HEALTH ASSESSMENT OF ESR EMPLOYING CONDITION RANKING TECHNIQUE TO CHECK NEED OF REPAIR AND RETROFITTING

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Abstract - *Water storage structures are very susceptible to damages due to corrosion. Assessment of the health of structure and suggesting action to improve the condition of the existing structure is very important to make structure withstand against future possible earthquake. Non-destructive testing has a wide role in identifying the damage and deterioration in structure. There is a lot of research on assessing the damage and deterioration of the old structure and making the structure seismically efficient, but a proper and systematic method of investigation concerning different phases of structural deterioration using advanced non-destructive testing is required. This paper deals with the condition ranking of existing elevated service reservoir by finding condition index (CI) of structure using advanced NDT by considering three phases of deterioration (1) de-passivation (2) cracking and (3) spalling of concrete. For corrosion analysis due to de-passivation DER i.e., Degree (D), extend (E) and Relevancy (R) rating and for cracking analysis Ultrasonic pulse velocity test and for spalling of concrete spalling Severity index table was used to find out condition index of elevated service reservoir (ESR). For condition assessment of structure half-cell potentiometer, rebar locator, rebound hammer test, and ultrasonic pulse velocity test was conducted.*

***Key Words*: NDT, DER rating, Condition ranking, Condition index, Elevated service reservoir.**

1. INTRODUCTION

The structure used to store water or coming in contact with water throughout life is susceptible to corrosion due to water and environmental factors such as humidity, moisture, carbon dioxide, and chloride. corrosion leads to deterioration such as loss of rebar cross-sectional area, loss of strength of the structure, formation of cracks, and spalling of concrete which causes the failure of the structure before the end of service life. To prevent failing and enhance the condition of the structure timely maintenance is required. But finding the exact method and location for maintenance such as repair, retrofit, rehabilitation or reconstruction is very difficult using only visual observation. It required some proper and systematic methods of investigation.

To overcome this problem lot of research was carried out to obtain in-situ conditions of the structure. Uniform Evaluation Procedures of Condition ranking for deteriorated Structures and current inspection and rating system defines a condition index which converts the physical state of the structure into quantitative values and gives guidelines for the maintenance and repair of the structures [1]. The functional condition index is used to assess the level of deterioration in the form of CI and calculated CI values comparatively near to the expert opinion expected values. The method of CI is reliable and economical for condition assessment of the structure [4]. DER rating technique is employed to search out the condition index of elevated service reservoir with the assistance of condition ranking procedure supported on the Analytical hierarchy process (AHP). The ranking assessment using condition index value for elevated service reservoir structure had been carried out using different Non-destructive tests and the DER rating technique helps to find out the level of deterioration [6]. Visual inspection and Non-Destructive testing are useful to deal with Major Repairs and Restoration of old deteriorated structures [8]. Failures of ESR due to collapse of supporting systems, insufficient maintenance without considering the sloshing effect, the demand of seismic forces, and improper arrangement of supporting elements to deal with this seismic analysis using software SAP 2000 of the tank is run by considering Uttarkashi earthquake [9].

Through various researches, it has been found that the level of deterioration is considered only due to the de-passivation in the initial phase of corrosion which further causes cracking because the resulting rust of rebar occupies a greater volume than the original. Expansion due to an increase in volume creates tensile stresses in the concrete member which eventually leads to cracking and concerning the time it converts into spalling in the propagation phase. If timely maintenance or action is not taken on the deteriorated member which leads to the collapse of the whole structure.

Though the satisfactory amount of research has been done on ESR health assessment, damage detection of the structural member and residual life assessment of overhead water tank, condition ranking of ESR using the different method but decision making for which action is required on a particular member by assessing the condition of that particular one to make it resistant against future probable damage has not been paid abundant attention by the researchers. The decision for finding the most deficient member for corrosion, cracking, and spalling of ESR which needs immediate repair, retrofit, reconstruction measures or replacement has a huge financial impact but is still done using personal judgment or visual observation.

