities of radioactive material, adequate safety precautions were taken before entering the silo.

The testing of the silo was carried out in August 2010. The objective of testing was to assess the condition of reinforcement with respect to corrosion. As there were no visual signs of corrosion (cracks, delamination, spalling etc.), the number of test points were limited to 8; four points on the outer face of the wall and four points on the inner face of the wall. A corrosion measuring equipment, which uses the Galvanostatic principle of corrosion measurement, was used for the above purpose. Figure 4 shows testing for the corrosion current density with the above said equipment. The equipment is provided with a guard ring feature for confining the applied polarization current. A detailed description of the equipment is provided by Peterson[6]. It directly gives the corrosion current density of the steel in terms of $\mu A/cm^2$, which is interpreted using the criteria presented in Table 3, as suggested by the manufacturer of the equipment. However no standard method exists to assess the corrosion rate of steel reinforcement in concrete through corrosion current density.

Figure 4: Measurement of corrosion current density of rebar

Table 3: Criteria to interpret the corrosion current test results obtained by the corrosion measuring equipment[6]

S.No.	Corrosion current density ($\mu A/cm^2$) as measured by the equipment	Corrosion Rate of reinforcing bar

1.	< 0.5	Negligible
2.	0.5 – 5.0	Slow
3.	5-15	Moderate
4.	> 15	High

The measurement of corrosion current of the reinforcing steel bar was preceded by first locating the same in the concrete wall using a rebar locator, which also gives the diameter of the bar. Access to the rebar was obtained by controlled breaking of the cover concrete using a drill machine, chisel and sickle. The exposed concrete surface was sprayed with phenolphthalein solution for detection of the carbonation of concrete (Fig. 5). The depth of the concrete cover was also measured and the condition of the reinforcement bar was visually inspected after breaking the cover concrete. (Fig. 5).

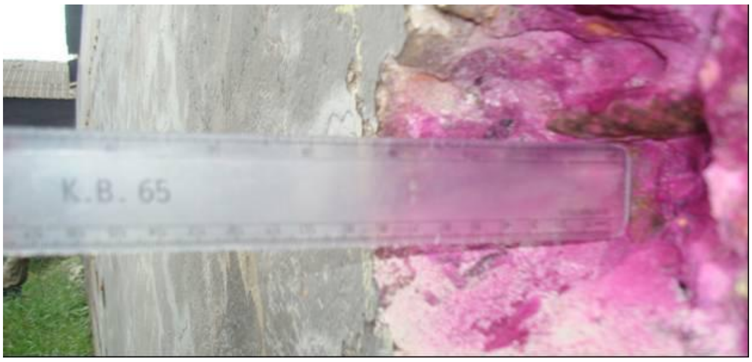

Figure 5: Measuring concrete cover and testing for concrete carbonation

RESULTS

CHETTUVA BRIDGE

The test results of the water absorption, concrete density, compressive strength (determined from concrete cores), and concrete carbonation are presented in Table 4. There has been no recommended or limiting value for water absorption of hardened concrete in Indian specifications. However, the water absorption of concrete was found to be less than the limiting value recommended in Belgian Standard[7]. The low water absorption indicates that the concrete in the piers of the bridge was well compacted and less porous.

Table 4: Some salient properties of concrete determined through core testing

S. No.	Property of concrete in the pier	Average value	Recommended / limiting / generally accepted value
1.	Water absorption	3.95 %	5.50 % (Ref. 7)
2.	Density	2385 kg/cum	2400 kg/cum
3.	Equivalent cube compressive Strength	25.44 MPa	Depends on design strength

The results of the NDT are presented in Table 5. Rebound hammer test was carried out on seven test points on each face. The rebound number at each point represents average of ten rebound hammer strikes. The rebound number for each face shown in Table 4 is the average rebound number of all the seven test points. The high rebound number indicates that the surface of the pier is strong. A uniformity in the rebound numbers at each test point was noticed indicating that the quality control exercised during construction was good. Direct method of measuring the UPV was adopted in this test. The thickness of the pier was 850 mm. The UPV presented in the table is the average of UPV at seven test points from each pier. Each of the individual UPV test values were higher than 4.0 km/sec.

