

# Mathematical Modeling to Predict the Change in the Rate of Degradation of Compressive Strength of Concrete Elements in an Abandoned Building Projects Using Non-Destructive Test Method

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**Abstract - Probing the structural integrity of abandoned building projects prior to its continuation and completion is a time and resource consuming task which informed the need to develop a model that will be of help in forecasting concrete strength degradation over time. This research studied three abandoned building projects at Federal Polytechnic, Oko, Anambra State, Nigeria with 12, 14 and 10 years of abandonment and exposure to environmental factors. The initial concrete compressive strength of the structural elements in the building were sourced from the Physical Planning Unit of the institution. The current concrete compressive strength of the structural elements in the building were estimated using Non Destructive Test method (Rebound hammer Test) while noting their exposure conditions and number of years of abandonment. With the estimated concrete compressive strength as the dependent variable, the initial concrete compressive strength, number of years of abandonment and exposure conditions as the independent variables a regression model of  $f_{cu}(t) = 0.5083 - 0.0331X_1 + 0.9850X_2$  was developed, tested and to be satisfactory. The study established that concrete compressive strength decreases slightly over time when exposed to severe environmental conditions, green growth and developed a model to predict concrete compressive strength degradation over time.**

**Keywords - Degradation, Concrete, Compressive strength, Exposure conditions.**

## I. INTRODUCTION

The preservation and repurposing of abandoned buildings pose significant challenges in ensuring their structural integrity and safety when the need arises for its completion and usage.

Abandoned building project is a problem world over but it is a bigger problem in developing countries like ours where it is estimated that 66% of the projects were abandoned since 1960. Some of the projects have lived so many years post their abandonment under harsh environmental conditions without any periodic maintenance. Buildings are fabricated by so many material some of which are composite like sandcrete blocks, reinforced cement concrete, tiles etc. Cement concrete as the oldest and one of the most

commonly used construction composite material because of its ease in handling and low

production cost. Cement concrete if left unprotected from harsh environmental conditions will deteriorate over time due to attack from chemicals and other factors. Understanding the dynamics of degradation and predicting future changes are crucial for effective maintenance and utilization of these structures. This research focuses on employing non-destructive test methods to investigate and form a mathematical model to predict the change in the degradation rate of compressive strength of concrete.

Abandoned buildings represent both a challenge and an opportunity for communities, developers, and policymakers. These structures often face neglect, weathering, and structural deterioration

over time due to various factors such as lack of maintenance, environmental exposure, and aging infrastructure. As a result, they become potential hazards to public safety and significant liabilities for property owners and developers due to likely deterioration of the building component like steel, timber and concrete. These building components can deteriorate over time when exposed to harsh environmental conditions and chemicals.

Traditionally, the assessment of structural integrity in abandoned buildings has relied on visual inspections and invasive testing methods, which are often time-consuming and costly. However, with advancements in technology, non-destructive testing (NDT) methods have emerged as valuable tools for evaluating the condition of buildings without causing a permanent damage to the building.

An NDT techniques such as rebound harmer test offer non-invasive means to assess the structural health of buildings, detect defects and its extent. These methods provide valuable insights into the extent of degradation over time, potential failure mechanisms, and remaining service life of abandoned structures.

By harnessing the capabilities of non-destructive test methods, researchers and Engineering practitioners can better understand the complex interactions between environmental factors, material properties, and structural performance in abandoned buildings. This knowledge enables the development of predictive models to mitigate risks, prioritize maintenance interventions, and prolong the lifespan of these structures.

However, despite the potential benefits of NDT in assessing abandoned buildings, there remains a need for comprehensive research to integrate these techniques into a holistic framework for structural durability assessment. This study address this gap by investigating and formulating a mathematical model to predict the rate of concrete compressive strength degradation in abandoned building projects using non-destructive test methods. Several empirical models have been developed to predict the compressive strength of concrete, such as the

Abrams' Law and the Feret's Equation. These models often relate compressive strength to the water-cement ratio and the proportions of the concrete mix components.

Concrete, as one of the most used construction materials in infrastructural development, is appreciated for its strength, durability and versatility. However, despite its strength, concrete is susceptible to various forms of deterioration over time, which can compromise the structural integrity and longevity of buildings and infrastructure. Understanding the types and causes of concrete deterioration is essential to develop effective maintenance, repair and prevention strategies.

Concrete deterioration is a complex process influenced by many chemical, physical, biological and mechanical factors. Understanding the types and causes of deterioration is essential to develop an effective preventive measures and maintenance strategies to extend the life of concrete structures.

AAR is an important chemical reaction that causes deterioration of concrete. It mainly includes alkali-silica reaction (RAS) and alkali-carbonate reaction (RAC). RAS occurs when alkaline cement reacts with the reactive silica present in some aggregates, leading to the formation of an expanded gel.

