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RC Jacketing on RCC frame of Overhead water tank using results of Non Destructive Testing - A case study.

A. Mishra[1*], M. Singh[2*], A. Srivastava[3*]

[1] Post-Graduate Student, Department of Civil Engineering, BITS-PILANI, Pilani, India
[2] Research Scholar, Department of Civil Engineering, BITS-PILANI, Pilani, India
[3] Associate Professor, Department of Civil Engineering, BITS-PILANI, Pilani, India
*Email: manpreet_singh04@yahoo.com TP: +919780508420

Abstract – A three storey RCC frame of an old overhead water tank in BITS Pilani campus had developed wide visible cracks, rusting of steel reinforcement and concrete spalling conditions at many locations. The condition of these structures was assessed by visual inspection, non-destructive testing (NDT) like rebound hammer, ultrasonic pulse velocities, rebar locator etc. and laboratory tests, to ascertain their suitability for further use. Based on the results of the tests conducted RC jacketing technique using anti corrosive agent, micro concrete and polymer modified mortar for retrofitting was suggested and implemented. The NDT was conducted again after the completion of retrofitting of the structure. This case study presents the use of standard and innovative repair materials, appropriate technology, workmanship, and quality control for successful repair, strengthening and restoration of damaged structures.

Key words – Retrofitting, Non-destructive testing, Rebound Hammer, UPV, rebar locator, micro-concrete, RC Jacketing

1. Introduction

Structures have a variety of performance requirements. Retrofitting of structures is done to improve these requirements like safety, serviceability and restorability. In retrofitting, the structure must be designed so that it serves its purpose of use and is both safe and durable. Consideration is given to the ease of retrofitting and post-retrofitting maintenance, as well as overall economy and environment-friendliness.

Of all the retrofitting processes, RC jacketing provides a better solution to avoid buckling problems. Retrofitting is a technical addition to the system of the building, which improves the load carrying capacity and the strength. It also increases the structural life span, with high serviceability.

To evaluate the performance of a structure and verify that it fulfills its performance requirements, it is necessary to express it in terms of quantifiable physical quantities that represent performance. This can be done using various tests. Ideally such tests should be done without damaging the concrete. The tests available for testing concrete range from completely non-destructive, where there is no damage to the concrete, to those where the concrete surface is slightly damaged i.e. partially destructive tests, such as core tests and pull out and pull off tests, where the surface has to be repaired after the test.

The condition can be assessed by various Non Destructive Tests (NDT) like rebound hammer test, Ultrasonic pulse velocity (UPV) test, rebar locator test, half-cell potential test, carbonation test and lab tests. The Rebound hammer test is used to access concrete compressive strength at several locations. When testing, “Rebound Number” is measured which depends upon the strength of concrete/mortar close to the surface and a site specific correlation is been developed to correlate compressive strength with likely compressive strength. To obtain information about Concrete quality i.e. voids, flows, cracks etc. the Ultrasonic Pulse Velocity test is done. The results help in identifying the areas required to be strengthened or retrofitted. The interpretation is done using the IS: 13311-Part 1, which characterizes the quality of concrete in terms of the ultrasonic velocity.

At the site for the determination of cover, for locating reinforcement bars and for finding the probable reinforcement bar diameter, Rebar Locator is used. For assessing the percentage risk of corrosion of reinforcement bars, Half-cell potential test is done. The interpretation is done using the ASTM Standard No. ASTM C 876:1991 (Re-approved 1999).

For repairing of the concrete structures, micro concrete which is a dry ready mix cementetious based composition formulated for use in repairs of areas where the concrete is damaged & the area is restricted in movement making the placement of conventional concrete difficult can be used.

2. Case Study

The Birla Institute of Technology & Science (BITS), Pilani is an all-India Institute for higher education. BITS is located in the Vidya Vihar campus adjacent to the town of Pilani in Rajasthan (India).

BITS has a vast campus and there are numerous structures which have been standing for the past many years. Over the years, due to ageing effect or other causes some signs of distress have appeared on these structures which need to be addressed.

