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Non-destructive Testing of Concrete Structures in Karad Region

Rajan L. Wankhade\textsuperscript{a}, Amarsinh B. Landage\textsuperscript{b}

\textsuperscript{a,b}Assistant Professor, Government College of Engineering, Karad, 415124, India

Abstract

Nondestructive testing plays an important role in identifying and detection of internal defects and cracks in many industrial applications such as concrete structures, pavements, and metal testing. Nondestructive testing of concrete allows the inspection of larger areas of concrete members at lesser cost than coring and provides more information than visual inspection. The deterioration of reinforced concrete structure such as elevated service reservoir is major problem in many countries of the world. Many of the existing water tanks in service today are inadequate to need the present water demand. To ensure safe durable service and selecting the most appropriate repair strategy it is essential to perform in situ inspection for a distressed concrete structure. The main objective of present work is to propose the developed systematic investigation for metrology and a condition ranking procedure based on Analytical hierarchy process (AHP). DER rating technique is used to find out the condition ranking of elevated service reservoir in Karad region in Maharashtra. The ranking assessment for elevated service reservoir structure has been carried our using different Non-destructive test methods like surface hardness, ultrasonic pulse velocity test, half cell potential methods and cover depth measure.

Keywords: Non-destructive testing, RCC ESR’s, DER rating, Karad region.

Nomenclature

\begin{tabular}{|l|l|}
\hline
\textbf{Abbreviation} & \textbf{Definition} \\
\hline
AHP & Analytical hierarchy process \\
ESR & Elevated Service Reservoir \\
D & Degree \\
E & Extent \\
R & Relevancy \\
I_i & Condition Index of each components \\
\hline
\end{tabular}

1. Introduction

Condition assessment of concrete for structural evaluation purposes has been performed in last two decades mostly by visual examination, surface sounding and coring to examine internal concrete conditions. Condition assessments can be made with NDT methods to provide information for the structural performance of the concrete, such as: Member dimensions; Location of cracking, delamination and debonding; presence of voids and honeycomb; Steel reinforcement location and size; Corrosion activity of reinforcement; and Extent of damage from freezing and thawing, fire, or chemical exposure.

When the actual compressive strength of the concrete in the structure is to be determined core testing as per IS 516:1959 ‘Method of test of strength of concrete’ [9] is more reliable. Core tests provide the most reliable in-situ strength assessment but also cause the most damage and are slow and expensive. However these methods are relatively cumbersome therefore use of non-destructive tests which not only provide an estimate of the relative strength and overall quality of concrete in the structure but also helps in deciding whether more rigorous tests like load testing or core drilling at selected conditions are
required as given in IS 13311:part 1, 1992 [7-8].

K. Subramanian et al. [1] studied on a non-destructive technique for monitoring the setting and hardening of Portland cement concrete based upon measuring the ultrasonic wave reflection factor between the hardening concrete and a steel interface. Yiching Lin [2] et al. conducted experimental investigation to evaluate mathematical models for predicting concrete pulse velocity. Bhaduria and Gupta [3] studied In-service durability performance of water tanks. Ayop and Mohamad Ismail [4] presented the development of condition assessment system for assessing the condition statuses of concrete marine structures in Malaysia based on the condition Index method developed by the U.S Army Corps of Engineers. Ming-Te Liang, Chin-Ming Lin and Chi-Jang Yeh [5] adopted the comparisons matrix method to assert the repair order of existing reinforced concrete bridge. Saito and Sinha [6] established relationships between subjective bridge condition ratings and the FHWA’s numeric ratings to find relationships between the numeric condition rating and the expected remaining service life of bridges.

ESR’s are large elevated water storage container constructed for the purpose of holding a water supply at a height sufficient to pressurize a water distribution system. RCC ESR’s undergoes deterioration due to corrosion of reinforcement, chloride diffusion, alkali aggregate reaction, freezing and thawing etc. which may lead failure of RCC ESR’s. Thus, assessment of quality of RCC ESR’s is necessary to ensure that the quality of execution is satisfactory and also to identify any deficiencies so that they can be rectified. This can be achieved only by conducting some in-situ tests on the structures besides visual inspection. Rebound hammer test, half cell potential test, rebar locater test, ultrasonic pulse velocity (UPV) test, Carbonation test, pH test and chloride content test are mostly used for the assessment of existing concrete structures. In present work the Condition Ranking of Existing R.C.C. ESRs in Karad region using a Non destructive module has been done.