Sulfate attack is another common form of chemical deterioration. It occurs when sulfate ions from external sources (eg soil, ground water) penetrate the concrete and react with the hydrated cement paste, forming expansive compounds such as ettringite. This expansion can lead to cracks, spalling and loss of strength (Mehta and Monteiro, 2014).

Carbonation is the process by which carbon dioxide (CO<sub>2</sub>) in the atmosphere reacts with calcium hydroxide in concrete to form calcium carbonate. This process lowers the pH of the concrete, which can lead to corrosion of the embedded steel reinforcement. Over time, carbonation reduces the alkalinity of concrete, compromising its ability to protect against corrosion (Papadakis et al., 1996).

In cold climates, concrete can deteriorate due to freeze-thaw cycles. Water entering concrete pores freezes and expands, causing micro cracks. As they melt, cracks release more water, exacerbating the deterioration process.

Concrete surfaces exposed to mechanical wear, such as floors and industrial floors, can suffer abrasion or erosion caused by water flow. These processes gradually remove the surface of the concrete, reducing its thickness and exposing the aggregates, which can lead to further degradation (Neville, 1996).

Thermal expansion and contraction can cause physical deterioration, especially in large concrete structures like concrete dams, rigid pavement, massive building etc. Temperature changes cause differential expansion and contraction, resulting in internal stresses that can cause cracks. In severe cases, thermal effects can lead to spalling, where parts of the concrete detach from the surface (Mindess et al., 2003).

Microbial corrosion (MIC) is a form of biological deterioration that occurs when bacteria and other microorganisms produce acid derivatives that corrode concrete.

Excessive loads beyond the design capacity of concrete structures can result in mechanical deterioration. Overloading causes microcracks and, in extreme cases, structural failure. The resulting cracks can further weaken the concrete to allow the penetration of harmful substances such as water, chlorides and carbon dioxide (ACI Committee 201, 2008).

Corrosion of steel reinforcement is one of the most common and serious causes of concrete deterioration. Chloride ions from deicing salts, seawater or contaminated aggregates can penetrate the concrete and reach the reinforcing steel.

Concrete structures are often exposed to various harsh environmental conditions which initiates some reactions within the concrete by its constituent members that can degrade their inherent properties over time. These environmental exposures conditions were classified into six by BS8110: part 1: 1997, Table 3.2 as shown in table 2.6.1

Table 2.6 1

Environment	Exposure Conditions
Mild	Concrete surface protected against weather or aggressive conditions
Moderate	Exposed concrete surface but sheltered from severe rain or freezing whilst wet or concrete surface continuously under non-aggressive water or concrete in contact with non-aggressive soil or concrete subjected to condensation
Severe	Concrete surface exposed to severe rain, alternate wetting and drying or occasional freezing or severe condensation.
Very Severe	Concrete surface occasionally exposed to sea water spray or de-icing salts (directly or indirectly) or concrete surface exposed to corrosive fumes or severe freezing conditions whilst wet.
Most Severe	Concrete surfaces frequently exposed to sea water spray or de-icing salts (directly or indirectly) or concrete in sea water tidal zone down to 1m below lowest low water
Abrasive	Concrete surface exposed to abrasive action, e.g. machinery, metal tyred vehicles or water carrying solids.

## II. MATERIALS AND METHODOLOGY

### Collection and Tabulation of Building Data

The following data concerning the three abandoned buildings to be investigated were collected:

- Structural element construction year and month (age of the Structural Element)
- Compressive strength during construction
- Environmental exposure conditions
- Current compressive strength (NDT).

### Rebound Hammer Test Procedure

### **Preparation**

- Surface Preparation:

Ensure the concrete surface is smooth, clean, and dry.

Remove any loose particles, dust, or debris from the surface.

If the surface is uneven or rough, smoothen it using a grinding stone.

- Selection of Test Points:

Identify and mark the test points on the concrete surface.

Ensure the test points are at least 25 mm away from any edge or corner.

Test points should be uniformly distributed over the area to be tested.

### **Data Collection**

#### **Rebound Hammer Test**

- Perform rebound hammer tests on multiple locations of the building's structural elements (columns, beams, slabs).
- Record the rebound number (RN) at each test location.
- Supplementary Data:
- Collect additional data such as construction year, environmental exposure conditions, and historical maintenance records if available.
- Data Preprocessing

#### **Data Cleaning**

- Discard any reading the impact crushes or breaks through a near surface air void.
- Remove any reading that differs from the average of the ten readings by more than 7 units and work on the average of the remaining.
- Normalize the rebound numbers to account for variations in testing conditions.

