STRUCTURAL HEALTH MONITORING OF REINFORCED CEMENT CONCRETE STRUCTURE USING NDT TECHNIQUES

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ABSTRACT

History of construction area shows that not only engineered structures but non engineered structures are also susceptible during its life span, hence there is need to check structural health of a structures periodically with proper investigation. As far as structural health monitoring is concern, old as well as newly constructed structures are also need to monitor. In this research case study was carried out and investigate different elevated storage tank located in Amravati region. Amravati district is located between 21º46` N to 20º32` N and 78º27` E to 76º37` E, which essentially indicates that Amravati district is in the Deccan Plateau. This region faces extreme variations in temperature with very hot summers and very cold winters. After a structural health monitoring of eight ESRs located in Amravati region it is concluded that ESR located at Nimbi need to be retrofitted by applying different strengthening/retrofitting measures.

INTRODUCTION

Nowadays, Reinforced cement concrete (RCC) used as a construction material frequently. In India, RCC has been used extensively from the last 50-60 years. During this period, large number of infrastructures were created in terms of buildings, bridges, water tanks, sports stadium, etc., which are lifeline for the civilized society. These were created with huge investment of resources. It is hard to even dream of recreating such assets out of limited national resources. It is therefore, essential to maintain them in functional condition. Since, deterioration of RCC is a natural phenomenon and has started exhibiting in large number of structures. Past experiences shows that concrete structures requires a closer inspection, not only immediately after construction but periodically at a regular interval for maintenance.

A long service life is considered synonymous with durability. Since durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. Durability is the ability of the structure to maintain its level of reliability and serviceability during its lifetime. That is, durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

ESR's are large elevated water storage container constructed for water storage purpose at a height, sufficient to pressurize a water distribution system. Elevated storage tank constructed with a RCC and Steel material. Generally, ESR is constructed in RCC material because it is economical than steel ESR's. RCC ESR's undergoes deterioration due to corrosion of reinforcement, chloride diffusion, carbonation, sulphate attack, alkali aggregate reaction, freezing and thawing etc. which may lead failure of RCC ESR's. It affects directly and indirectly to the national economy.

Fig. 1. Elevated Storage Reservoir

This research concentrated on the Structural Health Monitoring of RCC ESR's located in Amravati region. Amravati district is located between 21º46` N to 20º32` N and 78º27` E to 76º37` E, which essentially indicates that Amravati district is in the Deccan Plateau. This region faces extreme variations in temperature with very hot summers and very cold winters. The maximum recorded temperature till date was 47 degree celsius in the year 1995. The minimum recorded temperature of 4 degree Celsius was in the year 1994.

LITERATURE REVIEW:

An exhaustive literature survey was carried out to study enhancement in the area of structural health monitoring of structures and presented below

Sudhir Singh Bhadauria and Dr. Mahesh Chandra Gupta[1] in their paper entitled "In-Service Durability Performance of Water Tanks" a systematic in situ condition documentation, survey, and assessment of water tank structures has been done based on an empirical damage scale similar to that suggested in the literature and a bilinear graphical deterioration model for such water retaining structures in a semitropical region like India is presented on the basis of case studies.

Sudhir Singh Bhadauria and Dr. Mahesh Chandra Gupta[2] their paper entitled 'In Situ Performance Testing of Deteriorating Water Tanks for Structural Health Monitoring' presented a case study of deteriorated water tank structures situated in the semitropical region of India is presented. Some selected parameters-such as concrete cover, carbonation depth, chloride concentration, compressive strength, etc. which influence long term durability of structures.

A S. Bhaskar, P. Srinivasan and. Chellappan[3] in there paper entitled 'Condition Assessment of 30 Years Old Overhead RCC Reservoir' they have highlighted the importance and significance of different test methods employed to assess the present condition of RCC structure. A rational and systematic approach for the interpretation of test results based on NDT and PDT is presented for arriving at an economical repair procedure and rehabilitation measures.

Jahangir M. Abdoveis[4] in his paper entitled 'An Examination of Concrete Durability' provides a comprehensive guide to various types of concrete degradation and the mechanics involved with each type of degradation. For each type of the degradation, mechanism discussed , several methods of designing concrete structural members, using only minor alteration in the concrete member, to resist degradation are also provided in this paper.

Jahangir M. Abdoveis[5] in his thesis entitled 'An Examination of Concrete Durability' provides a comprehensive guide to various types of concrete degradation and the mechanics involved with type of degradation. For each type of the degradation mechanism discussed, several methods of designing concrete structural members , using only minor alterations in the concrete members, to resist degradation are provided in this paper.

Somnuk Tangtermsirikul[6] in his paper entitled 'Durability Problems of Concrete Structures in Thailand and Their Solutions' introduces some problems on deterioration of concrete structures in Thailand and some concepts on their future solutions. construction and maintenance are illustrated. Solutions were offered in two categories i.e. that for new construction and that for the existing structures.

Yu-Pu Song,, Li-Yuan Song, and Guo-Fan Zhao[7] in their paper entitled 'Factors affecting Corrosion and Approaches for Improving Durability of Ocean Reinforced Concrete Structures' presents discussion of the corrosion characteristics for ocean reinforced concrete structures along China's coast, based on real project cases and field surveys. Based on the analysis of these corrosion characteristics and affecting factors, the approaches available to improve the durability of ocean R.C. structures are proposed.

Nicholas J. Carino[8] in his paper entitled 'Nondestructive Techniques to Investigate Corrosion Status in Concrete Structures' provides an overview of the corrosion of steel in concrete and presents some nondestructive electrochemical tools that are commonly used in corrosion investigation. The objective of this paper is to provide the repair specialist with basic information to allow effective communication with corrosion engineer. Electrochemical principles involved in the corrosion of steel in concrete are reviewed.

Nicholas J. Carino[9] in his paper entitled 'Nondestructive test methods to evaluate concrete structures' has discussed about instruments, their working principle, Data collection, processing of test results, advantages and disadvantages of corresponding test methods.Nicholas J. Carino[10] in his paper entitled 'Non Destructive Testing of Concrete: History and Challenges' presented a brief review of nondestructive testing of hardened concrete over the past 50 years. This paper also discusses about the challenges for 21st century in the area of non- destructive testing.

Brandes, Lay, and Rucker[11] in their paper entitled 'Measuring Principle of CANIN-Fundamentals for an Optimum Interpretation' they have explained the fundamentals of steel corrosion in concrete, the principle of potential field measurements and the influences that have to be considered for an optimum interpretation of the test results.

Mereoni M. B. Bola[12] in his paper entitled 'Field Evaluation of Corrosion in Reinforced Concrete Structures in Marine Environment' selected eight sites for field evaluation in cooperation with the Harbors Division of the Hawaii Department of Transportation. Seven of the sites used a calcium nitrite based admixture as a corrosion inhibitor. The eighth site used epoxy coated reinforcing steel to combat corrosion.

