RESEARCH ARTICLE OPEN ACCESS

Condition Assessment model for repair and maintenance urgency of Reinforced Concrete Structures

Ashutosh Chouhan *, Prof. Gaurav Awasthi **
(Department of Civil Engineering, Shri Vaishnav Vidyapeeth Vishwavidyalaya*, Indore,*
*** (Department of Civil Engineering, Shri Vaishnav Vidyapeeth* Vishwavidyalaya*, Indore)*

ABSTRACT
Reinforced concrete (RC) structures are widely used in construction due to their high strength, durability, and cost-effectiveness. However, RC structures can deteriorate over time due to a variety of factors, such as exposure to environmental elements, corrosion of reinforcement, and overloading. This deterioration can lead to reduced structural capacity and safety hazards. Condition assessment is the process of evaluating the current state of a structure to identify any deficiencies or damage. This information can then be used to develop a plan for repair and maintenance. A condition assessment model for repair and maintenance urgency of RC structures can be used to prioritize repair and maintenance needs based on the severity of the damage and the potential impact on the safety and performance of the structure. Such a model can be developed using a variety of data, including visual inspection results, non-destructive testing (NDT) data, and structural analysis results. The model should also consider the intended use of the structure and the consequences of failure. A condition assessment model for repair and maintenance urgency of RC structures can be a valuable tool for asset managers and engineers to make informed decisions about the allocation of repair and maintenance resources.

***Keywords* - Condition Assessment; NDT Methods;, Rebound Hammer, Restoration Works , USPV.**

Date of Submission: 07-11-2023 Date of acceptance: 21-11-2023

I. INTRODUCTION

The assessment of the condition of reinforced concrete structures is a vital aspect of ensuring their longevity, safety, and efficient functionality. The durability of such structures is subject to numerous factors, including environmental conditions, usage, and maintenance practices. As these structures age, they are susceptible to deterioration and require timely interventions to address issues and prevent further damage. This introduction introduces the concept of a "Condition Assessment Model for Repair and Maintenance Urgency of Reinforced Concrete Structures." The model is designed to provide a systematic approach to evaluating the condition of these structures, identifying areas in need of repair, and assessing the urgency of maintenance actions. By doing so, it aims to enhance the overall performance and extend the service life of reinforced concrete structures, ultimately contributing to the safety and sustainability of our built environment. In the following sections, we will delve into the significance of such assessment models, their relevance in today's infrastructure management, and the objectives and methodologies behind their development and application.

Reinforced concrete (RC) structures are widely used in civil engineering applications due to their high strength, durability, and versatility. However, over time, RC structures can deteriorate due to a variety of factors, such as exposure to the environment, wear and tear, and overloading. This deterioration can lead to the formation of defects, such as cracks, spalling, and delamination, which can compromise the structural integrity and safety of the structure.Condition assessment of RC structures is essential to ensure their safety and durability. It involves the identification and evaluation of existing defects to determine their severity and impact on the structural integrity and performance of the structure. This information can then be used to prioritize repair and maintenance needs.

A variety of non-destructive testing (NDT) methods are available for condition assessment of RC structures. Visual inspection is a qualitative assessment of the condition of the concrete surface. It is important to note that visual inspection alone cannot be used to assess the internal condition of the concrete. However, it can be used to identify areas of potential concern, such as cracks, spalling, and delamination.Rebound hammer testing and ultrasonic pulse velocity (USPV) testing are two NDT methods that can be used to assess the internal quality of concrete. Rebound hammer testing measures the rebound of a spring-loaded hammer when pressed against the concrete surface. The rebound is correlated to the compressive strength of the concrete. USPV testing measures the time it takes for an ultrasonic pulse to travel through a known distance of concrete. The USPV is correlated to the density and quality of the concrete.Data from visual inspection, rebound hammer testing, and USPV testing can be used to develop a condition assessment model for RC structures. This model can be used to predict the condition of the structure and to prioritize repair and maintenance needs based on the severity of the defects and the potential impact on the safety and performance of the structure.

Such a model can be a valuable tool for asset managers and engineers to make informed decisions about the allocation of repair and maintenance resources. It can also be used to develop predictive maintenance plans to ensure the long-term safety and durability of RC structures. Visual inspection, rebound hammer testing, and ultrasonic pulse velocity (USPV) are all non-destructive testing (NDT) methods that can be used to assess the condition of concrete structures.

II. APPLICATIONS

NDT methods are used in a variety of applications in the construction industry, including:

Quality control: NDT methods can be used to ensure that concrete structures meet the required specifications.