A three storey RCC frame of an old overhead water tank in BITS Pilani campus, whose age would be around 40 years had developed wide visible cracks, rusting of steel reinforcement and concrete spalling conditions. The condition of some elements of RCC frames/stages carrying the water tank was critical including the bottom of tank. No Design Details and Architectural drawings were available.

The condition was assessed by various NDT test like Visual inspection, Rebound hammer test, Ultrasonic pulse velocity test, Rebar locator test, Half-cell potential test, Carbonation test and Lab test. And on the basis of results, design & recommendations for the retrofitting were determined.

3. Scope of Work

The scope of work includes following:
a) Visual inspection with photographs to assess physical condition of structural elements.
b) Carrying out various types of Non-destructive tests on structural elements.

The proposed non-destructive tests for RCC are broadly classified as:

• **Tests for strength and quality of concrete**
Schmidt's Rebound Hammer test, Core Sample testing and Ultrasonic Pulse Velocity testing on representative elements/samples. Determination of cement content in the laboratory.

• **Tests for assessing the risk of corrosion**
Determination of depth of concrete cover, depth Carbonation, half-cell Potential meter tests.

Below mentioned scope of work includes conducting various tests as suggested:

Table 1: Test and Instruments used

Sr. No.	Description of tests	Equipment used
A	Visual Inspection	
B	NDT of RCC Elements	
1	Schmidt's rebound hammer test	Concrete test hammer type N manufactured and supplied by PROCEQ SA ZURICH
2	Ultrasound Pulse velocity test	Ultrasonic Instrument TICO manufactured and supplied by PROCEQ SA ZURICH

3	Cover meter tests	Instrument PROFOSCOPE by PROCECQ
4	Carbonation test	PHENOLPHTHALEIN
5	Half-cell potential test	Instrument Contained copper sulphate electrode, sponger for electrode, case for connecting reinforcement with crocodile carrying case.
6	Taking out concrete cores (70mm/50mm dia.)	Core Drilling machine of make TYROLIT
C	Laboratory test	Compressive strength and density tests.

4. Test and Observations

4.1 Visual Inspection details:

Table 2: Details of Visual Inspection: Water tank

Sr. No	Location	Name of Distress	Photos
01	Outer wall of water tank C-3 & C-4, Outer wall of water tank C-5 & C-6, Outer Slab near C-1,C-2,C-3,C-4,C-5	Patch of dampness	 Figure 1
02	Outer wall of water tank above C-1, C-2	Water Seepage	 Figure 2

03	Vertical Cracks in bottom and middle parts of Column No. C-1. Horizontal cracks from bottom to top in Column No. C-2, C-3, C-4, C-5, C-6. Vertical cracks in bottom and middle parts of Column No. C-3, Beam No. B-2, B-4, B-5, B-6, B-7, B-8, B-9, B-10, B-11	Moderate Cracks (5mm to 10mm)	 Figure 3
04	Bottom Part of Column C-1, Middle part of Column C-1, Bottom Part of Column C-2, Inner side of Beam B-2, Soffit of Beam B-8, B-3, B-1, Patches in outer slab	Corroded Reinforcement	 Figure 4

4.2 Rebound Hammer Test Results

Table 3: Details of Rebound Hammer Test Results: Water tank

Interpretation: As Per IS:13311-Part II

→ *Denotes Rebound hammer Test Conducted in Horizontal Direction*
↓ *Denotes Rebound hammer Test Conducted in Vertically Downward Direction*
↑ *Denotes Rebound hammer Test Conducted in Vertically Upward Direction*

S.No.	Test Locations	*Impact Direction	Rebound No.						Average Rebound No.	Corrected Rebound No.	Observed Compressive Strength
			1	2	3	4	5	6			
	Ground Columns										
1	C	→	22	24	21	20	18	20	21	21	7
2	C	→	38	40	38	42	42	38	40	40	17
3	C-3 (Core	→	36	40	35	38	39	37	38	38	16
5	B	→	28	24	26	28	24	28	26	26	10
6	B	→	22	20	18	20	18	20	20	20	6