Ping Gu and J.J. Beaudoin[13] in there paper entitled 'Obtaining Effective Half-Cell Potential Measurements in Reinforced Concrete Structures' they have explained how various factors can affect the reliability of the data obtained.

Shamsad Ahmad[14] in his paper entitled 'Reinforcement corrosion in concrete structures, its monitoring and service life prediction—a review' has discussed causes corrosion, mainly when the rebar in the concrete is exposed to the chlorides or carbonation, assessment of the causes and extent of corrosion is carried out using various electrochemical techniques and presented various models for service life prediction of reinforced concrete structures.

Cawangan Kejuruteraan Awam and Struktur dan Jambatan[15] in their paper entitled 'Testing of Hardened Concrete' they have provided a simple and easy to understand reference for various hardened concrete tests such as Ultrasonic Pulse Velocity Test, Carbonation Test, Rebound Hammer test and Half-cell Potential test.

METHODOLOGY:

Structural Health Monitoring is the process of collecting and evaluating the information about the durability of structure. A comprehensive assessment of damage also helps in prediction of future performance of the structure. The Structural Health Monitoring of RCC ESR's includes the evaluation of causes of damage, degree of damage, amount of damage and expected progress of damage with time and effect of damage on structural behaviors. For this Structural Health Monitoring of structure using different NDT method and several techniques are now available for investigation of reinforced concrete structure. This project deals with systematic methodology to carry out durability assessment of RCC ESR's located at Nimbhi, Amravati by using some NDT methods. The IS specifications for some NDT methods are also explained and provisions of guidelines for interpretation of results are also discussed.

STRUCTURAL HEALTH MONITORING

Structural Health Monitoring is an examination of concrete for the purpose of identifying a defining area of distress. While it is referred in connection with assessment of concrete and embedded reinforcement that is showing some degree of distress, its application is recommended for all build RCC structures. The system is designed to be used for recording the history of the project from its inception to completion and subsequent life.

Fig:2 Photograph of structural health monitoring

NON-DESTRUCTIVE TECHNIQUES

Assessing the durability of concrete has become an important function of engineer's responsibility for maintaining concrete structures. Structural Health Monitoring of concrete structure is the process of collecting and evaluating the information about the condition of concrete structure. Depends both on the resistance of the concrete against physical or chemical attack and on its ability to protect steel bars against corrosion. Concrete is a popular material in civil engineering, because it is economical, easy to shape and to produce. However, due to poor making, casting and curing and environmental loads which are not considered in design phase of concrete structures, repair may be needed after just few years of service. Due to deterioration of concrete, many concrete structures get failed. The purpose of durability-based design is to increase the probability of achieving the intended service life for reinforced concrete structures. For determining and evaluating factors which is affecting durability of ESR's non destructive testing methods can be used.

Non-destructive testing is testing which perform on hardened concrete without destroying them. Recently, individuals and organizations have shown considerable interest in the use of NDT for assessing the performance of wood members in structures. Non-destructive materials evaluation is the science of identifying physical and mechanical properties of a piece of material without altering its end-use capabilities. Such evaluations rely upon non-destructive testing techniques to provide accurate information pertaining to the properties, performance, or condition of the material in question. This need is expanding because an increasing number of resources are being devoted to repair and rehabilitation of existing structures rather than to new construction.

Fig:3 Photograph of non-destructive test

RESULTS AND DISCUSSION

This research describes the systematic visual inspection of various RCC ESR's along with photographs and interpretation of results of various non-destructive tests such as rebound hammer, half-cell measurements and rebar locator. Chemical tests of concrete samples were carried out to determine the pH, depth of carbonation and chloride content of concrete. This chapter also presents and describes detailed investigation of RCC ESRs at Nimbhi. The tests were carried out at columns, braces, dome periphery, dome slab and balcony of RCC ESR's. The results of rebound hammer, carbonation depth and pH were presented in tabular form while the results of corrosion analyzer and profometer were presented in graphical form. Data interpretation was carried out in accordance with various reference codes.

Case study 1- Structural Health Monitoring of RCC ESR at Nimbhi

Salient features

a) Period of construction : 1983-84
b) Investigation done : 2022
c) Location : At. Nimbhi. Tah. Morshi.
d) Owned and maintained : Grampanchayata, Nimbhi
e) Total period of use : 38 yrs.
f) Is water tank under use? : Yes
g) Capacity : 30,000 liters
h) Staging height : 9.7 m
i) Column Shape : Circular
j) Number of column : 4 Nos
k) Bracing levels : Three stage
l) Structure/Geometry of tank: Tank with top spherical dome, cylindrical/ vertical wall, conical dome and bottom spherical.
m) Is the tank being maintained? : Maintenance of ESR done rarely