2. Methodology

2.1. Condition Rankings

It is a numerical index of damage level of the element and the whole structure, on the basis of in-situ tests and visual observation of the intensity and extent of damage and judging the urgency of repair. The assessment is based on physical deterioration as determined by measurable distress. The Condition Ranking / Condition Index (CI) are represented by a quantitative ranking between 0 and 100; 0 being the worst condition and 100 being the best condition. The index serves as guidelines for structures that require immediate repairs and further evaluation. The condition index scales (CI) developed by gleeman and sticker were used to convert the physical state of the structure into quantitative values as shown in Table 1.

| Zone | Condition Index | Condition Description | Recommended Action |
|------|-----------------|-----------------------|--------------------|
| 1    | 85-100          | Excellent: No noticeable defects. Some aging or wear may be visible. | Immediate action is not required |
|      | 70-84           | Very Good: Only minor deterioration or defects are evident |                      |
| 2    | 55-69           | Good: Some deterioration or defects are evident, but function is not significantly affected. | Economic analysis of repair alternatives is recommended to determine appropriate action |
|      | 40-54           | Fair: Moderate deterioration. Function is still adequate. |                      |
| 3    | 25-39           | Poor: Serious deterioration in at least some portions of the structure. Function is inadequate. | Detailed evaluation is required to determine the need for repair |
|      | 10-24           | Very Poor: Extensive deterioration. Barely Functional. | Rehabilitation or reconstruction. Safety evaluation is recommended |
|      | 0-9             | Failed: No longer functions, General failure or complete failure of major structural component. |                      |
2.2. Purpose and Significance of Condition Ranking/Condition Rating

Condition ranking evaluation work is generally performed for the following purpose,

- To determine the feasibility of changing the use of structure or retrofitting the structure of accommodates a different use from the present one. The feasibility of enlarging the structure or changing appearance of the structure may also to be determined.
- To determine the structure adequacy and integrity of a structure or selected elements.
- To evaluate the structural problem or distresses which result from unusual loading, exposure condition, inadequate design, or poor construction practices.
- To determine the feasibility of modifying the existing structure to conform to current codes and standards
- To determine the service life of existing structures. And To evaluate or determine the cost effectiveness of repairing, replacing and strengthening the existing structural members elements

2.3. Nondestructive Evaluation Rating

Nondestructive testing is a technology that need not destroy the reinforced concrete structure but can assess the determination of condition of the reinforced concrete. Here Nondestructive testing methods adopted are as follows,

1) Schmidt hammer test for concrete compressive strength.
2) Cover meter test
3) Rebar corrosion test.

Based on the result obtained from the NDT testing the structural adequacy is calculated using the condition ranking/condition index (CI). The formula for condition index (CI) is based on a point deduction system and weight average method. The water tank deficiencies score deduction points that are subtracted from a perfect score of 100 results in the condition index of each inspection item. In the present approach, each of the predefined elements of water tank is inspect by NDT and assessed in terms of three aspect of the defect i.e. Degree (D), Extent (E) and Relevancy (R) using a 0 to 4 ranking scheme which can be found out using table 2,3,4 and 5. Degree (D) is defined as the severity of the element defect under consideration (if the element has more than one defect then choose the most server defect for ranking). Extent (E) is the extent to which the defect occurs over the area of the water tank element. Each of this parameter is combined in the prioritization module to determine a priority ranking of water tanks requiring repair. After NDT inspection, the element condition index (CI) for each component of the water tank is calculated as follows.

\[
I_{ci} = 100 - 100 \times \frac{\max(D) + E \times R^a}{(4 + 4) \times 4^a}
\]  

(1)

Then the condition index water tank is calculated,

\[
CI = \frac{\sum_{i=1}^{n} I_{ci} \times W_j}{\sum_{i=1}^{n} W_j} \quad \text{where} \quad \sum_{i=1}^{n} W_j = 100
\]  

(2)

Where,

- \( I_{ci} \) = Condition index of each components
- \( i = 1 - n \) (n is the number of components of water tank)
- \( a \) = Parameter determined by the importance of the water tanks (usually the value of ‘a’ ranges tram 1 to 2).
- \( W_j \) = Weightings of water tank components. (Assume that the total weight of an all component group value

\[
\text{W} = \begin{cases} 1 & \text{Water tank } \text{component} \\ 0 & \text{Other component} \end{cases}
\]
is 10, 100, 1000 ------ so on, it is not unique)