7	B-4 (Core	→	43	44	39	43	40	41	42	42	18
8	B-5 (Core	→	30	32	33	29	32	31	31	31	13

Laboratory Test Results For Compressive Strength

Table 4: Details of Laboratory Test Results: Water tank

S. No.	Sample ID	Diameter	Length (mm)	L/D Ratio	Correction	Max. Load	Cylindrical Compressi	Corrected Cylindrical	Equivalent	Natural	Saturated	Density
	Ground											
	Columns											
1	C-3 (Core	67.47	134.3	1.991	0.999	39.18	11.0	10.9	**13.7**	2257	2311	
2	C-4 (Core	67.56	119.1	1.763	0.974	39.20	10.9	10.6	**13.3**	2228	2292	
	Be											
3	B-4 (Core	67.62	118.2	1.749	0.972	42.82	11.9	11.5	**14.5**	2187	2274	
4	B-5 (Core	67.51	124.4	1.902	0.989	38.52	10.8	10.6	**13.3**	2231	2316	

4.4 Test Results of Ultrasonic Velocity Tests

Table 5: Details of Ultrasonic Velocity Tests: Water tank

Interpretation: As Per IS:13311-Part I

** 'Direct': Probes Kept on Opposite Faces*
** 'Semi-direct': Probes Kept on Perpendicular Faces*
** Indirect': Probes Kept on Same Face*

S.No	Test Location	* Method of Probing	Observed UPV	Corrected UPV (m/sec)	Inference (IS : 13311-I)
	Ground Level				
	Colum				
1	C-	Dire	46	46	Doubtful
2	C-	Dire	37	39	Doubtful
5	C-3 (Core WT-1)	Dire	347	347	Medium
7	C-4 (Core WT-2)	Dire	356	356	Good
	Beam				
13	B-	Dire	45	65	Doubtful
14	B-	Dire	22	22	Doubtful
19	B-4 (Core WT-5)	Dire	344	344	Medium
20	B-5 (Core WT-6)	Dire	346	346	Medium

4.5 Rebar locator Test Results

Table 6: Details of Rebar locator Test Results: Water tank

Interpretation : As Per IS:456 – 2000						
Note: Only 'Clear' Concrete Cover is Measured. Approximate dia. will be calculated. *Accuracy of results depends on Depth, Diameter, Spacing & Positioning of Reinforcement Bars.*						
S.No.	**Test Location**	**Face**	**Size**	**Reinforcement**		
				Main	**Stirrups (mm)**	**Cover (mm)**
	Ground					
	Columns		**(Diameter)**			
1	C-		53	8X18 mmǿ	6 mm ǿ @ 220	35-
2	C-		53	8 X 20 mm ǿ	6 mm ǿ @ 225	55-
3	C-		53	8 X 20 mm ǿ	6 mm ǿ @ 220	28-
	Beam					
4	B-1(MID.)	I.Side(5	550X250	3 X 25 mm ǿ	10mm ǿ @ 325	30-
5	B-1(MID.)	Soffit(2	550X250	2 X 25 mm ǿ	10mm ǿ @ 325	20-
6	B-2(SUPP.)	OSide(5	550X250	4 X 25 mm ǿ	10mm ǿ @ 235	38-

4.6 Test Results of Carbonation Tests

Table 7: Details of Carbonation Test Results: Water tank

Interpretation:				
Indicator Color: Deep Purple				
Sl. N	**Test Location**	**Depth of Carbonation**	**Minimum Concrete Cover Measured**	**Minimum Concrete Cover IS -456**
	Ground Level			
	Columns			
1	C-	49	35	40
2	C-	56	55	40
3	C-3 (Core WT-1)	37	28	40
4	C-4 (Core WT-2)	51	62	40
	Beam			
5	B-	41	30	20
6	B-	49	30	20
7	B-4 (Core WT-5)	42	26	20
8	B-5 (Core WT-6)	36	28	20