Table 5: Results of NDT

Test	Pier & Location	Test Result-Average value	Remarks / Interpretation	Ref
Rebound Number	Pier 1 (i) North Face (ii) South Face	 45.4 49.1	Concrete surface is relatively hard	Ref. 1
Ultrasonic Pulse Velocity (km/sec)	Pier 1	4.24	Concrete quality is good	Ref. 2
	Pier 11	4.10		
Concrete cover (mm)	Pier 1 (i) South Face (ii) Well cap	 78.1 61.0	The recommended maximum cover to the concrete exposed to conditions such as salt spray is 75 mm.	Ref. 8
	Pier 2 (i) North Face (ii) Well cap	 73.0 84.0		

	Pier 11 (i) North Face	 76		
Concrete resistivity (K.Ohm-Cm)	Pier 1 (i) South Face (ii) North Face	 43.0 30.7	Low probability of corrosion	Ref. 9
	Pier 11 (i) South Face (ii) North Face	 36.4 43.7		
Concrete carbonation	Pier 1	Only on surface of pier		-

The chloride content of concrete of Piers 1 and 2 at different depths is presented in Table 6. There is a wide variation in the accepted threshold chloride content of hardened concrete, made with Ordinary Portland Cement (OPC), for initiation of reinforcement corrosion[10,11]. It varies from 0.2 to 1.2 % by weight of cement for un-coated deformed carbon steel reinforcement bars (average = 0.7 %). The threshold chloride content is also dependent on the C_3A content of the cement. The C_3A content of OPC generally varies from 6 to 12% by weight, and accordingly, the threshold chloride content varies from 0.6 to 0.9 % by weight of cement (Average = 0.75 %). Hence a threshold chloride content of 0.75 % by weight of cement is considered in the present analysis. As the mix proportions of the concrete mix of the bridge were not known, it was assumed that the grade of concrete used for piers as M 25, a cement content of 300 kg/cum, in tune with the practice during 1980's, and the concrete density as 2400 kg/cu.m. Thus, the threshold chloride content would be 2.25 kg / cu.m of concrete which equals to 0.094 % by weight of concrete.

Table 6: Chloride contents (% by weight of concrete) of the piers at different depths

Pier No.	Depth from the surface (mm)							
	5	10	15	20	25	30	35	40
P1	0.79	0.73	0.67	0.41	NA	0.03	0.03	NA
P2 Well Cap	0.67	0.62	0.27	0.27	0.23	0.23	0.17	0.08

Figure 6 shows a plot of the variation of the chloride contents (chloride profile) with the depth from the surface for the Well cap of Pier 2. The chloride content was found to be higher at the surface, up to about 40 mm, than the threshold chloride level. In other words, the

CORCON
17-20 September 2017
Mumbai, India

chloride could penetrate up to about half of the concrete cover in about 27 years. Although it may be concluded that the chloride content at the reinforcement level would be considerably lower than the threshold chloride level for corrosion, however, the results indicate a warning signal in-terms of the impeding chloride attack on the reinforcement of the well cap.