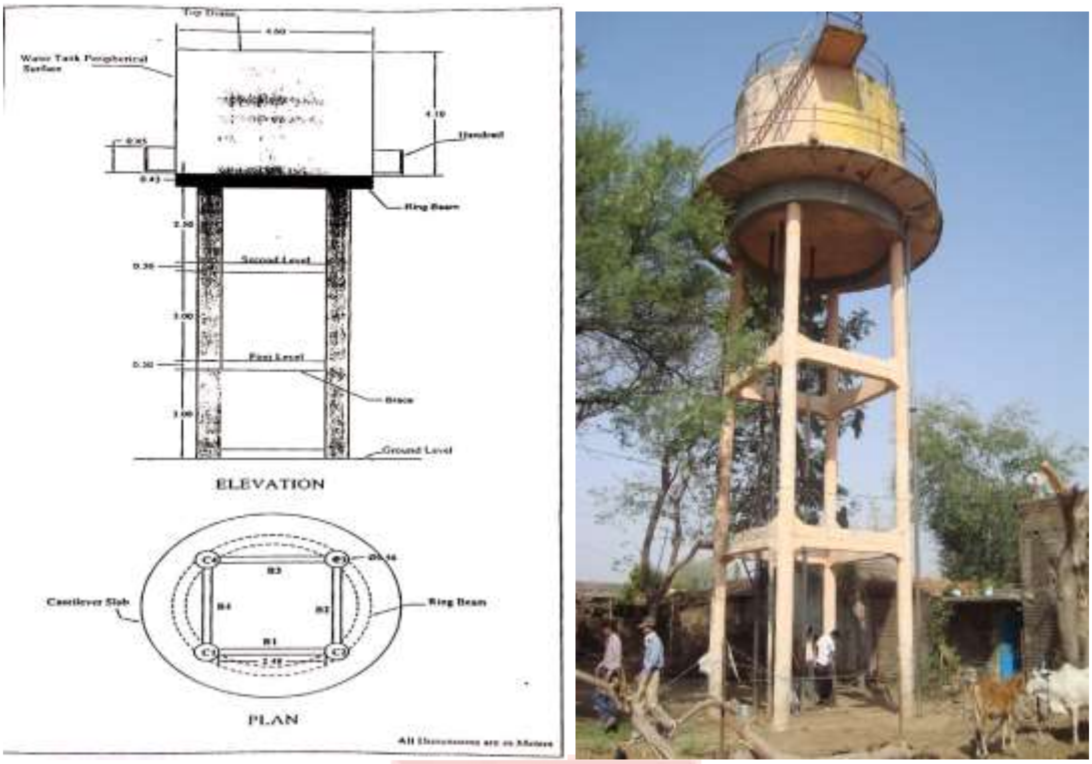

Fig. 4 Plan elevation and dimensional details of RCC ESR at Nimbhi

Table 1 Rebound hammer test results for reinforced concrete ESR

Sr. no.	Test surface location		Angle / direction of test	No. of readings	Mean rebound number (RN) value	Min. RN value	Max. RN value	Standard deviation	Coefficient of variation %	Comp. Strength N/mm2
1	Column C1	GL Bb- 1st Bb	0º Horizontal	9[31,33,39,32,41,36,30,37,40]	35.444	30	41	4.08	11.51	34.2
		1st Bb- 2nd Bb	0º Horizontal	9[29,31,29,33,34,34,39,41,42]	34.67	29	42	4.64	13.38	34
		2nd Bb – Ring Beam	0º Horizontal	9[33,35,35,39,41,43,31,30,29]	35.11	29	41	4.52	12.89	34.8
2	Column C2	GL Bb- 1st Bb	0º Horizontal	9[29,33,34,31,31,36,38,39,41]	34.66	29	41	4.08	11.08	34.9
		1st Bb- 2nd Bb	0º Horizontal	9[24,26,27,27,35,31,33,32,25]	28..88	24	35	3.91	13.56	24
		2nd Bb – Ring Beam	0º Horizontal	9[29,29,27,28,35,35,33,31,32]	31	27	35	2.95	9.54	28
3		GL Bb- 1st Bb	0º Horizontal	9[37,33,31,30,31,39,32,32,40]	33.88	30	40	3.75	11.08	31

	Column C3	1st Bb- 2nd Bb	0^o Horizontal	9[41,41,37,36,35,34,31,32,30]	35.22	30	41	3.99	11.33	35
		2nd Bb – Ring Beam	0^o Horizontal	9[29,33,33,32,37,31,39,40,30]	33.78	29	40	3.96	11.71	32
4	Column C4	GL Bb- 1st Bb	0^o Horizontal	9[39,36,36,31,32,30,40,41,33]	35.33	31	41	4.06	11.50	35
		1st Bb- 2nd Bb	0^o Horizontal	9[22,21,21,27,24,29,28,28,30]	25.56	21	30	3.57	13.98	20
		2nd Bb – Ring Beam	0^o Horizontal	9[35,33,33,29,29,25,27,27,31]	29.88	25	35	3.33	11.15	36
5	Brace Beam B2	GL	Vertically Down	9[37,39,39,32,32,31,43,41,29]	35.88	29	43	4.98	13.89	36
		1st level	Vertically Down	9[29,29,33,31,30,35,34,35,28]	31.55	29	35	2.74	8.69	28.8
			0^o Horizontal	9[31,33,33,27,25,28,22,29,32]	29.22	22	33	3.19	10.92	24
		2nd level	Vertically Down	9[31,32,33,33,30,29,28,35,31]	31.33	28	35	2.17	6.95	28
			0^o Horizontal	9[33,27,25,33,31,26,29,32,31]	29.67	25	33	3.04	10.25	26
6	Top dome		Vertically Downward	24[30,19,25,20,27,28,34,40,32,35,34,30,29,28,20,21,28,30,35,41,33,38,22,24]	29.29	19	38	6.31	21.55	26
7	Water tank peripherical surface		0^o Horizontal	40[30,35,34,40,35,36,38,39,32,33,34,,36,37,40,40,32,30,40,29,29,41,40,41,33,31,35,36,31,32,33,28,33,32,33,39,40,36,38,31,30]	35.3	29	41	3.71	11.98	34

Discussions on the results of rebound hammer test are made as below,

a) The compressive strength values determined for columns are in the range of 20 N/mm2 to 36 N/mm2. And the standard deviation and coefficient of variation for few location were obtained these results shows that the columns are in good condition.

b) The compressive strength of columns between G.L-1st Brace Beam is 35 N/mm^2 and 31 N/mm^2 respectively. This is an indicative of good hard surface layer of concrete in lower columns.

c) The compressive strength values determined for brace beam are in the range of 24 N/mm^2 to 40 N/mm^2 which indicates that surface of concrete layer is hard.

d) Rebound hammer tests on water tank container indicate that its compressive strength 34 N/mm^2. Compressive strength indicates very hard and good concrete surface of the container.

e) The original concrete mix or grade is not known. Assuming minimum grade of M20, the compressive strength values obtained from rebound hammer tests are on higher side as compared to original, might be because of carbonation to concrete test surface is high.

REBAR LOCATOR

This section deals with the results obtained from the rebar locator test on various elements of RCC ESR at Nimbhi.