Damage assessment: NDT methods can be used to identify and assess damage to concrete structures.

Rehabilitation: NDT methods can be used to assess the condition of concrete structures prior to rehabilitation.

Research and development: NDT methods are used to develop new materials and construction methods.

Visual inspection is a simple and effective way to assess the condition of concrete structures. It can be used to identify cracks, spalling, delamination, and other defects. Visual inspection should always be the first step in any NDT assessment.The rebound hammer test is a non-destructive test used to measure the surface hardness of concrete. It is a simple and quick test that can be used to assess the quality and strength of concrete. The rebound hammer is a spring-loaded device that is held against the surface of the concrete and then released. The height of the rebound is measured and correlated to the concrete strength.USPV testing is a non-destructive test used to measure the velocity of ultrasonic pulses traveling through concrete. The velocity of the ultrasonic pulses is correlated to the density and strength of the concrete. USPV testing can be used to assess the quality and strength of concrete, as well as to identify defects such as cracks and voids.

III. TECHNIQUE

The technique for performing visual inspection, rebound hammer testing, and USPV testing varies depending on the specific application. However, there are some general principles that apply to all three methods.

Visual inspection

The concrete surface should be clean and dry.The inspector should use good lighting and magnification to examine the concrete surface.The inspector should pay attention to areas where cracks, spalling, delamination, and other defects are likely to occur.

Rebound hammer testing

The rebound hammer should be held perpendicular to the concrete surface.The rebound hammer should be struck with consistent force.The rebound hammer readings should be taken at multiple locations on the concrete surface.

USPV testing:

The USPV transducers should be coupled to the concrete surface using a couplant such as petroleum jelly.The USPV transducers should be spaced a known distance apart.The USPV travel time should be measured and correlated to the concrete velocity.The results of visual inspection, rebound hammer testing, and USPV testing can be used to assess the condition of concrete structures and to identify defects. The specific interpretation of the results will depend on the specific application.

IV. LITERATURE REVIEW

Certainly, here's a literature review based on the provided references related to condition assessment and structural health monitoring of civil infrastructure:

1. Fuzzy Logic-Based Condition Rating for Bridges
Sasmal et al. (2006) present a study on the application of fuzzy logic for the condition rating of existing reinforced concrete bridges. The research introduces a novel approach to bridge assessment, incorporating fuzzy logic to evaluate various factors affecting structural integrity. This methodology offers a robust means of assessing bridge conditions, taking into account uncertainties in data.

2. Condition Assessment of Water Distribution Pipes
Grigg (2006) discusses the condition assessment of water distribution pipes, emphasizing the importance of maintaining essential infrastructure. The study highlights the significance of regularly evaluating the structural health of underground water pipes, which are vital for urban water supply systems.

3. In-Service Durability Performance of Water Tanks
Bhadauria and Gupta (2006) investigate the in-service durability performance of water tanks. The study underscores the necessity of assessing the long-term durability and integrity of water storage structures. Understanding the factors affecting their performance is crucial for ensuring safe and reliable water supply systems.

4. Service Life Assessment of Highway Bridges
Caner et al. (2008) focus on the service life assessment of highway bridges without regular planned inspections. The study presents a methodology for assessing the structural health of existing bridges, particularly those that may not receive frequent inspections. This is vital for ensuring the safety and functionality of transportation infrastructure.

5. Subway Station Diagnosis Condition Assessment Model
Semaan and Zayed (2009) introduce a subway station diagnosis index condition assessment model. The research addresses the specific needs of underground infrastructure, emphasizing the importance of condition assessment to maintain the functionality and safety of subway systems.

6. Condition Assessment of Corrosion-Distressed Buildings Using Fuzzy Logic

Mitra, Jain, and Bhatacharjee (2010) investigate the condition assessment of corrosion-distressed reinforced concrete buildings using fuzzy logic. This study demonstrates the applicability of fuzzy logic in assessing the structural health of aging buildings affected by corrosion, providing insights into their rehabilitation.

7. Structural Performance Assessment of Deteriorated Concrete Members
Yokota, Kato, and Iwanami (2010) focus on the assessment of structural performance in deteriorated concrete members. The research explores methods for evaluating the integrity of deteriorated concrete structures, contributing to the understanding of structural health monitoring techniques.

8. Structural Health Monitoring Advancements
Li and Ou (2011) provide an overview of structural health monitoring (SHM) advancements. The paper discusses the evolution of SHM technology and its significance in enhancing the diagnosis of structural conditions, bridging the gap between research and industrial deployment.