In this paper, assessment of the health of elevated service reservoir is carried out using DER rating and Spalling severity index table for corrosion, cracking, and spalling with the help of NDT such as half-cell potentiometer, rebar locator, rebound hammer test, and ultrasonic pulse velocity test and finding the condition of a damaged member of ESR subjected to corrosion, cracking and spalling first by visual observation and then by NDT methods which helps the engineer to suggest action required to enhance the health of that particular member of ESR for better utilization of resources and money as well.

2. SELECTION OF ESR FOR CONDITION ASSESSMENT

The ESR was selected for a health assessment with the help of Non-destructive testing situated at GST Bhavan Amravati constructed in 1992. The ESR is circular supported on four columns C1, C2, C3, and C4 having dimensions 310mm x 310mm with horizontal bracing beams B1, B2, B3, and B4 having size 225mm x 345mm connected to the column. The height of stagging is 19.5 m above ground level. The ESR consists of an RCC top dome, Tank container. The health assessment was carried out with the help of visual inspection and Non-destructive testing. The tests are as follows:

1) Visual inspection
2) Half-cell potentiometer test
3) Rebar locator test
4) Rebound hammer test
5) Ultrasonic pulse velocity test

Results assessed from the NDT test are useful to obtain the condition of ESR for corrosion, cracking, and spalling of concrete.

Figure -1: Photograph of ESR

3. VISUAL INSPECTION

Visual inspection was done for collecting visual data according to the status of the material. It was proven that the most common method is to check the material or object condition before conducting an NDT test. Method of visual observation involves the inspection of the surface of an object to judge the presence of surface discontinuities like corrosion of member, spalling of concrete, cracks, and damage in the structural member, which would help for giving priority to conduct NDT testing for assessing the integrity and properties of the structure which are responsible to promote the extreme deterioration in member. The following table represents the visual observation of different member of old ESR which describe the in-situ condition of the structure.

Table -1: Visual observation of members

Visual Inspection	Photograph	Visual Inspection	Photograph
Column C1: **3-4 mm propagated Crack observed vertically near edges**		**Beam 11: Blackish patches observed due to corrosion and spalling of concrete initiated**	
Beam B13: **The Longitudinal crack propagated throughout the length of the beam**		**Beam B15: Spalling of concrete observed near column beam joint location on both beams**	
Column C3: **Crack observed near column beam joint propagated near edges of the column**		**Beam B7: Large spalling occurred on the beam and steel reinforcement were exposed to the atmosphere**	

4. METHODOLOGY FOR CONDITION ASSESSMENT OF ESR

For assessing the present condition of deteriorated ESR subjected to the tropical condition of climate methodology divided into three parts A) Condition Assessment for de-passivation B) Condition Assessment for cracking C) Condition Assessment for spalling. Condition assessment for de-passivation or corrosion is based on condition ranking using DER rating conducted with the help of half-cell potentiometer, rebar locator and rebound hammer test and condition assessment for cracking in concrete conducted with Ultrasonic pulse velocity test and spalling of concrete assessed with the help of spalling index table. The following figure represents the phases of deterioration with respect to time.

