Model for Repair Urgency in RC Structure using NDT Data

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Abstract

Monitoring of concrete structure like buildings, bridges etc is very essential to ensure safety, stability and serviceability. The structure should, not only being safe, also be functioning as its intended use. Heavy cracking, excessive deflections, corrosion, spalling of concrete, surface stains are main characteristics of the degraded properties of a RC structure. The final goal of condition assessment of a building is to find the urgency of repair, nature of repair and cost associated with repairing. A condition assessment model based on five parameter: Visual inspection, ultrasonic pulse velocity, resistivity of concrete and age factor was prepared. On the basis of above condition index, repair urgency associated with structure was assigned. Prepared model then applied to existing structures.

Keywords: Condition assessment, Degradation of concrete, Non-destructive tests, Repair urgency, Structural health monitoring

I. INTRODUCTION

The reinforced cement concrete has been the first choice to be used as building material, because of its high strength, economy and durability. Reinforced concrete structures have the potential to be durable and capable of withstanding a variety of adverse environmental conditions however premature failure of structure often observed as a result of corrosion of reinforcement due to chloride ingress and carbonation, sulphate attack, cracks due to temperature/moisture fluctuations etc. Assessment of structural characteristics viz. residual Strength of concrete, corrosion etc are used to identify current situation and future durability problem of structure, which is the basic need of maintenance plan. Current durability status of structure helps in prediction of its residual life. This assessment also helps in determining the life cost of structure which includes construction cost, maintenance cost, operational cost etc. By condition assessment, one can decide the repair urgency of RC structure.

II. RELATED WORK

Sasmal et al. [1] explored the possibilities of using fuzzy mathematics for condition assessment and rating of bridges. Author had developed a systematic procedure and formulations for rating existing bridges using fuzzy mathematics. Grigg[2] reports advances in condition assessment for water distribution pipes which can be also applied to transmission, in plant and service pipe line. Author had presented a definition and framework for condition assessment, plan for renewal of pipe and also utility practices in implanting the available method and technology. Bhadauria and Gupta [3] presented a systematic in-situ condition assessment, documentation, survey of water tank structures, which had been done on an empirical damage scale of 0 to 10. Caner et al.[4] had proposed a simple method to assess the remaining service life of a bridge by defining a relationship between its current condition rating and its age by evaluating a set of bridges at different ages. Semaan et al.[5] developed a condition assessment model (subway station diagnosis index). It also utilized both the Preference Ranking Organization method of Enrichment Evaluation and the Multi-attribute Utility Theory to determine the station diagnosis index SDI. Mitra et al. [6] presented a method for obtaining condition index of corrosion distressed RC buildings. Method had been developed using concepts of fuzzy logic and it integrates visual inspection with in situ investigations. Yokota et al.[7] proposed a simplified assessment system of RC member suffered from chloride-induced corrosion as the deterioration grading system (a,b,c,d). To link it to structural performance a total of 30 reinforced concrete slabs extracted from superstructures of open-type wharves aged 30 to 44 years was experimentally load tested to examine the load-carrying capacities after corrosion of reinforcement occurred. Few decades ago the repair prioritization of a RC building was done by combination of visual inspection, knowledge and experience. There is always a need of research to quantify current condition. In above paper few paper are based on fuzzy logic analysis of visual inspection data but only visual inspection data cannot be a parameter for decision making.

III. PROBLEM FORMULATION

As explicit relation between the variety of condition assessment data and the corresponding repair urgency cannot be achieved and also implicit functions are also difficult to develop. Hence a rational formulation for comparison of urgency of repair can be a useful and a consistent tool. A number of factor will be introduce viz. visual inspection, rebound hammer, ultra sonic pulse velocity, resistivity meter and age factor. All arrange in a condition indexing say 0-5 every parameter will be measured as Condition Index.

Table - 1
Proposed condition rating and associated repair priority

Condition Index	Definition based on repair priority scale
0	No requirement of repair
1	Very low priority, repair can be delayed for long time, not urgent
2	Low priority repair, Repair can be delayed for significant time
3	Medium priority repair, Repair action might be required
4	High priority repair, Repair action required urgently
5	Very high priority repair, Condition is critical

IV. MODEL FOR REPAIR URGENCY

Parameters used in condition assessment: Visual inspection, Concrete Strength, Concrete Quality, Concrete resistivity, Actual Life / Estimated service life.

A. Visual Inspection

Rational categorization for visual inspection is done by combining two inputs Rusting/cracks, Delamination/spalling are used on basis of manifestation presented in Mitra et al. [6]:

Table - 2
State of Distress condition

State	Distress condition
Manifestation: 'Rusting/Cracks'	
1	No visible crack on the surface
2	Rusting with some cracks parallel to rebar in one direction
3	Rusting with several cracks parallel to rebar in both directions
4	Rusting with extensive cracks parallel to rebar in both directions
Manifestation: 'Delamination/spalling'	
1	No visible delamination or spalling on the surface
2	Some delamination with no spalling
3	Extensive delamination with considerable spalling
4	Extensive delamination, extensive spalling
5	Extensive delamination, extensive spalling with some broken stirrups and buckled main

Combination of the above visual inspection data gives 1 to 5 Condition Indexing.