#### **Categorization**

- Categorize the collected data based on structural elements and environmental exposure.

### **Testing Procedure**

- Positioning the Hammer:
- Hold the rebound hammer perpendicular to the concrete surface.
- Ensure firm contact between the hammer and the surface.

- Avoid any vibrations or movement during testing.

- Performing the Test:

- Press the plunger of the rebound hammer firmly against the concrete surface until the hammer strikes.

- Record the rebound number indicated on the scale of the hammer.

- Repeat the test for 10 times at each test point, ensuring that each impact point is at least 25 mm apart.

### **Results Tabulation**

#### **Test Conditions**

- No two impact test shall be closer together than 25mm.
- Discard the reading if the impact crushed or breaks through a near surface air void.
- Discard all the readings if more than two readings differ from the average by 7 units.
- Discard any rebound number readings that differs with more 7 units from the average of the 10 readings and determine the average of the remaining readings.
- Calculate the average of the recorded rebound numbers.

#### **Report**

- Note the structural element identification, Location and curing condition.
- Note the position of rebound harmer during test such as downward, upward, horizontal, or at a specific angle.
- Note down the rebound numbers for each test point.
- Calculate the average rebound number.
- Estimate the compressive strength using correlation chart.

#### **Reporting**

- Documentation:
- Prepare a detailed report including:
  - Description of the structure and test locations.
  - Date and time of testing.
  - Details of the rebound hammer used, including calibration data.
  - Average rebound numbers and corresponding estimated compressive strength.
  - Any correction factors applied.

- Observations regarding the surface condition and environmental factors.  $\beta_1$  and  $\beta_2$  are the degradation coefficients,  $X_1$  is the age multiplied by exposure condition and  $X_2$  is the initial strength.

### Modeling The Rate of Degradation

#### Regression Model

$$f_{cu}(t) = \beta + \beta_1 X_1 + \beta_2 X_2$$

where:  $f_{cu}(t)$  is the compressive strength at time ( t ),

$\beta$  is the intersection,

### III. RESULT AND DISCUSSIONS

Table 4.6 Summary Table for dependent and independent variables

S/N	Y	X <sub>1</sub>	X <sub>2</sub>
1	19.3	39	22.5
2	22	26	22.5
3	23	26	22.5
4	22	39	22.5
5	21.5	26	22.5
6	22.3	39	22.5
7	20.2	39	22.5
8	22.3	39	22.5
9	22	26	22.5
10	21	39	22.5
11	21.3	52	22.5
12	21	39	22.5
13	21.2	52	22.5
14	22	52	22.5
15	21	52	22.5
16	19.8	26	21.1
17	21	26	21.1
18	20.2	26	21.1
19	21.4	39	21.1
20	19.7	26	21.1
21	20	39	21.1

22	20.1	39	21.1
23	20.8	39	21.1
24	21	26	21.1
25	20	39	21.1
26	19.8	39	21.1
27	22	39	21.1
28	20	26	21.1
29	19.5	39	21.1
30	19.9	26	21.1
31	18.7	52	19.8
32	19.2	39	19.8
33	20	39	19.8
34	18	52	19.8
35	18.4	52	19.8
36	19	39	19.8
37	18.2	52	19.8
38	18.4	39	19.8
39	19	26	19.8
40	18	26	19.8
41	18.5	52	19.8
42	17.8	52	19.8
43	19	39	19.8
44	19.2	39	19.8
45	18.8	39	19.8
46	21	28	21.7
47	22	28	21.7
48	20.5	42	21.7

49	21	42	21.7
50	20.5	42	21.7
51	21.5	28	21.7
52	21.2	28	21.7
53	20.3	42	21.7
54	22	28	21.7
55	20	56	21.7
56	20.3	56	21.7
57	20	56	21.7
58	20.5	42	21.7
59	21	42	21.7
60	19.5	56	21.7
61	21	42	21.4
62	20.5	28	21.4
63	20.8	28	21.4
64	21	28	21.4
65	20.7	42	21.4
66	20.5	42	21.4
67	20.5	42	21.4
68	20.8	28	21.4
69	21	28	21.4
70	20	56	21.4
71	20.5	42	21.4
72	19.8	56	21.4
73	20	56	21.4
74	19.9	56	21.4
75	19.5	56	21.4

76	19.5	42	20.6
77	20	28	20.6
78	20	42	20.6
79	18	56	20.6
80	19	42	20.6
81	19	56	20.6
82	18.5	56	20.6
83	20.5	28	20.6
84	19.5	42	20.6
85	19	56	20.6
86	18.5	56	20.6
87	18.8	56	20.6
88	19	42	20.6
89	20.2	28	20.6
90	18.8	56	20.6