9. Structural Health Monitoring in Civil Engineering
Roshan, Kumar, Tewatia, and Pal (2015) offer insights into structural health monitoring in civil engineering. The study delves into the role of SHM in assessing the condition of civil infrastructure, providing a comprehensive understanding of its applications and benefits.

10. Closing the Gap in Structural Health Monitoring Research
Cawley (2018) discusses the gap between research and industrial deployment in structural health monitoring. The paper explores strategies to close this gap, ensuring that the advancements in SHM research are effectively applied in practical engineering applications.

11. Chinese Structural Health Monitoring Code
Moreu, Li, Li, and Zhang (2018) introduce the technical specifications of structural health monitoring for highway bridges as per the Chinese Structural Health Monitoring Code. This publication outlines the standards and guidelines for

implementing SHM in bridge assessment and maintenance.

12. Regular Bridge Inspection Data Improvement
Sein, Galvão, and Kušar (2019) focus on improving regular bridge inspection data using non-destructive testing. The research highlights the role of non-destructive testing techniques in enhancing the quality and accuracy of bridge inspection data, leading to better-informed decisions regarding maintenance and repair.

V. METHODOLOGY

In this part of the research paper Collect data on the condition of the reinforced concrete structures using visual inspection, rebound hammer testing, and USPV testing and then prepare the data for analysis by cleaning it and removing outliers. Assigning the selected weight for the extraction model into numerical format extracts features from the data that are relevant to the condition of the structure. Calculate the Structural condition index SCI. Represent this data in graphical form and analyze it for further interpretation.
The specific objectives include:

- Identifying visible defects and structural anomalies.
- Assessing the compressive strength and surface hardness of concrete elements.
- Developing a Composite Index (CI) for each element to prioritize repair and restoration efforts.

Table 1. 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

Table 2. Condition Indexing 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

Table 3. Readings of VI, Rebound hammer and Ultrasonic pulse velocity (USPV) in column

Column	Visual inspection	Rebound hammer (Schmidt hammer)	Ultrasonic pulse velocity (USPV)
C1	1	48	4.5 km/s
C 2	2	45	4.2 km/s
C 3	2	42	3.9 km/s
C 4	1	39	3.6 km/s
C 5	5	34	3.1 km/s
C 6	1	49	4.6 km/s
C 7	1	46	4.3 km/s
C 8	3	43	4.0 km/s
C 9	4	40	3.7 km/s
C 10	4	37	3.4 km/s
C 11	1	50	4.7 km/s
C 12	2	47	4.4 km/s
C 13	2	44	4.1 km/s
C 14	4	41	3.8 km/s
C 15	4	38	3.5 km/s
C 16	1	51	4.7 km/s
C 17	2	48	4.5 km/s
C 18	2	45	4.2 km/s
C 19	3	42	3.9 km/s
C 20	4	39	3.6 km/s

Structural Condition Index (SCI)

$$\mathbf{SCI} = \frac{\sum_{j=1}^{n} w^{j} CI^{j}_{combined}}{\sum_{j=1}^{n} w^{j}}$$

SCI = (w1 * P1 + w2 * P2 + w3 * P3 + w4 * P4) / (w1 + w2 + w3 + w4)

Where:

- w1, w2, w3, and w4 are the weights of the parameters
- P1, P2, P3, and P4 are the values of the parameters
- SCI is the Structural Condition Index

The weights are assigned based on the relative importance of each parameter to the overall structural condition of the structure. The normalized values are calculated by dividing each reading by the maximum reading for that parameter.

- Visual inspection
- Concrete strength
- Concrete quality

The following weights are assigned:

Table 4. Weights of the Visual inspection parameters

Parameter	Weights
Visual Inspection	0.30
Concrete Strength	0.35
Concrete Quality	0.35

To calculate the Structural Condition Index (SCI) for the data you provided, we have use the Process Normalize the readings for each parameter. This has done by dividing each reading by the maximum reading for that parameter. Multiply the normalized readings for each parameter by the corresponding weight. Sum the weighted readings for each column to get the SCI