Table 2. DER Rating scale for visual inspection

| Rating | 0 | 1 | 2 | 3 | 4 |
|--------|---|---|---|---|---|
| D      | No such item | Good | Fair | Poor | Severe |
| E      | Cannot be inspected | < 10% | < 30% | < 60% | < High |
| R      | Cannot be decided | Minor | Small | Medium | High |

Table 3. Schmidt hammer test for concrete compression strength

| D-value rating | 0 |
|----------------|---|
| 0              | No such item |
| 1              | $P_d \leq P_t$ |
| 2              | $0.85P_d \leq P_t < P_d$ |
| 3              | $0.75P_d \leq P_t < 0.85P_d$ |
| 4              | $P_t \leq 0.75P_d$ |

($P_d$ and $P_t$ are the design and test results of the concrete compression strength)

Table 4. Rebar locator for cover thickness

| D-value rating | Test Results |
|----------------|--------------|
| 0              | No such item |
| 1              | $0.75D_e \leq D_t$ |
| 2              | $0.5D_e \leq D_t < 0.75D_e$ |
| 3              | $0.25D_e \leq D_t < 0.5D_e$ |
| 4              | $D_t < 0.25D_e$ |

($D_e$ and $D_t$ are the design concrete cover thickness and in-situ concrete cover thickness)

Table 5. Corrosion test

| D-value rating | Test Results |
|----------------|--------------|
| 0              | No such item |
| 1              | $V_2 \leq V_e$ |
| 2              | $V_2 - 0.5\Delta V \leq V_e < V_2$ |
| 3              | $V_1 \leq V_e < V_2 - 0.5\Delta V$ |
| 4              | $V_2 < V_1$ |

($V_e$ is the measured electrical potential; $V_1 = -350mV$, $V_2 = -200mV$ when electrical solution is CuSO$_4$, while $V_1 = -90mV$, $V_2 = -240mV$ when electrical solution is AgNO$_3$)

The damage and deterioration of concrete due to corrosion of reinforced is one of the most serious cause for durability problem. Following methodology is adopted to carry out the proposed work:

1. Collection of details and information about the RCC ESRs design, construction, utilization, maintenance in the post. Collecting the complete record of RCC ESRs, design details and drawings, architectural details, construction details of the area and foundation particulars, details of any repair or retrofitting done from the time of construction.

2. Visual inspection at site and recording details of distress and deterioration. The visual inspection includes:

   - Verification of the accuracy of the original drawings or determination of basic ESRs information, if no
drawings are available.
• Identification of major alternations not shown on the original construction documents.
• Identification of visible structural damage and deterioration such as concrete cracking or spalling and observations on quality of construction.
• Observation on the condition of soil and the foundation.
• Documentation of existing conditions with photograph at key locations.

3. NDT testing will be carried out on structure ESRs.

4. Developed NDT method and Interpretation of the test are interpreted with criteria given in different IS codes, standard. Such as:

- Indian standard code of practice for non destructive testing of concrete- Method of test (Ultra sonic pulse velocity) I. S. 13311 (Part 1, 1992) Bureau of Indian Standard (BIS).
- Indian standard code of practice for non destructive testing, of concrete- method of test (Rebound hammer) I. S. 13311 (Part 2, 1992) Bureau of Indian Standard (BIS).
- Indian Standard code of practice for Nondestructive testing of concrete- method of test (Core Cutter) I.S. 1199-1959.

Condition ranking is found out with assessment in different ESRs. Comparative study is adopted. For maintenance of RCC ESRs arrangement selection will be suggested.

3. Case study

3.1. ESR at Government College of Engineering, Karad

Non Destructive Testing of RCC ESR located at Government college of Engineering, Karad was selected for study purpose. The water tank is 23 years old. The capacity of the ESR is 1.5 lack liters. Tank is supported on four columns of size (0.4m x 0.4m) on the periphery. The staging height approximately is 23.5 m above ground level. It consists of 4 columns and brace beam which are connecting the columns and braces of rectangular shape. Size of brace is 0.4m x 0.5m. For identification purposes, the columns are numbered as column C1 to Column C4 in clock wise direction. Brace beams are numbered as brace beam B1 to brace beam B4 such that brace B1 appears after column C1 in clockwise direction. The ESR consists of RCC top dome, Tank container and stair case. Fig 1. shows a detailed drawing of water tank located at Government College of Engineering, Karad.