Table - 3
Condition State according to Distress Manifestation

Manifestation		Rusting/Cracks			
Delamination/spalling	State	1	2	3	4
	1	1	1	2	3
	2	1	2	3	4
	3	2	3	4	4
	4	3	4	4	5
	5	4	4	5	5

B. Concrete Strength

In situ concrete strength is generally measure by using correlation between rebound number and compressive strength British standard institution [8].

In condition assessment practices, the estimated in situ concrete strength values are checked against acceptance criteria (British standard 2007) is adopted.

$$f_{insitu} \geq 0.85(f_{ck} - 4) \quad \text{........1}$$

Repair action will not be required if the estimated concrete strength value satisfies acceptance criteria by considering Factor of Safety. FOS=1.2(BS 1981).

$$f_{insitu} \geq (0.85X1.2)(f_{ck} - 4) \quad \text{........2}$$

C. Concrete Quality

Concrete quality is generally assessed by measuring ultra-sonic pulse velocity by penetrate it through concrete. International atomic energy agency (IAEA [9]) recommends concrete quality corresponding to different pulse velocity.

D. Deterioration Specific Parameters

Resistivity of concrete: According to CPWD Handbook [10] and IAEA [9], resistivity of concrete and corrosion susceptibility was taken

E. Current Age/ Estimated Service Life

Only carbonation is considered as degradation parameter, following equations may be used to calculate estimated service life. From Sarja & Vesikari [11] Initiation period due to carbonation →

$$t_o = \left(\frac{c}{K_c}\right)^2 \quad \text{......3}$$

t_o = Time of initiation in years; c= Concrete cover (mm) K_c = Carbonation Depth depends on various factors
According to Hakkinen[14]:

$$K_c = c_{env} c_{air} a(f_{ck} + 8)^b \quad \text{......4}$$

c_{env} = environmental coefficient= 1 and 0.5 for structures sheltered from rain and structures exposed to rain respectively; c_{air} = air content coefficient= 1 and 0.7 in non air- entrained and air-entrained concrete, respectively; a and b = 1,800 and −1.7 for Portland cement = 360 and −1.2 for Portland cement +28% fly ash
Propagation time based on cracking of concrete cover:

$$t_1 = 80\frac{c}{Dr} \quad \text{.... .5}$$

where, c = Concrete Cover in mm ; D = Diameter of Bar in mm; r= rate of corrosion of steel in concrete µm/year; According to Firodiya et al. (2015): Average Corrosion rate

Table - 8
Average Corrosion rate (Firodiya et al)

		Reinforcement Bar	
		Mild Steel	Cold Deformed bar
Exposure condition	Wet	5.2 µm/year	7.7 µm/year
	Dry	5.7 µm/year	11.1 µm/year

$$\text{Service Life} = t_o + t_1$$

By estimating approximate service life of RC building, following condition indexing can be assigned to each member.
For combining all condition index of various parameters mean of all has been take

$$\bar{x} = \frac{\sum_1^n w_i x_i}{\sum_1^n w_i} \quad \text{.. ...6}$$

Table - 9
Condition index and upper-lower limit of various parameters

	Visual Inspection		Concrete Strength		Concrete Quality		Concrete Resistivity		Age Factor	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
0	--	1	--	$f_{insitu} \geq 1.02(f_{ck} - 4)$	--	3.50	--	20000	--	0.25
1	1	2	--	--	3.50	3.25	20000	15000	0.25	0.35
2	2	3	--	--	3.25	3.00	15000	10000	0.35	0.45
3	3	4	$f_{insitu} \geq 1.02(f_{ck} - 4)$	$f_{insitu} \geq 0.85(f_{ck} - 4)$	3.00	2.50	10000	5000	0.45	0.55
4	4	5	--	--	2.50	2.00	5000	2500	0.55	0.65
5	5	--	$f_{insitu} \geq 0.85(f_{ck} - 4)$	--	2.00	--	2500	--	0.65	--

V. OBSERVATION AND RESULTS

Above model was applied on existing building, constructed 60 years ago. The USPV is measured by ultrasonic pulse velocity meter, resistivity by concrete resistivity meter, Concrete strength by rebound hammer, age factor by applying specified model of carbonation. On the basis of result Condition index and its normalised values are calculated and same produced in following table. (R= reading)