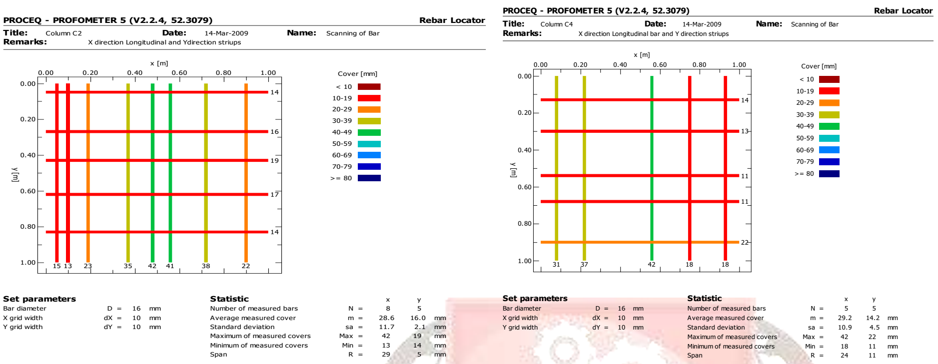

Fig. 5 Details of reinforcement in column C2 & C4

Fig 6 Variation in concrete cover of column C2

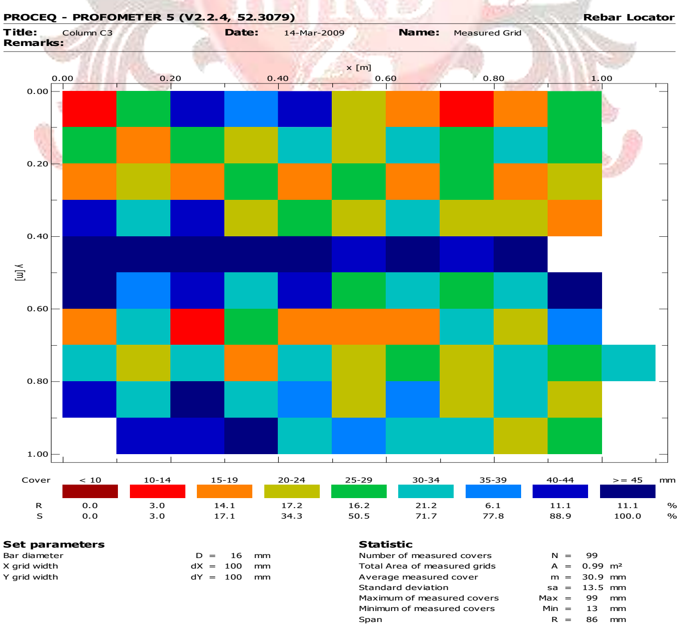

Fig. 7 Variation in concrete of cover column C3

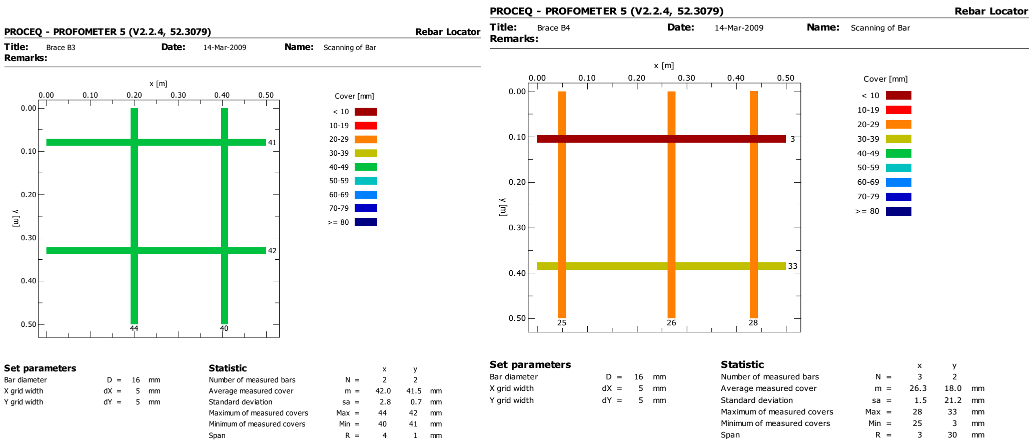

Fig. 8 Details of reinforcement in brace beam B3 & B4

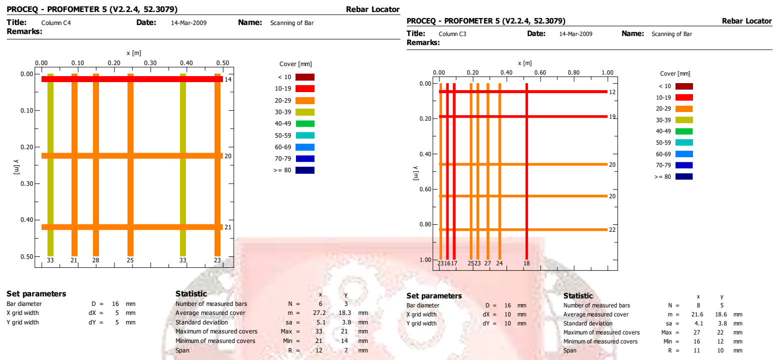

Fig. 9 Details of reinforcement in column C4 (first floor) ESR & C3 (first floor)

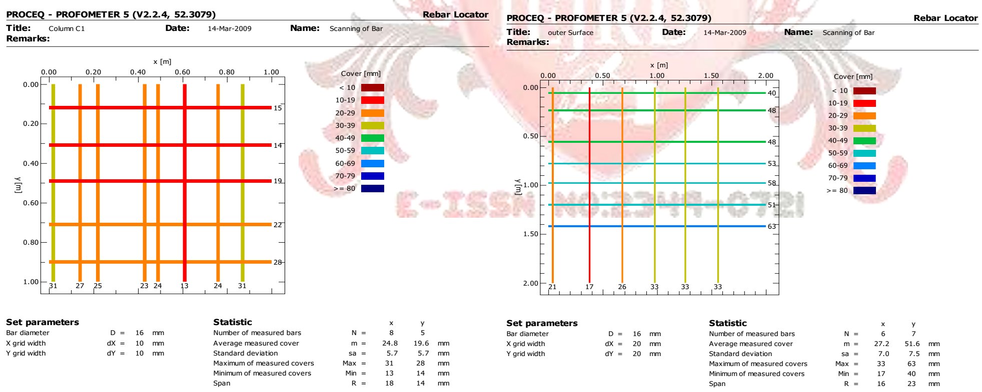

Fig. 10 Details of reinforcement in column C1 (first floor) & water tank container