4.7 Test Results of Half-Cell Potential Tests

Table 8: Details of Half-Cell Potential Tests Results: Water tank

Interpretation: As Per ASTM:C876-1991			
By convention, potentials are considered negative when measuring the steel with respect to the electrode. The interpretation of measurements is in terms of the likelihood of corrosion.			
Sl. N	**Test Location**	**Half-cell Reading**	**Risk of corrosion**
	Ground		
	Columns		
1	C-	0.46	90
2	C-	0.42	90
3	C-	0.38	90
	Beam		
4	B-	0.32	90
5	B-	0.40	90
6	B-	0.46	90

4.8 Conclusions from the results

To assess the damages, Visit was made. Following points noted:

a. There are visible signs of rusting of steel reinforcement in columns, beams & roof slabs. This has caused the Spalling/ deterioration of concrete.

b. There are serious cracks and damages in the columns, beams and slabs.

c. As per NDT test report, the concrete has deteriorated at many places.

d. During the visit, many places were found to have severe structural cracks, corrosion of reinforcement. Proper rehabilitation measures need to be taken to rectify the damages.

5. Methodology

5.1 Repair Scheme for Column

The following repairs scheme is adopted for the correction of column:

1. Propping the beams on all the sides of the columns for full vertical height. The props shall be able to take the total load coming on to the column.
2. Chipping open the cover concrete until all the corroded steel rods are and cleaning of rods with brush
3. Chipping the spelled surface of concrete to remove all loose materials. Then brushing it with steel wire brush to remove all loose particles.Washing the surface with potable water.
4. Applying a coat of anticorrosive coating like NITO-ZINCPRIMER manufactured by M/s FOSROC or approved equivalent to all the existing reinforcement.
5. Anchoring new bars by drilling holes in the tie beams for a length of 10 times the diameter of bar.(10XDia of bar)or into the pedestal. Additional bars thus introduced are bonded with the concrete using Hilti chemicals for re-barring. Tie new longitudinal bars using new column ties. The ties have to be anchored into the concrete by drilling holes in the concrete and inserting the ends of the ties into the holes. The depth of drilling shall be such that length of the ties from the center of

new longitudinal bar is 8 times the diameter of tie.

6. Leak proof formwork which should not deform or leak due to pressure of concrete shall be fabricated and erected in position. The formwork should be coated with mould release agent prior to the final fixing in position. Making proper supporting arrangements for keeping the shutter in correct line and length.
7. Encasement using high slump concrete of grade M25 (minimum).It shall be ensured that clear cover to the new steel is 50mm. Curing compound is to used for curing purposes.

5.2 Repair Scheme for Beams

Basic steps involved in the repair of beams are same as that for columns except for the following point.

1. Encasement is done using micro concrete of SIKA/ FOSROC or equivalent approved material with 25% aggregate (washed/cleaned) by weight of size 6.4 mm and down size. The curing has to be done immediately after stripping the formwork.

5.3 Repair Scheme for Slabs

The repair of slabs is also almost the same as that of columns and beams except for the following points:

1. Propping the slab at intervals of say about 1.5 m.
2. Additional bars introduced are anchored to the beam. Additional steel shall be tied to the existing steel or anchored using anchors drilled into the slab.
3. The micro concrete, with 25% aggregate of size 6.4 mm and down is poured by funnels by drilling holes of about 50 mm dia. at 2 m intervals in both directions. The curing has to be done immediately after stripping the formwork. It shall been ensured that clear cover to the new steel is 25 mm.

5.4 Repair Scheme for Tank Dome

1. Cracked or any surface of concrete which is prone to cracks are repaired with polymer modified mortar.

5.5 After the completion of the project the NDT tests will be conducted again to ascertain the quality and strength of aspects improved in the structure.

6 Conclusions

This paper deals with strengthening and enhancement of performance of existing structure. The use of NDT for functional and structural evaluation of a structure is shown. The study of design method of reinforced concrete jacketing for strengthening of structure including design of beams and columns and use of innovative construction materials i.e micro concrete, epoxy grouting and polymer modified mortar is done.

Further scope of work –

1. Detailed economic analysis of the work.

2. Cost- benefit study for the selection of RC jacketing over demolishing and reconstructing a new structure.

3. Studying performance of structure after retrofitting.

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