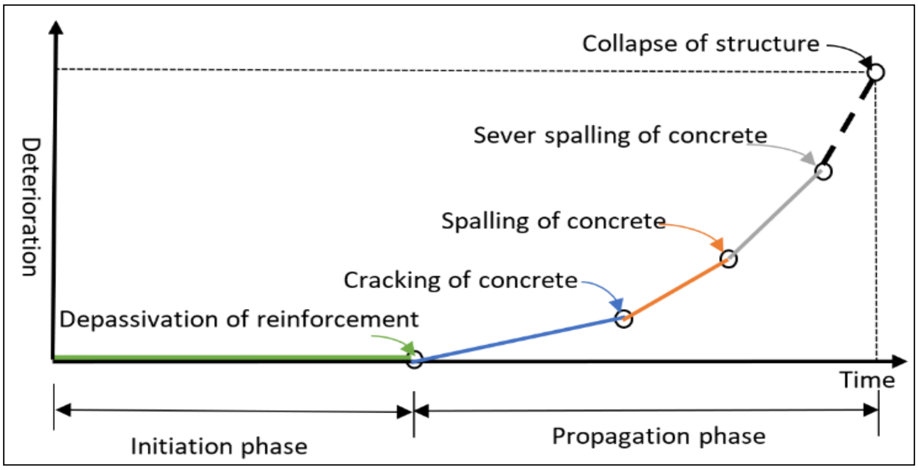

Figure -2: Phases of deterioration

4.1 Condition Assessment for de-passivation

Concrete can provide physical and chemical protection to the reinforcing steel against penetrating chlorides which may break down the iron passive film and cause steel de-passivation, further leading to steel corrosion. Corrosion assessment of ESR based on condition index (CI) method which was introduced by U.S Army corps of engineer Greimann and Stecker in 1990. The condition assessment of ESR is based on physical deterioration due to climatic conditions. Damage and deterioration of concrete structure due to corrosion of reinforcement is one of the most serious problems for durability. Once steel reinforcement is subjected to corrosion it shows an effect on the compressive strength of concrete and initiated cracking and spalling of concrete. The CI scale is used to convert the physical state of structure into quantitative value. Quantitative value varies from 0 to 100 where 0 is the worst condition and 100 is the best condition and divided into three zones describes particular member for which condition is assessed and based upon that suggesting a guideline for immediate action required for repair or not, rehabilitation or reconstruction and safety evaluation for deteriorated structure.

Table -2: Condition index scale Table [1]

Zone	CI value	Condition	Description	Action
1	85-100	Excellent	No noticeable defects Some aging or wear visible	Immediate action is not required
	70-84	Very good	Only minor deterioration or defects evident	
2	55-69	Good	Some deterioration or defects evident Function not impaired	Economic analysis of repair alternatives is recommended to determine appropriate maintenance action
	40-54	Fair	Moderate deterioration Function not seriously impaired	
3	25-39	Poor	Serious deterioration in at least some portion of the structure Function seriously impaired	A detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended
	10-24	Very poor	Extensive deterioration Barely functional	
	0-9	Failed	General failure or failure of a major component No longer functional	

4.1.1 Condition Ranking of ESR

To assess the condition ranking of ESR condition index of structure need to find out. It is a numerical value that gives the damage level of in situ structure. Non-destructive testing such as half-cell potentiometer, rebar locator, and rebound hammer test helps to obtain CI of structure. The advantage of the use of non-destructive testing is that it saves time and money also not disturbed the original structure and increased product reliability. The results obtained from NDT helps to find CI of ESR using the DER rating method with three different aspects of defects i.e., Degree (D), extend (E) and Relevancy (R) rating using 0 to 4 ranking schemes (Nordengen and de Fleuriot, 1998; known as the D-E-R rating scale showing in Table 3) [2]. Table 2 gives the Rating scale for D, E, and R which describes the rating number for a member of ESR where the D value evaluated with the help NDT test and E, R evaluated with the help of visual inspection. Table 4,5 and 6 gives Degree (D) describes the severity of deteriorated member using half-cell potentiometer test for corrosion, rebar locator test for cover depth measure, and rebound hammer test for hardness of member. The value Dmax is the maximum value of Degree (D) obtained from tables 4, 5, and 6 respectively [6]. This Dmax, E, and R-value use to calculate the condition index of each member of ESR using equation 1

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Table- 3: DER Rating scale for visual inspection

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

Table -4: D value rating table of half-cell potentiometer test for corrosion

D-ValueRating	Test Result
4	$V_2 < V_1$
3	$V_1 \le V_e < V_2\text{-}0.5\Delta V$
2	$V_2\text{-}0.5\Delta V \le V_e < V_2$
1	$V_2 \le V_e$
0	No such item