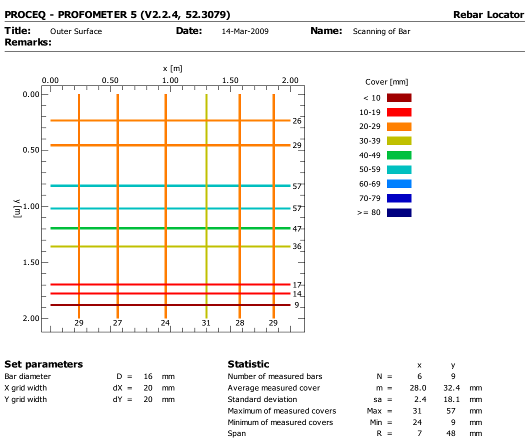

Fig. 11 Details reinforcement of water tank container

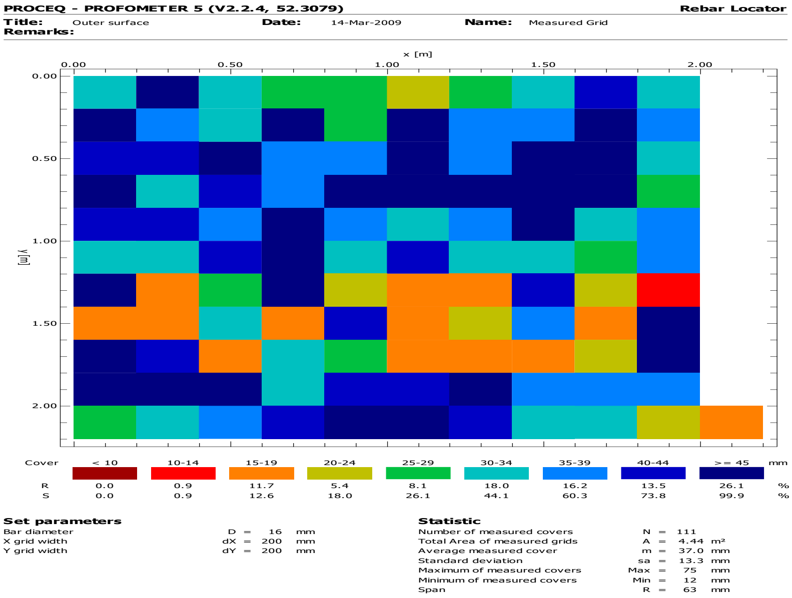

Fig. 12 Variation in concrete of cover of water tank container

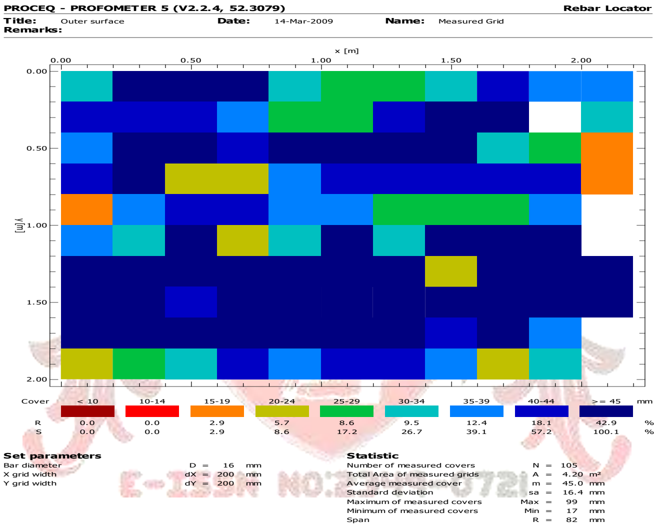

Fig. 13 Variation in concrete of cover water tank container

Discussions on the results of half cell potential test are made as below.

a) The profometer rebar locator test on column C2 (ground level) gives average concrete cover along X - direction 28.6 mm and along Y- direction 16.0 mm. This cover is poor as an actual requirement.

b) The profometer rebar locator test on Column C4 gives average concrete cover along X direction 29.2 mm and along Y- direction 14.2 mm. This cover is poor as an actual requirement. The profometer rebar locator test on column C3 measured with grid gives average concrete cover of 30.9 mm. This cover is less than actual requirement.

c) The profometer rebar locator test on column C4 measured with grid gives average concrete cover of 38.9 mm. This cover is sufficient than actual requirement.

d) The profometer rebar locator test on Brace B4 gives average concrete cover along X -direction 26.3 mm and along Y -direction 18mm. This cover is poor as an actual requirement.

e) The profometer rebar locator test on Brace B3 gives average concrete cover along X- direction 42.0 mm and along Y- direction 41.5 mm. This cover is sufficient as an actual requirement.

f) The profometer rebar locator test on column C4 (first floor) gives average concrete cover along X - direction 27.2 mm and along Y- direction 18.3 mm. This cover is poor as an actual requirement.

g) The profometer rebar locator test on Column C3 (first floor) gives average concrete cover along X- direction 21.6 mm and along Y -direction 18.6 mm. This cover is poor as an actual requirement.The profometer rebar locator test on column C1(first floor) gives average concrete cover along X -direction 24.8 mm and along Y -direction 19.6 mm.. This cover is poor as an actual requirement

h) The profometer rebar locator test Water tank container gives average concrete cover along X- direction 27.2 mm and along Y- direction 51.6 mm. This cover is sufficient as an actual requirement.

i) The profometer rebar locator test Water tank container gives average concrete cover along X- direction 28.0 mm and along Y -direction 38.3 mm. This cover is less than actual requirement. The profometer rebar locator test on Water tank container measured with grid gives average concrete cover of 37.0 mm. This cover is less than actual requirement.

j) The profometer rebar locator test on Water tank container measured with grid gives average concrete cover of 45.0 mm. This cover is sufficient than actual requirement.

Profometer rebar locator test results indicate average concrete cover thickness values of concrete in G.L. column is 28.9 and 15.1 mm, First floor columns are 25.53 and 28.25 mm and brace beam are 34.15 and 29.75 mm respectively and columns shows variation in cover thickness ranging from 30 mm to 50 mm. These cover values are on lower side than actual requirement. This ultimately leads to corrosion of reinforcement.

CORROSION ANALYZER

The results of corrosion analyser are interpreted as per recommendations of ASTM C786. The results of half cell measurement are as below.

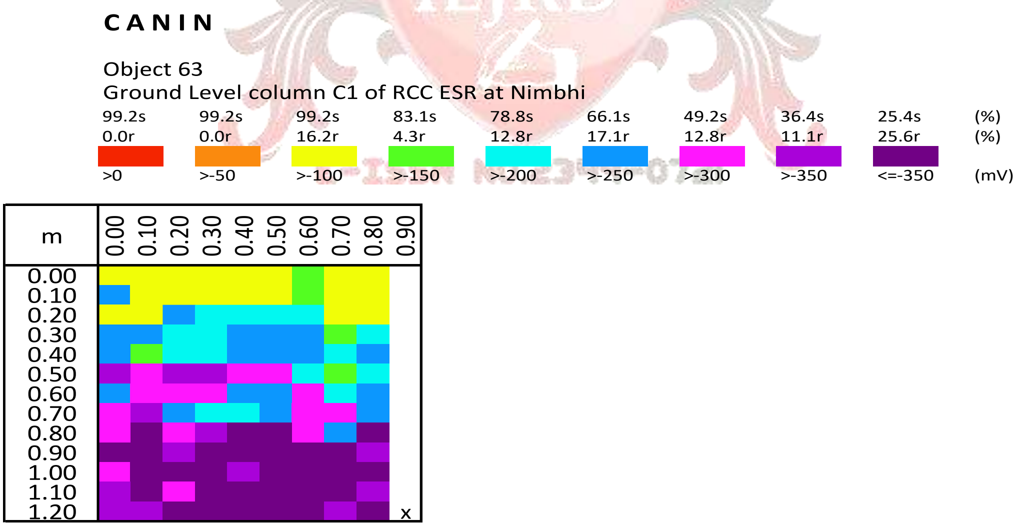

Fig. 14 Corrosion mapping of ground level column C1

Table 2 Interpretation of corrosion mapping of column C1

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	24%	90% probability of no corrosion
-200 to -350 mV	45%	50% probability of corrosion
More than -350 mV	31%	95% probability of corrosion