From the regression analysis output we have;

- $\beta = 0.5083$
- $\beta_1 = -0.0331$
- $\beta_2 = 0.9850$

#### 4.6.1 TEST ON MODEL

$$f_{cu}(t) = \beta + \beta_1 X_1 + \beta_2 X_2$$

$$f_{cu}(t) = 0.5083 - 0.0331X_1 + 0.9850X_2$$

Table 4.7 Summary Table for dependent and independent variables

S/N	Y	X <sub>1</sub>	X <sub>2</sub>	f <sub>cu</sub> (t)
1	19.3	39	22.5	21.38
2	22	26	22.5	21.81
3	23	26	22.5	21.81
4	22	39	22.5	21.38
5	21.5	26	22.5	21.81
6	22.3	39	22.5	21.38

7	20.2	39	22.5	21.38
8	22.3	39	22.5	21.38
9	22	26	22.5	21.81
10	21	39	22.5	21.38
11	21.3	52	22.5	20.95
12	21	39	22.5	21.38
13	21.2	52	22.5	20.95
14	22	52	22.5	20.95
15	21	52	22.5	20.95
16	19.8	26	21.1	20.431
17	21	26	21.1	20.431
18	20.2	26	21.1	20.431
19	21.4	39	21.1	20.001
20	19.7	26	21.1	20.431
21	20	39	21.1	20.001
22	20.1	39	21.1	20.001
23	20.8	39	21.1	20.001
24	21	26	21.1	20.431
25	20	39	21.1	20.001
26	19.8	39	21.1	20.001
27	22	39	21.1	20.001
28	20	26	21.1	20.431
29	19.5	39	21.1	20.001
30	19.9	26	21.1	20.431
31	18.7	52	19.8	18.29
32	19.2	39	19.8	18.72
33	20	39	19.8	18.72

34	18	52	19.8	18.29
35	18.4	52	19.8	18.29
36	19	39	19.8	18.72
37	18.2	52	19.8	18.29
38	18.4	39	19.8	18.72
39	19	26	19.8	19.151
40	18	26	19.8	19.151
41	18.5	52	19.8	18.29
42	17.8	52	19.8	18.29
43	19	39	19.8	18.72
44	19.2	39	19.8	18.72
45	18.8	39	19.8	18.72
46	21	28	21.7	20.956
47	22	28	21.7	20.956
48	20.5	42	21.7	20.493
49	21	42	21.7	20.493
50	20.5	42	21.7	20.493
51	21.5	28	21.7	20.956
52	21.2	28	21.7	20.956
53	20.3	42	21.7	20.493
54	22	28	21.7	20.956
55	20	56	21.7	20.029
56	20.3	56	21.7	20.029
57	20	56	21.7	20.029
58	20.5	42	21.7	20.493
59	21	42	21.7	20.493
60	19.5	56	21.7	20.029

61	21	42	21.4	20.197
62	20.5	28	21.4	20.661
63	20.8	28	21.4	20.661
64	21	28	21.4	20.661
65	20.7	42	21.4	20.197
66	20.5	42	21.4	20.197
67	20.5	42	21.4	20.197
68	20.8	28	21.4	20.661
69	21	28	21.4	20.661
70	20	56	21.4	19.734
71	20.5	42	21.4	20.197
72	19.8	56	21.4	19.734
73	20	56	21.4	19.734
74	19.9	56	21.4	19.734
75	19.5	56	21.4	19.734
76	19.5	42	20.6	19.409
77	20	28	20.6	19.873
78	20	42	20.6	19.409
79	18	56	20.6	18.946
80	19	42	20.6	19.409
81	19	56	20.6	18.946
82	18.5	56	20.6	18.946
83	20.5	28	20.6	19.873
84	19.5	42	20.6	19.409
85	19	56	20.6	18.946
86	18.5	56	20.6	18.946
87	18.8	56	20.6	18.946

88	19	42	20.6	19.409
89	20.2	28	20.6	19.873
90	18.8	56	20.6	18.946

#### IV. CONCLUSION

The study confirmed that concrete compressive strength reduces slightly over the years due to Severe exposure to environment and lack of maintenance, by comparing the current estimated concrete compressive strength with the initial concrete compressive strength while taking into cognizance the years of exposure and exposure conditions.

The study estimated the current compressive strength of concrete using non-invasive test method (Rebound harmer test).

The model  $f_{cu}(t) = \beta - \beta_1 X_1 + \beta_2 X_2$  was tested as shown on table 4.7 and found to be satisfactory that the degradation model stated above can be used to determine the future concrete compressive strength of abandoned structural element in South East Nigeria considering their years of abandonment and exposure conditions.

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