(V_e is the measured electrical potential; V_1= -350mV, V_2= -200mV when electrical solution is CuSO4, while V_1= -90mV, V_2=-240mV when electrical solution is AgNO3)

Table -5: D value rating table of rebound hammer test

D- Value Rating	Test Result
4	$P_t < 0.75P_d$
3	$0.75P_d \le P_t < 0.85P_d$
2	$0.85P_d \le P_t < P_d$
1	$P_d < P_t$
0	No such item

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

Table 6: D value rating table of rebar locator for depth of cover

D- Value Rating	Test Result
4	$D_t < 0.25D_e$
3	$0.25D_e \le D_t < 0.5D_e$
2	$0.5D_e \le D_t < 0.75D_e$
1	$0.75D_e \le D_t$
0	No such item

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

Each of these parameters is combined in the prioritization module to determine a priority ranking of water tanks requiring repair. From obtained results of NDT inspection of demanding members the condition index for each member (I_{C_i}) of the ESR is calculated using equation 1

$$I_{C_i} = 100 - 100 \times \frac{[\max(D) + E] \times R^a}{(4+4) \times 4^a} \quad (1)$$

And condition index of the whole ESR is calculated using the following equation

$$CI = \frac{\sum_{i=1}^{n} I_{C_i} \times w_i}{\sum_{i=1}^{n} w_i} \quad \text{Where } \sum_{i=1}^{n} w_i = 100 \quad (2)$$

Where Ici is the CI of each component, i = 1~n in which n is the number of components of the water tank and a = 1, the value of a can be set a = 2 according to the importance of the water tank. It is the Parameter determined by the importance of the water tanks usually the value of 'a' ranges from 1 to 2 and W_i is the Weightings of water tank components. assume that the total weight of an all-component group value is 10, 100, 1000 ----so on, it is not a unique value (Ming–Te Lians, Chi-Jang Yeh, 2003) [3].

4.2. Condition Assessment for Cracking

Appearing of cracks in concrete can affect its durability which further leads to de-passivation of reinforcing steel of ESR member resulting in corrosion of reinforcing steel or sometimes the corrosion occurs first due to high permeable concrete which increases the possibility of penetration of corrosion inducing agent. once the steel is get corroded it increases the volume of reinforcing steel about 6-10 times due to formation of rust resulting the cracks in reinforcing steel member [7]. The presence of Crack in concrete shortens the corrosion initiation time and also accelerates the propagation of corrosion during the service life span of the structure. This induced corrosion creates significant cracking and converted to spalling of concrete leads to loss of sectional area and load-carrying capacity of reinforced concrete structure which may allow the premature failure of the structure.

Therefore, the assessment of cracks in concrete to avoid failure of structure is needed. There is a lot of methods in some past research for assessing cracks through visual inspection and expert opinion but visual inspection only gives the ideas about surface cracks and not for internal hidden cracks. Here in this paper ultrasonic pulse velocity test is employed to assess the condition of a reinforced concrete structure subjected to cracking. The test is conducted only on those members having the possibility of corrosion occur more than 50 percent with the help of IS Code 516 (part-5/ sec-1) 2018.

Table -7: Concrete Quality table of UPV test for cracks

Sr. No	Average value of pulse velocity Km/s	Concrete Quality Grading
1	Above 4.40	Excellent
2	3.75 to 4.40	Good
3	3.00 to 3.75	Doubtful
4	Below 3.00	Poor

According to the grading of concrete obtained from table 7 condition ranking of each member of ESR is done. If the grading of a member of ESR comes under in Excellent, good, and poor condition then it is false under in zone 1, zone 2, and zone 3 in table 2 accordingly the action is suggested for detailed evaluation, Repair, rehabilitation, or reconstruction and for doubtful grading of concrete some other test needed to be carried out as suggested by IS Code 516 (part-5/ sec-1) 2018.