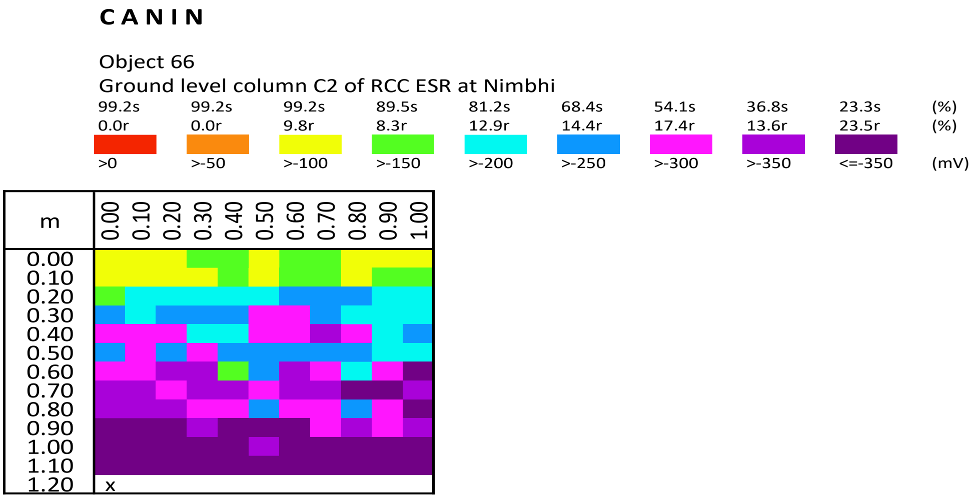

Fig. 15 Corrosion mapping of ground level column C2

Table 3 Interpretation of corrosion mapping of column C2

Electric potential	Reading (in %)	Corrosion activity
Less than -200 mV	17%	90% probability of no corrosion
-200 to -350 mV	62%	50% probability of corrosion
More than -350 mV	21%	95% probability of corrosion

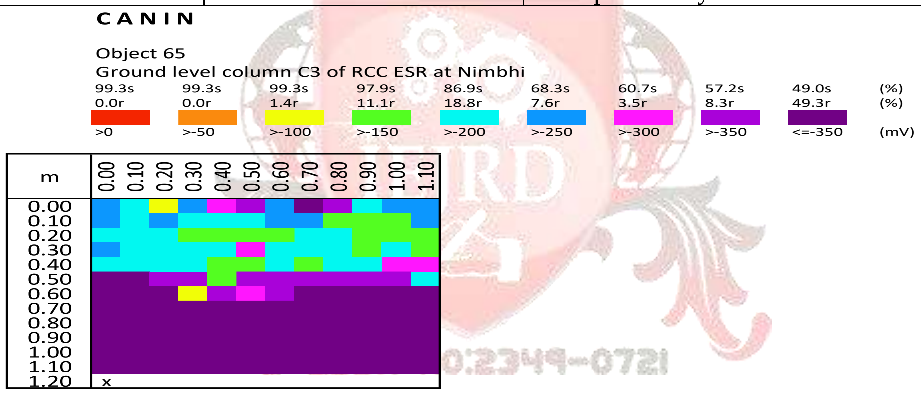

Fig. 16 Corrosion mapping of ground level column C3

Table 4 Interpretation of corrosion mapping of column C3

Electric potential	Reading (in %)	Corrosion activity
Less than -200 mV	14%	90% probability of no corrosion
-200 to -350 mV	37%	50% probability of corrosion
More than -350 mV	49%	95% probability of corrosion

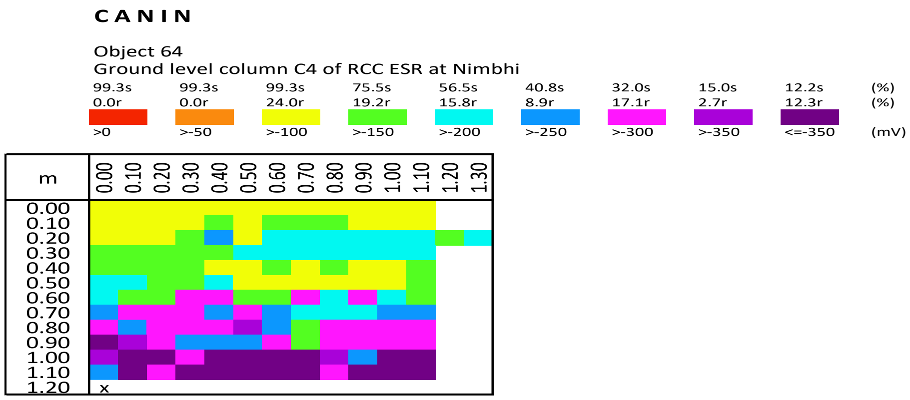

Fig. 17 Corrosion mapping of ground level column C4

Table 5 Interpretation of corrosion mapping of column C4

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	51%	90% probability of no corrosion
-200 to -350 mV	35%	50% probability of corrosion
More than -350 mV	15%	95% probability of corrosion

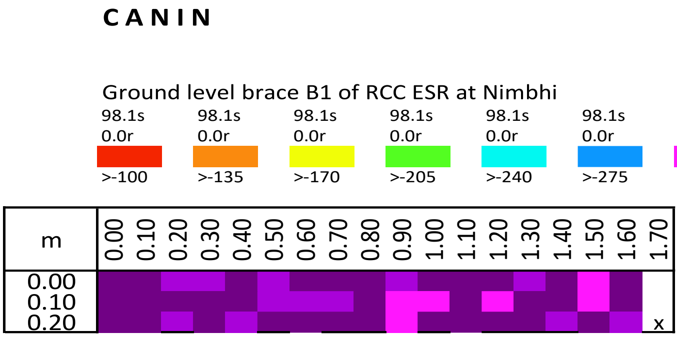

Fig. 18 Corrosion mapping of ground level brace B1

Table 6 Interpretation of corrosion mapping of brace B1

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	0%	90% probability of no corrosion
-200 to -350 mV	35%	50% probability of corrosion
More than -350 mV	65%	95% probability of corrosion

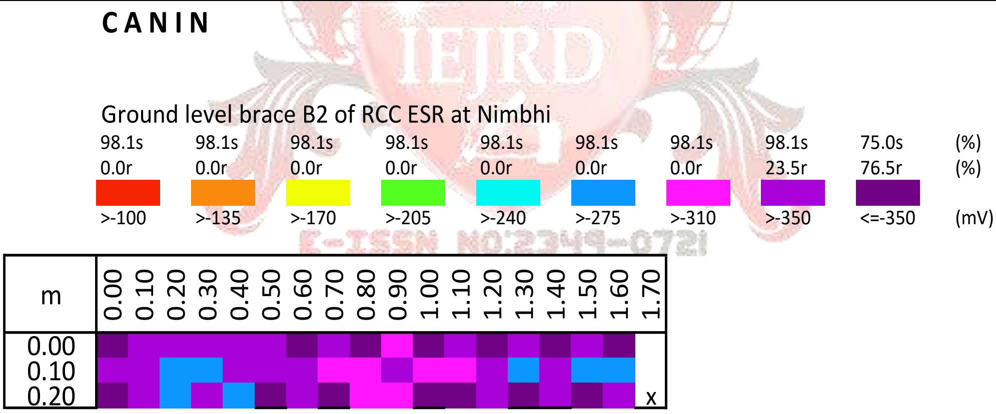

Fig. 19 Corrosion mapping of ground level brace B2

Table 7 Interpretation of corrosion mapping of brace B2

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	0%	90% probability of no corrosion
-200 to -350 mV	29%	50% probability of corrosion
More than -350 mV	71%	95% probability of corrosion