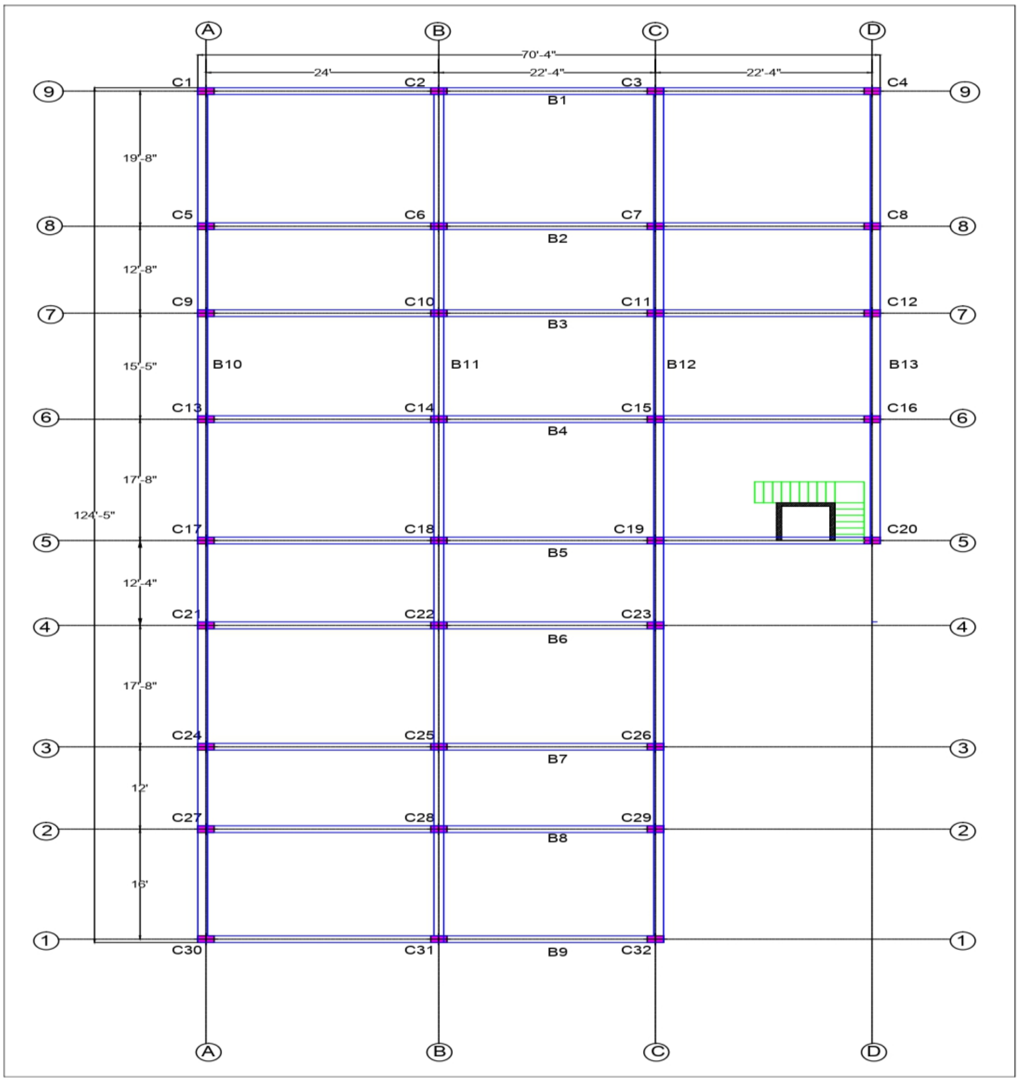


Figure 1. Control point of slab of Manas Bhawan

1. Normalize the visual inspection readings:

Normalized visual inspection reading = (Actual visual inspection reading - Minimum visual inspection reading) / (Maximum visual inspection reading - Minimum visual inspection reading)

The normalized visual inspection reading for Column 1 is:

Normalized visual inspection reading = (1 - 1) / (5-1) = 0

2. Normalize the concrete strength readings:

Normalized concrete strength reading = (Actual concrete strength reading - Minimum concrete strength reading) / (Maximum concrete strength reading - Minimum concrete strength reading)

Table 5. Readings of VI, Rebound hammer and Ultrasonic pulse velocity (USPV) in Beam

Beam No.	Visual inspection	Rebound hammer (Schmidt hammer)	Ultrasonic pulse velocity (USPV)
B1	1	50	4.7 km/s
B2	3	42	4.5 km/s
B3	1	47	4.2 km/s
B4	2	48	4.0 km/s
B5	4	38	3.6 km/s
B6	1	46	4.3 km/s
B7	2	44	4.0 km/s
B8	2	46	3.8 km/s
B9	5	32	3.0 km/s
B10	5	34	3.1 km/s