4.3. Condition Assessment for Spalling

Spalling of concrete happens because some chemical reactions occur on reinforcing steel due to initiation of corrosion leads to the formation of rust of steel which increases the volume. Insufficient space in members for rust exhibits the tensile stress as a result of cracks are formed to expel the internal pressure will further propagate and spalling is occurred seen as the concrete break itself and free from the structure resulting reinforcement expose to the atmosphere. Exposed reinforcement to the atmosphere increased the chance of heavy corrosion of steel will eventually lead up the failure of steel turns into danger of collapse of a structure due to failure of the reinforced member.

For compressive members, spalling of concrete can reduce the effective cross-section of the concrete due to which the area of the concrete resisting the load is reduced. This reduction in the area reduces the shear carrying capacity, moment carrying of members leads to failure of the structure. To assess spalling of concrete Table 8 is used for grading each member of ESR from excellent to poor given by Sallehuddin shah ayop in 2006 based upon which the action is suggested with the help of table 2.

Table -8: Concrete Quality table for spalling [4]

Severity Level	Description	Overall Quality
1	Good original surface, hard material	Excellent
2	A small chip or popouts Surface spalling that exposed coarse aggregate	Very Good
3	Spalling of concrete with 1/3d to 1/2d in depth	Good
4	Spalling of concrete results in 10% to 15% area of component affected Large spall 150mm or more in width and depth 1/2d to 1d	Fair
5	Spalling more than 15% area of beam or 30% area of the slab Spalling depth >1d	Poor

(Where d is the depth of concrete cover of the member for which the spalling of concrete need to be assessed.)

5. Results and discussion

5.1. Results for Condition assessment for de-passivation

5.1.1. Half-cell potentiometer test results

Table -9: Half-cell potentiometer test of column, slab and tank wall

Description	Half-cell potential (mv)										Average Potential Difference
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	
C1	-330	-310	-390	-230	-360	-430	-320	-330	-280	-240	-322
C2	-370	-340	-260	-280	-330	-360	-330	-380	-320	-340	-331
C3	-330	-230	-220	-220	-210	-220	-230	-240	-250	-210	-236
C4	-180	-170	-110	-310	-290	-240	-300	-230	-280	-220	-233
Bottom slab	-140	-330	-340	-130	-290	-230	-130	-140	-270	-280	-228
Tank wall	-280	-190	-180	-290	-160	-370	-180	-360	-360	-170	-254

Table -10: Half-cell potentiometer test of the beam

Description	Half-cell potential (mv)										Average Potential Difference
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	
B5	-340	-340	-330	-310	-310	-340	-290	-330	-280	-350	-322
B7	-130	-290	-120	-280	-130	-210	-170	-270	-170	-290	-206
B12	-290	-470	-230	-280	-290	-270	-270	-440	-470	-280	-329
B14	-260	-310	-280	-230	-230	-210	-360	-220	-270	-320	-269
B19	-360	-280	-390	-260	-380	-340	-380	-270	-320	-370	-335
B21	-140	-150	-360	-310	-190	-330	-280	-310	-180	-320	-257

In the above tables, the member excluding beam 7 and bottom slab indicates that there is a 50% possibility of corrosion of steel bars and member beam 7 and bottom slab having 10% possibility of corrosion according to the code of ASTM C 876-15.