A detailed visual inspection was carried out on almost all assessable location of the water tank. This included several visually under damaged member. Cracks developed on column and braces of water tank were up to the 15 cm in length and 2-4 mm width. The extent of deterioration was more than 75%. Cracks were observed on Top dome and talk wall was 1.0 cm length and 1 mm width. Rebar’s can be seen at all the component of tank with maximum portion was exposed corroded. Stair case of water tank was not assessable for movements. It was fully deteriorated and rebar were corroded. The field work was carried out which consists of visual inspection and Nondestructive testing. The tests are as follows.

1) Visual inspection/observation
2) Halt-cell potentiometer test
3) Rebar locator test
4) Rebound hammer test
5) Resistivity Meter test

Results of the Profometer test for column C2 and Staircase of the water tank is shown in Fig 2. and Fig 3. respectively. Thus using Profometer test cover for each bar can be directly measured which is helpful in deciding the status of reinforcement in the concrete member.
Fig. 1. Plan & Elevation of Water Tank at GCE Karad

Result of rebar locator:

Fig. 2. Results of Rebar Locator for Column C2, Water Tank at GCE Karad
Condition index is determined by NDT evaluation by DER Rating approach for all the component/element of water tank.

Assume,
- Design strength of concrete (M25)=25 N/mm²
- Design concrete cover for columns, Dc=50mm
- Design concrete cover for brace beams, Dc=30 mm
- Design concrete cover for tank container, top dome and stair case, Dc = 25 mm
- Parameter ‘a’ is related to importance of water tank = 2

1) Condition Ranking/condition index for column – 1 (Ic1)
  
Pd=25 N/mm², a=2, Dc = 50mm
  
  Value of E and R from DER Rating Visual inspection table 2, E=3 and R=4

  i) Concrete compressive strength measured by rebound hammer test = Pd=17 N/mm², from table 3, D=4
  ii) Average cover measured by rebar locator = Dc = 39.5 mm, from Table 11, D=1
  iii) Average potential difference measured by half-cell potential Vc = -250mV, from table 4, D=1

  Above three value of ‘D’ – max D = 4

In the same way for columns – C2, C3, C4 Ic1 is calculated.

Condition Index for bracing beams- 1 (Ic5)

Assume Pd = 25 N/mm², Dc=30 mm, a=2

Value of E and R from Table 2, E=4 and R=4

i) Average compressive strength measured for bracing beam B1 by rebound hammer Pd=07 N/mm², from table 3, D=4
ii) Average cover measured by rebar locator Dc = 215.5, from table 4, D=2
iii) Average potential difference measured by to half-cell potential Vc = -250mV, from table 5, D=1

From above three values, Dmax = 4

Ic5 = 0

In the same manner condition index for bracing beams – B2, B3, B4, Stair Case, Top Dome and Water tank container is calculated.
Finally, Condition index (CI) of water tank is

\[ CI = \frac{\sum_{i=1}^{n} I_i \times w_i}{\sum_{i=1}^{n} w_i} \], \text{ where } \sum_{i=1}^{n} w_i = 100

\[ CI = 16.48 \]

From Table 1 of condition index scales, for CI = 16.48 which lies between CI = 10 to 24, it means that condition of water tank is very poor, extensive deterioration and barely functional.

3.2. ESR at Malkapur, Karad

Fig 4. shows the RCC ESR at Malkapur Karad which was selected for the detailed study of the work. The capacity of the RCC ESR is 3.0 lakhs liters. It is supported on 4 columns. These columns are circular in shape. For identification purposes, the columns are numbered as column C1 to column C4. Braces are numbered as brace B1 to brace B4 such that brace B1 appears after column C1 in anticlockwise direction. The diameter of column is 0.4 m and size of rectangular brace is 0.4m x 0.5m. ESR consists of steel stair case. A detail visual inspection was carried out on almost all assessable location. This included several visually under damaged member. Cracks developed on water tank were up to 10 cm length and 0.5m width on column and braces. The extent of deterioration was more than 40%. The minor cracks were observed on top dome and tank wall. Results of the profometer test for column C1 and bracing B1 is as shown in Fig 5. and Fig 6. respectively.