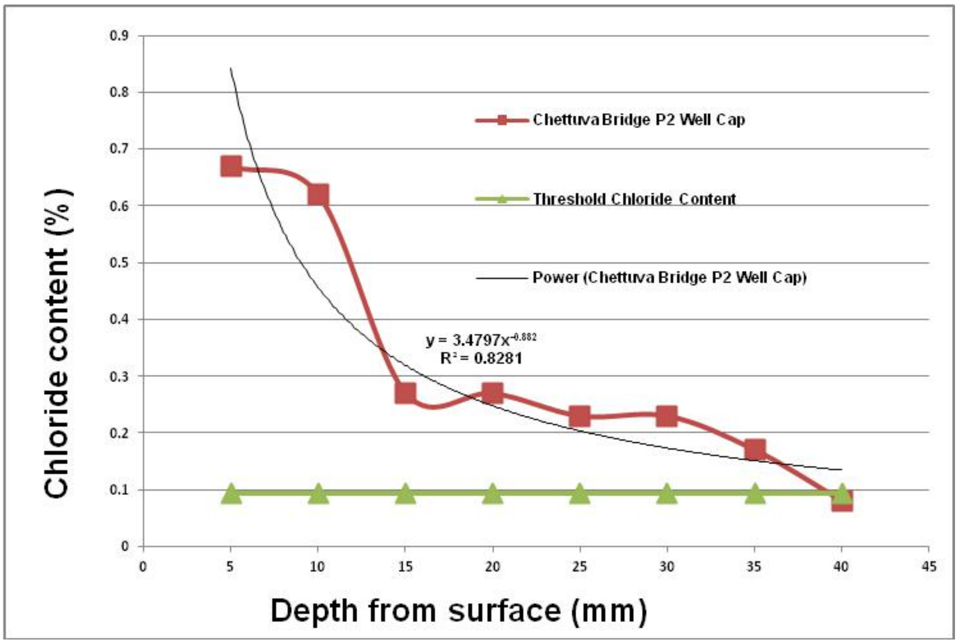

Figure 6: Chloride profile of concrete in Pier cap of Chettuva Bridge

Assuming similar aggressiveness of the exposure conditions, it could take about another 20 years for the chloride content to reach the level of reinforcement (conservative estimate). As the chloride content is less than the threshold value at the level of reinforcement, no corrosion was observed at the location of the testing. The chloride content of the concrete in Pier was found to be less than that of the well cap. The well cap was in contact with water and is subjected to alternate wetting and drying. Hence penetration of chlorides due to diffusion is higher in well cap as compared to the Pier.

RCC SILO

The visual inspection of the RCC wall revealed that the surface of the concrete wall appeared to be in good condition. The concrete cover over the reinforcement as measured was about 60-80 mm. No carbonation of concrete as evidenced from the pink coloration obtained after spraying the phenolphthalein solution on the broken concrete surface (Fig. 5). The reinforcement bar appeared to be in good condition, and the ribs over the reinforcement

CORCON
17-20 September 2017
Mumbai, India

bar and the binding wire used were intact (Fig. 7). The corrosion current density results and their interpretation are presented in Table 7.

Figure 7: Condition of rebar - binding wire seen intact in the concrete (inside face of the wall)

It was concluded from the visual observations, carbonation test and corrosion current density measurements on the walls of the RCC Silo that the corrosion rate of the reinforcement was negligible on the outer surface of the north side wall, and inside surface of the walls and, is slow on the outer surface of the south side wall. The reason for the relatively higher corrosion on the south side wall could be due to its direct exposure to sea face and relatively more humid conditions.

Table 7: Corrosion current density of reinforcement of RCC walls of the Silo

Test point No.	Location	Corrosion current density ($\mu A/cm^2$)	Interpretation of corrosion current density as per criteria given in Table 6

CORCON 2017
17-20 September
Mumbai, India

1	Outer surface of wall between N2-N3	0.492	Negligible
2	Outer surface of wall between N5-N6	0.453	Negligible
3	Outer surface of wall between S1-S2	1.072	Slow
4	Outer surface of wall between S3-S4	1.099	Slow
5	Inner surface of wall between W2-W3	0.143	Negligible
6	On buttress at S7	0.207	Negligible
7	Inner surface of wall between S7-S8	0.267	Negligible
8	On buttress at N6	0.204	Negligible

REMARKS ON THE OBSERVED TEST RESULTS

It was concluded from the test results that the concrete material in the both the structures was in good condition and there was no corrosion of reinforcement or concrete carbonation.