5.1.2 Rebound hammer test results

Table -11: Rebound hammer test of Column

Sr. No	Description	Rebound number										Average (Rebound number)	Average (Compressive strength) N/MM2
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*		
		1st STAGING											
1	C1	38	30	26	22	32	22	28	30	30	32	29	23.53
2	C2	32	36	22	26	24	30	34	26	25	32	28.7	23.53
3	C3	22	30	28	20	24	30	34	26	25	32	27.1	20.59
4	C4	36	26	28	20	24	26	22	32	30	38	28.2	21.57
		2nd STAGING											
5	C1	24	23	26	20	24	38	22	40	42	22	28.1	21.57
6	C2	26	24	18	16	22	20	22	28	26	25	22.7	13.72
7	C3	42	22	26	28	20	20	24	20	24	24	25	17.65
8	C4	24	12	22	24	22	16	30	26	30	28	23.4	14.71
		3rd STAGING											
9	C1	38	24	30	22	36	18	24	30	36	22	28	21.57
10	C2	12	14	26	18	22	27	26	23	22	18	20.8	11.76
11	C3	30	18	18	20	30	36	40	22	20	30	26.4	19.61
12	C4	36	21	35	42	45	24	16	25	40	18	30.2	25.49
		4th STAGING											
13	C1	30	26	19	22	28	18	42	22	41	23	27.1	20.59
14	C2	16	18	30	19	17	23	21	25	23	30	22.2	12.74
15	C3	19	18	27	25	29	29	33	22	33	35	27	20.59
16	C4	23	17	35	19	20	28	26	32	33	22	25.5	18.63
		5th STAGING											
17	C1	40	20	22	20	32	16	18	24	26	32	25	17.65
18	C2	36	32	30	25	30	28	42	32	18	36	30.9	26.47
19	C3	24	13	18	34	20	20	18	19	16	23	20.5	10.78
20	C4	35	23	19	20	37	37	26	23	35	24	27.9	21.57
		6th STAGING											
21	C1	24	18	34	21	18	30	32	38	38	20	27.3	20.59
22	C2	19	23	12	15	23	34	23	19	18	18	20.4	10.78
23	C3	24	15	21	25	28	21	19	21	31	30	23.5	14.71
24	C4	20	23	22	29	39	28	30	24	28	17	26	19.61

Table -12: Rebound hammer test of Beam

Sr. No	Description	Rebound number										Average (Rebound number)	Average (Compressive strength) N/MM2
		1	2	3	4	5	6	7	8	9	10		
		1st STAGING											
1	B1	18	32	32	16	34	36	32	40	30	32	30.2	31.88
2	B2	28	32	22	30	31	30	21	28	25	26	27.3	25.49
3	B3	24	25	18	25	28	28	32	18	31	34	26.3	24.51
4	B4	28	17	24	28	32	20	46	28	42	31	29.6	30.4
		2nd STAGING											
5	B5	30	20	22	23	26	19	40	12	24	20	23.6	20.59
6	B6	30	28	26	34	22	20	22	30	26	33	27.1	25.49
7	B7	16	30	25	14	12	29	14	30	28	16	21.4	17.65
8	B8	28	36	32	40	32	40	37	18	40	42	32.9	35.3
		3rd STAGING											
9	B9	23	34	32	38	33	30	36	40	33	33	33.2	35.3
10	B10	36	28	31	30	37	21	34	31	26	37	31.1	32.36
11	B11	33	34	28	33	27	31	33	18	32	18	28.7	28.43
12	B12	24	25	18	28	32	25	20	21	17	22	23.2	19.61
		4th STAGING											
13	B13	20	24	18	19	18	27	25	15	22	20	20.8	19.61
14	B14	27	30	28	31	24	23	30	25	28	26	27.2	16.67
15	B15	15	21	23	19	26	18	22	30	17	24	21.5	25.49
16	B15	24	18	26	17	26	15	26	21	24	30	22.7	18.63
		5th STAGING											
17	B17	20	19	17	18	23	19	16	18	30	25	20.5	16.67
18	B18	17	22	32	28	26	19	33	24	24	12	23.7	20.59
19	B19	30	31	28	22	17	21	24	23	21	13	23	19.61
20	B20	14	22	22	18	27	17	24	29	19	22	21.4	17.67
		6th STAGING											
21	B21	28	20	26	24	27	25	27	30	21	28	25.6	18.63
22	B22	32	27	31	32	33	27	30	22	28	29	29.1	23.53
23	B23	27	33	22	34	32	29	34	29	19	34	29.3	23.53
24	B24	17	36	13	30	28	25	27	19	29	35	25.9	25.49

Table -13: Rebound hammer test of Top slab, Bottom slab, and container

Sr. No	Description	Rebound number										Average (Rebound number)	Average (Compressive strength)
		1	2	3	4	5	6	7	8	9	10		
1	Bottom slab	17	23	18	18	17	35	21	17	24	20	21	16.67
2	Top slab	18	15	15	26	18	18	17	28	13	34	20.2	15.69
3	Tank wall	39	43	48	40	43	43	46	40	42	36	42	37.26

In the above table surface hardness of members of ESR is tabulated according to the code of IS 13311 (PART 2): 1992 in the form of average compressive strength in the dry surface condition of the concrete.