Table - 10
Observation of survey lab SGSITS Indore

Element ID	Visual Inspection		USPV		Resistivity		Concrete Strength		Age factor		Mean
	R	CI	R	CI	R	CI	R	CI	R	CI	
Column											
C1	4	4	0.99	5	10053.3	2	16.5	0	0.74	4	3.00
C2	3	3	1.65	5	12886.7	2	15.0	0	0.72	4	2.80
C3	5	5	2.09	4	14123.3	4	10.0	3	0.72	4	4.00
C4	4	4	1.69	5	11963.3	2	7.80	5	0.74	4	4.00
C5	3	3	1.49	5	8936.7	3	11.0	3	0.69	4	3.60
C6	2	2	1.47	5	11476.7	2	5.10	5	0.70	4	3.60
C7	2	2	1.01	5	20293.3	0	7.80	5	0.71	4	3.20
C8	4	4	0.90	5	12836.7	2	7.80	5	0.79	4	4.00
C9	5	5	1.27	5	14163.3	2	12.5	0	0.77	4	3.20
C10	3	3	1.41	5	19650.0	1	10.0	3	0.80	4	3.20
C11	4	4	1.66	5	19343.3	1	13.2	0	0.73	4	2.80
C12	5	5	1.86	5	23533.3	0	16.5	0	0.69	4	2.80
Beam											
B1	4	4	2.48	4	15370.0	1	12.5	0	0.65	4	2.60
B2	4	4	2.33	4	16573.3	1	13.2	0	0.67	4	2.60
Slab											
A1	4	4	2.18	4	36300.0	0	6.80	5	1.11	5	3.60
A2	4	4	1.49	5	20300.0	0	8.80	5	0.95	5	3.80
A3	5	5	1.70	5	16133.3	1	11.1	3	1.33	5	3.80
B1	3	3	2.35	4	23676.7	0	10.0	3	1.09	5	3.00
B2	3	3	2.38	4	17633.3	1	8.80	5	1.20	5	3.60
B3	2	2	1.69	5	17400.0	1	13.2	0	1.02	5	2.60
C1	2	2	2.93	3	32900.0	1	11.1	3	1.20	5	2.80
C2	4	4	1.84	5	20166.7	0	12.5	0	1.14	5	2.80
C3	5	5	1.91	5	20200.0	0	13.2	0	0.95	5	3.00
D1	3	3	1.55	5	35100.0	0	7.80	5	0.87	5	3.60
D2	4	4	2.56	3	17800.0	1	7.80	5	1.04	5	3.60
D3	3	3	1.95	5	17000.0	1	11.1	3	0.82	4	3.20
E2	5	5	2.33	4	36300.0	0	7.80	5	1.17	5	3.80
E3	4	4	2.73	3	15233.3	1	11.1	3	1.11	5	3.20

In slab total 14 points were chosen for test and on each point three readings were taken. In above table readings are the average reading of observations taken. So, from above values and study, condition index of Survey lab = 3.28, hence its repair urgency lies in high priority repair.

VI. CONCLUSION

A condition assessment model based on five parameter: Visual inspection, ultrasonic pulse velocity, resistivity of concrete and age factor. Condition index for each parameter had been developed on basis of standard given in various research and departmental guidelines. The produced model is applied on existing building and its repair priority was found to be High Priority.

REFERENCES

[1] Sasmal S, Ramanjaneyulu K., Gopalakrishnan S and Lakshmanan N. (2006) "Fuzzy Logic Based Condition Rating of Existing Reinforced Concrete Bridges ",Journal of Performance of Constructed Facilities Vol. 20, No. 3, 261–273
[2] Grigg N (2006), "Condition Assessment of Water Distribution pipe", Journal of infrastructure System © ASCE 12(3)/ September 2006, 147-153
[3] Bhadauria S and Gupta M (2006), "In- Service Durability Performance of Water Tanks", Journal of Performance of Constructed Facilities © ASCE 20.(2) / May2006
[4] Caner A, Yanmaz A., Yakut A, Avsar O and Yilmaz T (2008). "Service Life Assessment of Existing Highway Bridges with No Planner Regular Inspections." Journal of Performance of Constructed Facilities © ASCE, 22(2)/March- April 2008, 108-114
[5] Semaan N and Zayed T(2009) "Subway Station Diagnosis Index Condition Assessment Model", Journal of Infrastructure System © ASCE 15(3)/ September 2009, 222-231
[6] Mitra G, Jain K and Bhatacharjee B (2010) "Condition Assessment Of Corrosion Distressed Reinforced Concrete Buildings Using Fuzzy Logic" Journal of Performance of Constructed Facilities © ASCE 24(6)/ November 2010, 562-570.
[7] Yokota H., Kato E. & Iwanami M. (2010) "Simplified members assessment on structural performance of deteriorated concrete" Proceedings of FraMCoS-7, May 23-28, 2010, 274-279
[8] British Standards Institution (2007). "Assessment of in-situ compressive strength in structures and precast concrete components", BS EN 13791, London
[9] International Atomic Energy Agency (IAEA) (2002) "Guidebook on non-destructive testing of concrete structures", Training course series no.17, IAEA-TCS-17, Vienna, Austria
[10] Central Public Work Department (CPWD)(2002) "Handbook on repair and rehabilitation of RCC buildings, Government of India , New Delhi, India
[11] Sarja A and Vesikari E (1996) "Durability design of concrete structures", Report of RILEM technical Committee 130-CSE, ISBN 0419214100
[12] Payal K. Firodiya, Amlan K. Sengupta and Radhakrishna G. Pillai (2014) "Evaluation of Corrosion Rates of Reinforcing Bars for Probabilistic Assessment of Existing Road Bridge Girders"