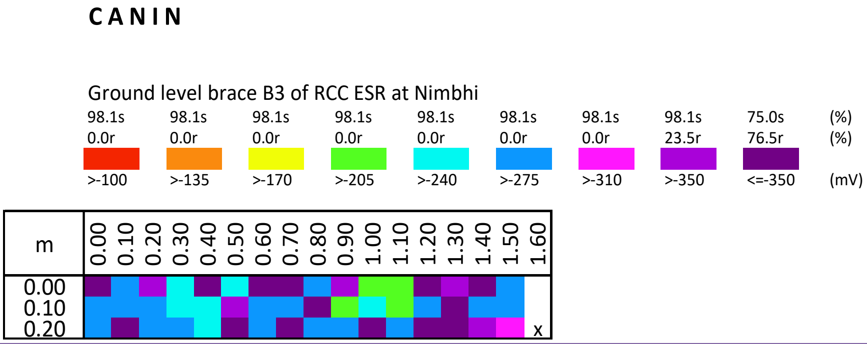

Fig. 20 Corrosion mapping of ground level brace B3

Table 8 Interpretation of corrosion mapping of brace B3

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	8%	90% probability of no corrosion
-200 to -350 mV	52%	50% probability of corrosion
More than -350 mV	40%	95% probability of corrosion

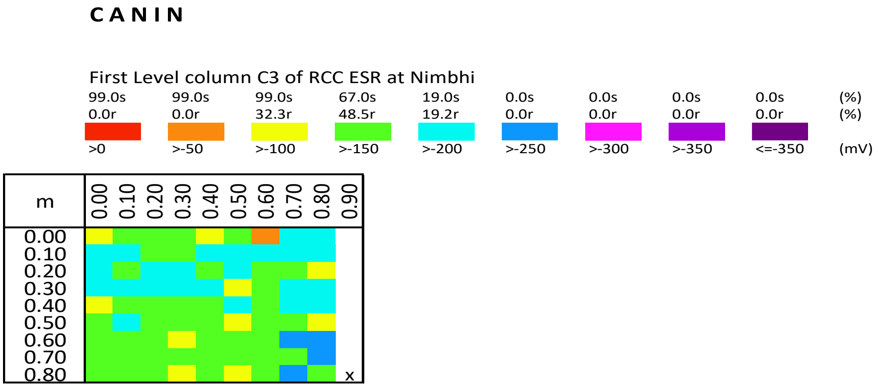

Fig. 21 Corrosion mapping of first level column C3

Table 9 Interpretation of corrosion mapping of Column C3

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	47%	90% probability of no corrosion
-200 to -350 mV	53%	50% probability of corrosion
More than -350 mV	0%	95% probability of corrosion

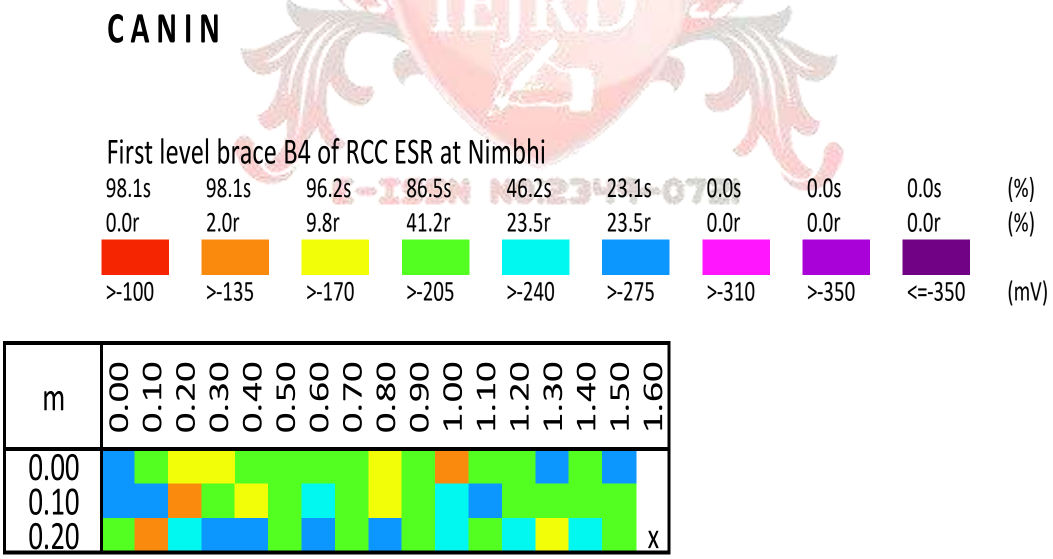

Fig. 21 Corrosion mapping of first level brace B4

Table 10 Interpretation of corrosion mapping of brace B4

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	57%	90% probability of no corrosion
-200 to -350 mV	43%	50% probability of corrosion
More than -350 mV	0%	95% probability of corrosion

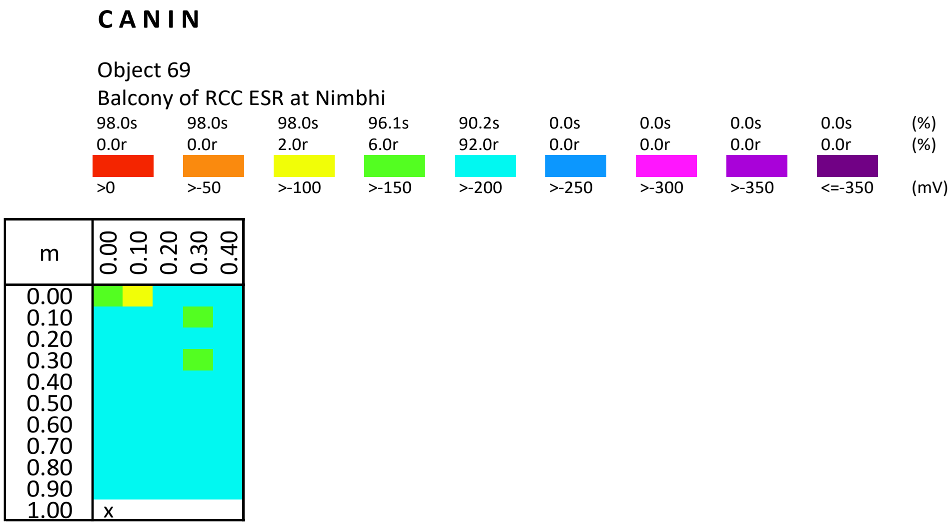

Fig. 22 Corrosion mapping of balcony of RCC ESR.