In this connection, it may be noted that the grade of concrete used in early 1980's was only of 25 MPa or 30 MPa, and the cement available in those days was only OPC 33 grade i.e which attains a compressive strength of 33 MPa in 28 days. The high strength grade cements i.e. 43 Grade or 53 Grade were not yet introduced in to Indian market in those days. The absence of corrosion of steel reinforcement or concrete carbonation, despite use of low strength grade of OPC and exposure of the structures to marine environment, can only be attributed to the good quality of construction (high rebound numbers and high UPV), and high and uniform concrete cover. The state of Kerala experiences heavy rains and the atmosphere is generally wet due to which the structures are subjected to washing-out of concrete surface. This explains the absence of carbonation of concrete. The study therefore highlights the importance of quality construction and adequate concrete cover to achieve durable structures. The structures are standing examples with long service life which can be built without using advanced materials or advanced construction methods.

CONCLUSIONS

Two concrete structures namely, a RCC / PSC bridge and a RCC silo were tested by non-destructive and semi-destructive methods to assess the condition of concrete and steel reinforcement. Based on the test results the following conclusions are drawn:

i) The quality of concrete is generally good and no distress was noticed in the form of cracks, delamination or spalling.
ii) High concrete cover was observed in both the structures.
iii) The rebound hammer test and UPV test yielded high values to confirm the good quality of concrete
iv) No concrete carbonation was observed.
v) The chloride front did not reach the level of reinforcement in the bridge piers
vi) The concrete structures exemplify for the durability of concrete in spite of the low grade of cement used for construction.

ACKNOWLEDGMENTS

The authors express their sincere thanks to the management of Network Research Project SIP-30 for providing funds for carrying out this work. Authors convey their gratitude to the PWD officials of Kerala for allowing the CRRI team to carry out the testing work on the piers of the bridge and for extending all possible help. Thanks are also due to M/s Aryan Engineers, Mumbai for awarding the work on RCC silo. Sincere gratitude is due to all the staff of Bridges and Structures Division in CSIR-CRRI for taking part in the NDT work and related laboratory work. The authors express their gratitude to the Director, CSIR-CRRI for allowing them to write this paper.

REFERENCES

1. IS (2004) 13311 (Pt. 2): Indian standard for Non-destructive testing of concrete – Method of Test – Rebound hammer, Bureau of Indian Standards, New Delhi, India
2. IS (2004) 13311 (Pt. 1): Indian standard for Non-destructive testing of concrete – Method of Test – Ultrasonic Pulse Velocity, Bureau of Indian Standards, New Delhi, India

17-20 September 2017
Mumbai, India

3. IS (2004) 1199: Indian Standard Methods of Sampling and Analysis of Concrete, Bureau of Indian Standards, New Delhi, India
4. IS (2004) 516: Indian Standard Methods of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi, India.
5. Application Bulletin (132/e) (2010): Chloride Titration with potentiometric indication, Metrohm, Switzerland.
6. Peterson CG (2003) Corrosion rates determined by the GalvaPulse. Germann Instruments, Copenhagen, p. p 1-13.
7. NBN (1989) B15 – 215: Concrete Testing-Absorption of water by immersion, Belgian Standard
8. IS (1978) 456: Indian Standard Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi, India.
9. Bungey JH, Millard SG and Grantham MG (2006) Durability Tests. In *Testing of concrete in Structures*, Taylor & Francis, London pp. 191-194.
10. Alonso C, Andrade C, Castellote M and Castro P (2000) Chloride threshold values to depassivate reinforcing bars embedded in a standardised OPC mortar. Cement and Concrete Research **Elsevier** 30: 1047-1055.
11. Angst U and Vennesland (2009) Critical chloride content in reinforced concrete In Concrete Repair, Rehabilitation and Retrofitting II (Alexander et.al (eds). Taylor & Francis Group, London, U.K., pp. 311-316.