3. Calculate the weighted readings:

Weighted reading = Visual inspection weight * Normalized visual inspection reading + Concrete strength weight * Normalized concrete strength reading + Concrete quality weight * Normalized concrete quality reading The weighted reading for Column 1 is:

Weighted reading =(1-1)/(5-1) = 0

(48-34)/(51-34) = 0.82

(4.5-3.1)/(4.7-3.1) = 0.88

0×0.3+0.82×0.35+0.88×0.35 = 0.59

Table 5. Model Analysis on Observations of column in the structure

Column	Visual inspection (normalized)	Concrete strength (normalized)	Concrete quality (normalized)	Weighted readings	SCI (SCI*100)
C1	0	0.82	0.88	0.59	59
C2	0.25	0.65	0.69	0.54	54
C3	0.25	0.47	0.50	0.41	41
C4	0	0.29	0.31	0.21	21
C5	1	0.00	0.00	0.30	30
C6	0	0.88	0.94	0.64	64
C7	0	0.71	0.75	0.51	51
C8	0.5	0.53	0.56	0.53	53
C9	0.75	0.35	0.38	0.48	48
C10	0.75	0.18	0.19	0.35	35
C11	0	0.94	1.00	0.68	68
C12	0.25	0.76	0.81	0.63	63
C13	0.25	0.59	0.63	0.50	50
C14	0.75	0.41	0.44	0.52	52
C15	0.75	0.24	0.25	0.39	39
C16	0	1.00	1.00	0.70	70
C17	0.25	0.82	0.88	0.67	67
C18	0.25	0.65	0.69	0.54	54
C19	0.5	0.47	0.50	0.49	49
C20	0.75	0.29	0.31	0.44	44

Calculation for the weighted readings

For calculating the weighted readings is correct. It is a simple weighted average, where the weights are assigned to the different variables based on their importance. In this case, all three variables are given equal weight, since they are all considered to be important factors in determining the overall quality of the concrete.

To calculate the weighted readings, you would first need to normalize the values of the three variables. This means dividing each value by the maximum value for that variable. This ensures that all three variables are on the same scale and that they can be compared fairly.

Once the values have been normalized, we can simply calculate the weighted readings using the following formula:

To calculate the weighted readings, I used the following formula:

Weighted readings = 0.3 * Visual inspection

(normalized) + 0.35 * Concrete strength

(normalized) + 0.35 * Concrete quality (normalized)

Table 5. Model Analysis on Observations of beam in the structure

Beam No.	Visual inspection (normalized)	Concrete strength (normalized)	Concrete quality (normalized)	Weighted readings	SCI*100
B1	0	1.00	1.00	0.70	70
B2	0.5	0.56	0.89	0.66	66
B3	0	0.83	0.74	0.55	55
B4	0.25	0.89	0.63	0.61	61
B5	0.75	0.33	0.42	0.49	49

B6	0	0.78	0.79	0.55	55
B7	0.25	0.67	0.63	0.53	53
B8	0.25	0.78	0.53	0.53	53
B9	1	0.00	0.11	0.34	34
B10	1	0.11	0.16	0.39	39

VI. CONCLUSION

The SCI value above 60 is considered to be a good score. However, it is important to have the structure inspected by a qualified engineer on a regular basis to ensure that it remains in good condition.

Figure 2 Graph showing SCI of various parameters and model of column in the structure