Table 11 Interpretation of corrosion mapping of balcony of RCC ESR

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	08%	90% probability of no corrosion
-200 to -350 mV	92%	50% probability of corrosion
More than -350 mV	0%	95% probability of corrosion

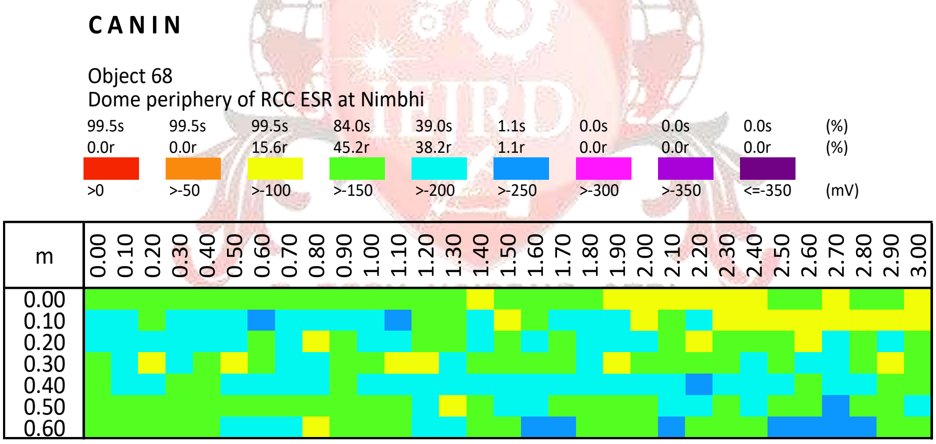

Fig. 23 Corrosion mapping of dome periphery

Table 12 Interpretation of corrosion mapping of periphery of RCC ESR

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	59%	90% probability of no corrosion
-200 to -350 mV	41%	50% probability of corrosion
More than -350 mV	0%	95% probability of corrosion

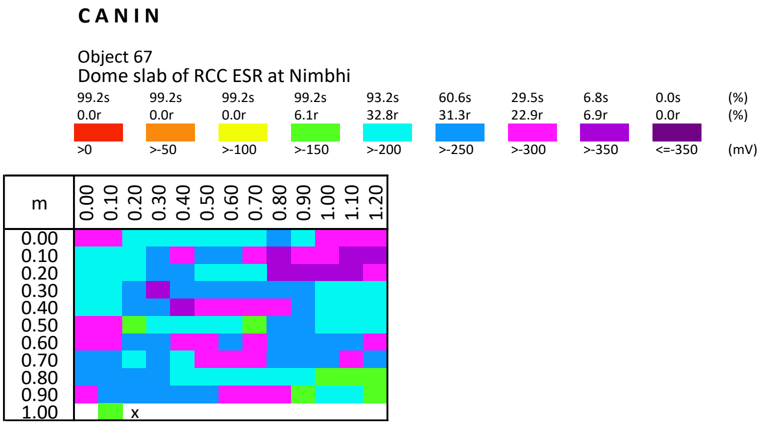

Fig. 24 Corrosion mapping of dome slab

Table 13 Interpretation of corrosion mapping of slab of RCC ESR

Electric potential	No of Reading (in %)	Corrosion activity
Less than -200 mV	04%	90% probability of no corrosion
-200 to -350 mV	96%	50% probability of corrosion
More than -350 mV	0%	95% probability of corrosion

Carbonation test

Carbonation test was conducted and results were interpretation of carbonation test as per the guidelines mentioned in chapter 3. The results of carbonation test are as shown in table.14

Table 14 Results of Carbonation test

Sr. no.	Member / element	Whether colour changes to pink / violate red	Remarks
1	First level brace beam 2-3-4	Colorless	Carbonation
2	G.L. brace beam 1-3-4	Colorless	Carbonation
3	G.L. column 1	Colorless	Carbonation
4	G.L. column 2	Colorless	Carbonation
5	G.L. column 3	Colorless	Carbonation
6	G.L. column 4	Colorless	Carbonation
7	Water container Outer surface	Colorless	Carbonation

PH Test

The data of pH test was conducted and interpreted as per guidelines. The pH test is as shown in table 15

Table 15 Results of pH test

Sr. no.	Member / element	P^H Value	Remark
1	First level brace beam 2-3-4	9	Moderate
2	G.L. brace beam 1-3-4	8	High
3	G.L. column 1	9	Moderate
4	G.L. column 2	10	Moderate
6	G.L. column 4	7	High
7	Water container Outer surface	10	Moderate

Chloride content test

The interpretations of the results of chloride content test are as shown in table 16.

Table 16 interpretation of the results of chloride content test

Sr. no.	location of sample	Chloride content (Kg/m^3)	Chloride content in % of sample	Corrosion risk
1	C4	0.752	0.0376	High
2	B2	0.622	0.0311	High

CONCLUSION

This research deals with detailed systematic methodology in conducting the Structural Health Monitoring of RCC ESR's in Amravati region using non-destructive testing techniques. Research demonstrates detailed systematic Structural Health Monitoring of RCC ESR's at Nimbhi (Case Study). The durability of these RCC ESR's has been assessed based on various in-situ NDT methods and chemical tests such as Rebound hammer test, rebar locater test, corrosion analyzing test pH test, carbonation test and chloride content test. After structural assessment of ESR following conclusions are drafted.

1. From results obtained of rebound hammer test of eight ESR located at Nimbhi, the compressive strength normally the ranges between 22N/mm^2 to 44 N/mm^2. This results indicates availability of good hard surface layer of concrete but due to carbonation of concrete the readings obtained on higher side. Thus, it is difficult to rely on results of rebound hammer test in case of these ESR's.
2. Compressive strength range calculated from rebound hammer test of Nimbhi ESR are between 10N/mm^2 to 25 N/mm,^{2} which shows poor condition elevated water tank.
3. The results obtained from a rebar locator of RCC ESR's at at Nimbhi shows a large variation in concrete cover along X and Y direction of columns, braces, and dome periphery and hence it indicated a poor condition of concrete layer over a reinforcement.
4. The results obtained from corrosion analyzer test on RCC ESR's at Nimbhi shows the average potential difference range is between -220mV to -260mV it indicates that the corrosion has affected about 50% to 60% area.
5. Results obtained from carbonation test shows that carbonation reached up to the depth of reinforcement in all ESR cases.
6. The results of the pH test ranges between 7 to 10 which indicate that the pH of the members has been reduced due to carbonation alkali aggregate reaction for all tested ESR's
7. The result obtained from chloride content test shows that chloride content of water tanks at Nimbhi 1.7% by weight of concrete sample it shows high concentration of chloride in concrete and hence, the probability of corrosion is more.
8. After a structural health monitoring of eight ESRs located in Amravati region it is concluded that ESR located at Nimbi need to be retrofitted by applying different strengthening/retrofitting measures.

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