Calculation of Condition Index for Elevated service reservoir for corrosion

- Design strength of concrete (pd) M25=25 N/mm2
- Concrete cover for columns and beams Dc = 40 mm
- Concrete cover for tank container, top dome Dc = 25 mm
- Parameter 'a' is related to the importance of water tank = 2

1) I_{C_i} for Column C1 (I_{C_1})
   Design strength of concrete Pd=25 N/mm2, Importance of water tank a = 2, Concrete cover Dc = 40 mm from Table 3, E = 3 and R = 3

a. Average compressive strength (pt) for column C1= 20.91 N/mm2 then from Table 2, D = 3
b. Avg. concrete cover measured by Rebar locator = Dt = 31.3mm from table 4 is D=1
c. Average potential difference for column C1, Ve = -322.22 mv from Table 1, D = 1 From above three value of D then Dmax = 3, using Equation of Condition index

$$I_{C_1} = 100 - 100 \times \frac{[\max(D) + E] \times R^a}{(4+4) \times 4^a}$$

$$I_{C_1} = 100 - 100 \times \frac{[3+3] \times 3^2}{(4+4) \times 4^2}$$

$$I_{C_1} = 57.81$$

As I_{C_1} calculates for Column 1, in the same way, Condition index of Column C2, C3, C4 and Beam B5, B7, B12, B14, B19, B21and Bottom slab, and Container wall is calculated.

After the CI of the whole Tank is calculated using the equation: CI= $\frac{\sum_{i=1}^{n} I_{C_i} \times w_i}{\sum_{i=1}^{n} w_i}$ Where $\sum_{i=1}^{n} w_i = 100$

$$= \frac{(578.1 + 125 + 125 + 250 + 462.48 + 650 + 100 + 0 + 100 + 0 + 75 + 346.86)}{10 + 10 + 10 + 10 + 8 + 8 + 8 + 8 + 8 + 8 + 6 + 6}$$

CI = 28.12

The value of Condition index 28.12 from table 3.1 lies between 25-39 it shows that condition of the structure is poor and structure is Serious deteriorated in at least some portion of the structure and Function seriously impaired for which the action required is Detailed evaluation to determine the need for repair, rehabilitation or reconstruction, and Safety evaluation is recommended for structure.

5.2 Results for Condition assessment for cracking

Table -14: Result of ultrasonic pulse velocity of column

Sr. No	Description of object	Method	Length (mm)	Time (µs)	velocity (km/sec)	Condition of the object (IS 516:2018)
1	C1	Direct	310	76.3	4.06	Good
2	C2	Direct	310	215	1.44	Poor
3	C3	Semi Direct	219.2	68.3	3.2	Doubtful
4	C4	Direct	310	261	1.18	Poor