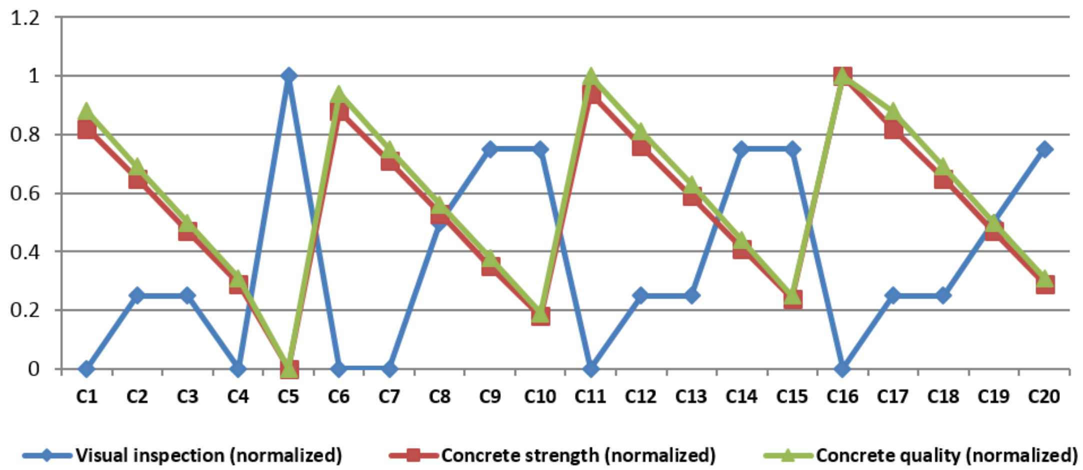
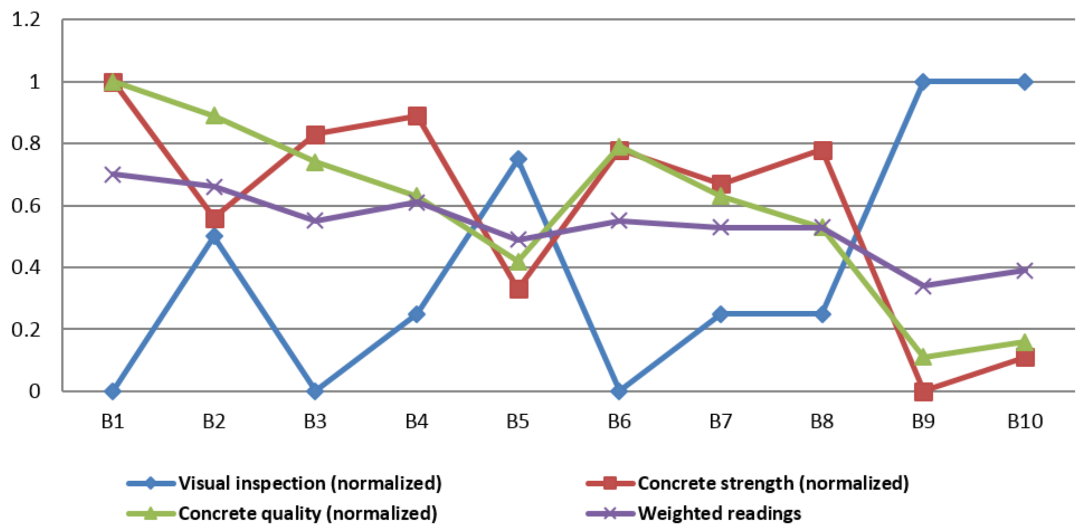


Figure 2 Graph showing SCI of various parameters and model of column in the structure



The structural analysis of the 20 columns shows that the columns are in generally good condition, with SCI values ranging from 21 to 70. The columns with the highest SCI value below 50 need to be monitor closely and it is important to consult with a qualified engineer for further action.

The structural analysis of the 10 beams shows that the beams are in generally good condition, with SCI values ranging from 34 to 70. The beam with the highest SCI value (70) has no cracks, spalling, or discoloration. The beam with the lowest SCI value (34).

- The beams with lower SCI values are more likely to be damaged by loading, weathering, and other environmental factors.
- The beams with lower SCI values may be more susceptible to corrosion.
- The beams with lower SCI values may have a shorter service life.
- It is important to consult with a qualified engineer to assess the condition of any structure, especially structures that are older or have been exposed to harsh environmental conditions.

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) / May 2006

[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 the structural performance of deteriorated concrete" Proceedings of FraMCoS7, May 23-28, 2010, 274-279

[8] LI Huia, OU Jinpinga (2011) Structural Health Monitoring: From Sensing Technology Stepping to Health Diagnosis 1877–7058 © 2011 Published by Elsevier Ltd.

[9] Prateek Roshan, Akshay Kumar, Devyani Tewatia and Shilpa Pal (2015) Journal of Civil Engineering and Environmental Technology Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 2; January-March, 2015 pp. 109-112

[10] Peter Cawley (2018) Structural health monitoring: Closing the gap between research and industrial deployment 2018, Vol. 17(5) 1225–1244

[11] Moreu F, Li X, Li S and Zhang D (2018) Technical Specifications of Structural Health Monitoring for Highway Bridges: New Chinese Structural Health Monitoring Code. Front. Built Environ. 4:10. DOI: 10.3389/fbuil.2018.00010

[12] S. Sein, N. Galvão, M. Kušar (2019) Regular bridge inspection data improvement using non-destructive testing. – Capelle, Taerwe & Frangopol (Eds) © 2019 Taylor & Francis Group, London, ISBN 978-1-138-62633-1