![Fig. 4. Plan and Elevation for ESR at Malkapur, Karad](image-url)
Results of rebar locator

Fig. 5. Results of Rebar Locator for Column C1, Water Tank at Malkapur Karad

Fig. 6. Results of Rebar Locator for Bracing B1, Water Tank at Malkapur Karad
Condition index of water tank is determined by NDT evaluation by DER rating approach for all the component/element of water tank.

Assume,
- Design comp. strength of concrete = \( P_d = 25 \text{N/mm}^2 \)
- Design concrete cover for column = \( D_c = 50 \text{mm} \)
- Design concrete cover for brace beams = \( D_c = 30 \text{mm} \)
- Design concrete cover for top dome, tank container = \( D_c = 25 \text{mm} \)
- Parameter ‘a’ is related to importance of water tank = 2

1) Condition Ranking/condition Index for column – \( C_1 (I_{c1}) \)

\[ P_d = 25 \text{ N/mm}^2, \ a=2, \ D_c=50\text{mm} \]

Value of E and R from Table 2 DER rating visual inspection \( E=3 \), and \( R=3 \)

i) Concrete comp. strength measured by rebound hammer test = \( P_t = 12.4 \text{ N/mm}^2 \)
   From table 3 is \( D=4 \)

ii) Avg. concrete cover measured by Rebar locator = \( D_c = 38\text{mm} \)
   From table 4 is \( D=1 \)

iii) Arg. corrosion measured by halt-cell potentiometer = \( V_e = -280\text{mV} \)
   From table 5, \( D=1 \)

From above three values of \( D \), \( D_{\text{max}} =4 \)

\[ I_{c1} = 100 - 100 \times \frac{[4+3] \times 3^2}{(4+4) \times 4^2} = 50.78 \]

Hence,

Similarly, columns – \( C_2, C_3 \) and \( C_4 \), condition index is calculated.

2) Condition Ranking/condition Index for bracing beams – \( B_1 (I_{c5}) \)

Assume,
\[ P_d = 25 \text{ N/mm}^2, \ D_c=30\text{mm}, \ a=2, \ \text{Value of E and R from table 2 is } E = 4 \text{ and } R=4 \]

i) Concrete comp. strength measured by rebound hammer test, \( P_t = 26.50 \text{ N/mm}^2 \), From table 3, \( D=1 \)

ii) Avg. concrete cover measured by Rebar locator = \( D_c = 37.3\text{mm} \), From table 4, \( D=1 \)

iii) Avg. corrosion measured by halt-cell potentiometer = \( V_e = -205\text{mV} \), From table 5, \( D=3 \)

From above three value of \( D \), \( D_{\text{max}} =4 \)

\[ I_{c5} = 100 - 100 \times \frac{[4+3] \times 3^2}{(4+4) \times 4^2} = 50.78 \]

Similarly, condition Index for brace beams \( B_2, B_3 \) and \( B_4 \) and Top dome and tank wall is calculated.

Finally, The condition index of water tank

\[ CI = \frac{\sum_{i=1}^{10} I_{c_i} \times w_i}{\sum_{i=1}^{10} w_i}, \ \text{Where} \sum_{i=1}^{10} w_i = 100 \]
\[
\frac{610.24+692.71+610.24+225+225+577.78+577.78+356.81+65.0+65}{12+12+12+10+10+10+7+5} = 40.05
\]

From the table 1 of condition index scale, CI=40.05 which is between 40 and 54, it means that condition of water tank is fair, moderate deterioration occurred and function is still adequate.

**Conclusion**

The developed systematic investigation for metrology and a condition ranking procedure based on Analytical hierarchy process (AHP) has been proposed. DER rating technique is used to find out the condition ranking of elevated service reservoir in Karad region in Maharashtra (India). The ranking assessment for elevated service reservoir structure has been carried our using different Non-destructive test methods like half cell potential methods, cover depth measure, surface hardness and ultrasonic pulse velocity test. The condition index for RCC ESR at GCE, Karad is found to be CI =16.48 which implies that condition of water tank is very poor there and extensive deterioration is occurred and the water tank is barely functional. For water tank at Malkapur in Karad region, CI=40.05, it means that condition of water tank is fair, moderate deterioration occurred and function is still adequate. Thus using DER rating technique Condition Ranking of RCC ESR’s are found out.

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