Table -15: Result of ultrasonic pulse velocity of Beam

Sr. No	Description of object	Method	Length (mm)	Time (µs)	Velocity	Condition of the object (IS 516:2018)
	1st STAGING					
1	B1	Direct	225	285.4	0.79	Poor
2	B2	Direct	225	280.6	0.8	Poor
3	B3	Direct	225	48.9	4.6	Excellent
4	B4	Direct	225	60.4	3.73	Doubtful
	2nd STAGING					
5	B5	Direct	225	53.9	4.17	Good
6	B6	Direct	225	58.4	3.85	Good
7	B7	Direct	225	155.6	1.45	Poor
8	B8	Direct	225	55.4	4.06	Good
	3rd STAGING					
9	B9	Direct	225	56.9	3.95	Good
10	B10	Direct	225	69.5	3.24	Doubtful
11	B11	Direct	225	120.8	1.86	Poor
12	B12	Direct	225	57.9	3.89	Good
	4th STAGING					
13	B13	Direct	225	175.6	1.28	Poor
14	B14	Direct	225	56.4	3.99	Good
15	B15	Direct	225	96.4	2.33	Poor
16	B16	Direct	225	65.6	3.43	Doubtful
	5th STAGING					
17	B17	Direct	225	67.4	3.34	Doubtful
18	B18	Direct	225	62.6	3.59	Doubtful
19	B19	Direct	225	58.9	3.82	Good
20	B20	Direct	225	70.5	3.19	Doubtful
	6th STAGING					
21	B21	Direct	225	62.4	3.61	Doubtful
22	B22	Direct	225	73.2	3.07	Doubtful
23	B23	Direct	225	55.4	4.06	Good
24	B24	Direct	225	65.4	3.44	Doubtful

Table -16: Result of ultrasonic pulse velocity of the Bottom slab and Tank container wall

Sr.no	Description of object	Method	Length (mm)	Time (µs)	velocity (km/sec)	Condition of the object (IS 516:2018)
1	Tank wall	Indirect	300	170.1	1.76	Poor
2	Bottom Slab	Direct	200	76.6	2.61	Poor

In the above tables Quality of members of ESR is tabulated according to the code of IS 516 (part5/ sec 1):2018 with direct, semi-direct, and indirect methods of testing.

5.3 Results for Condition assessment for spalling

Table -17: Results of Spalling assessment

Sr. No	Description of the object	Spalling length	Spalling width	Spalling depth	Condition of the object
1	C1	223mm	70mm	17mm	Good
2	C2	262mm	82mm	26mm	Good
3	B7	386mm	57mm	42mm	Poor
4	B11	285mm	196mm	22mm	Fair
5	B13	97mm	52mm	26mm	Good
6	B18	103mm	39mm	18mm	Good

The condition of members of ESR shown in the above tables is tabulated with the help of a visual inspection table given by Sallehuddin shah ayop in 2006.

Condition Index Because of cracking and spalling of concrete from the above tables of cracking and spalling assessment, for Poor condition lies between 25-39 which describe the member as Serious deteriorated and function impaired, for which the action required is the need of repair, rehabilitation or reconstruction, and for fair and good, condition index lies between 40-69 describe the condition of the member is Moderate deterioration or Some deterioration or defects are evident, but the function is not significantly affected, for which the action of Economic analysis of repair or retrofitting alternatives are recommended to determine appropriate action and it comes under in Zone 2 and Zone 3.

6. CONCLUSION

This study includes the Health assessment of the Elevated service reservoir of reinforced concrete structure focused on the condition assessment, safety evaluation, and suggested action for repair and restoration to existing aged RC water tank members.

1. Visual inspection of a member of ESR in table 1 showed that the structural member subjected to deterioration in terms of corrosion, cracking and spalling which might be imparted serious health issues to the ESR in the future required urgent repair.
2. Obtained condition index for corrosion due to de-passivation is 28.12 represent the poor condition of a structure subjected to serious deterioration and impaired function needs to do a detailed evaluation of ESR members.
3. More than 50% corrosion and loss of strength occurred in a member show surface cracks in visual observation, to prevent further corrosion and loss of strength a suitable repair and retrofit methods need to be adopted.
4. Ultrasonic pulse velocity test given that more than 30% of the member of ESR is in poor condition and if timely maintenance is not done create spalling of concrete and increases a chance of failure of the member.
5. Initiated spalling of concrete in some members due to which steel reinforcement exposed to atmosphere cause corrosion and rusting of steel imparted poor and fair condition of the member.
6. The systematic methodology followed in this work for Condition ranking is useful for finding condition index of structure to describe the health of structure using NDT for three phases such as depassivation, cracking and spalling of concrete and suggesting action for repair, rehabilitation, and retrofitting.

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