Chapter 12: Hardened Concrete – Non-Destructive Tests

Introduction

Concrete is one of the most widely used construction materials due to its strength, durability, and adaptability. Once concrete has hardened, it is critical to evaluate its properties to ensure structural integrity and serviceability. While destructive testing (e.g., compressive strength test on cubes) provides accurate results, it is not always practical or permissible—especially for in-situ structures. This is where **Non-Destructive Testing (NDT)** methods are invaluable.

NDT methods evaluate the concrete's characteristics **without damaging or impairing the structure**. These tests are used to assess quality, detect defects, and estimate strength. The most common NDT techniques for hardened concrete include:

- **Rebound Hammer Test (Schmidt Hammer)**
- **Ultrasonic Pulse Velocity (UPV) Test**
- **Core Cutting and Testing** (semi-destructive, often used in correlation with NDT)

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1. Rebound Hammer Test

1.1 Principle

The **Rebound Hammer Test**, also known as the **Schmidt Hammer Test**, is based on the surface hardness of concrete, which correlates with its compressive strength. The rebound hammer impacts the concrete surface with a spring-driven plunger and measures the rebound distance of the mass.

1.2 Apparatus

- **Rebound Hammer** with calibrated scale
- Flat and smooth concrete surface
- Test anvil (for calibration)

1.3 Procedure

1. Select a smooth, clean, and dry surface.
2. Hold the hammer perpendicular to the surface (horizontal, vertical, or inclined, based on location).
3. Press the hammer plunger against the surface until the spring releases the mass.
4. Record the **rebound number** shown on the scale.
5. Take a **minimum of 10 readings** at each test location and compute the average after discarding outliers.

1.4 Interpretation of Results

The **rebound number** correlates with the compressive strength of concrete through standard calibration curves provided by the manufacturer.

Indicative values (as per IS 13311 Part 2):

Average Rebound Number	Quality of Concrete
> 40	Very Good
30 – 40	Good
20 – 30	Fair
< 20	Poor
0	Delaminated or void

1.5 Advantages

- Simple, quick, and inexpensive
- Portable and suitable for fieldwork
- Useful for preliminary strength estimation

1.6 Limitations

- Surface hardness may not reflect internal quality
- Influenced by:
    - Surface smoothness and moisture
    - Carbonation
    - Aggregate type and size
    - Orientation of hammer

- Not reliable as a stand-alone test—should be supplemented with other methods

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2. Ultrasonic Pulse Velocity (UPV) Test

2.1 Principle

The UPV test measures the **velocity of ultrasonic pulses** passing through the concrete. Higher pulse velocity generally indicates good quality, dense, and uniform concrete, while lower velocity suggests voids, cracks, or deteriorated zones.

2.2 Apparatus

- Ultrasonic pulse generator and receiver
- Transducers (typically 54 kHz)
- Couplant (grease, gel, or petroleum jelly)
- Timer and display unit

2.3 Methods of Transmission

There are three configurations based on the accessibility of the concrete surface:

1. **Direct Transmission (most accurate)** Transducers placed on opposite faces of the concrete.

2. **Semi-Direct (Angle) Transmission** Transducers placed on adjacent faces.

3. **Indirect (Surface) Transmission** Both transducers placed on the same face.

2.4 Procedure

1. Calibrate the equipment with a standard bar.

2. Apply couplant to ensure acoustic contact.

3. Place transducers in the selected configuration.

4. Send an ultrasonic pulse and measure the **time of travel**.

5. Calculate **Pulse Velocity** (V) using:

$$V = \frac{L}{T}$$

Where:

- o V = Pulse velocity (m/s)
- o L = Path length (m)
- o T = Time taken (s)

2.5 Interpretation of Results

As per IS 13311 Part 1, the quality of concrete based on UPV is:

Pulse Velocity (km/s)	Quality of Concrete
> 4.5	Excellent
3.5 – 4.5	Good
3.0 – 3.5	Medium
< 3.0	Poor

2.6 Applications

- Detecting internal cracks and voids
- Monitoring uniformity and homogeneity
- Estimating dynamic modulus of elasticity
- Quality control and comparative analysis

2.7 Advantages

- Deep penetration into concrete
- Reliable for detecting internal flaws
- Non-invasive and accurate in direct transmission

2.8 Limitations

- Requires good surface preparation and coupling
- Not effective on heavily cracked or deteriorated concrete
- Results may vary based on moisture content, temperature, and path length

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3. Core Cutting and Testing

Although not entirely non-destructive, **core testing** is often included in NDT discussions as it **validates** the results of rebound hammer and UPV.

3.1 Purpose

- To obtain **actual samples** of in-situ concrete for compressive strength testing
- Used when doubts arise about quality or strength in critical structural elements

3.2 Apparatus

- **Core cutting machine** with diamond-tipped core bit
- Water supply for cooling
- Core extraction tools
- Testing machine (for compressive strength)

3.3 Procedure

1. Select the core location (preferably where NDT results are available).
2. Drill cylindrical concrete cores of **minimum 100 mm diameter** and **length ≥ 2 × diameter**.
3. Label and transport samples with care to avoid damage.
4. Test for:
   - Compressive strength (IS 516)
   - Density
   - Visual inspection for voids/cracks

3.4 Guidelines

As per IS 456 and IS 516:

Core Strength (as % of specified)	Structural Assessment
> 85%	Acceptable
75 – 85%	Further analysis may be needed
< 75%	Generally considered unsatisfactory

3.5 Precautions

- Ensure alignment and verticality of drill
- Avoid reinforcement cutting
- Use water cooling to avoid heat-induced micro-cracks

- Restore structure post-drilling (grouting)

3.6 Advantages

- Direct measurement of actual strength
- Provides detailed insight into in-place concrete

3.7 Limitations

- Slightly destructive—leaves holes in the structure
- Time-consuming and costly
- May weaken the structure if done improperly

Comparison of Rebound Hammer, UPV, and Core Cutting

Feature	Rebound Hammer	UPV	Core Cutting
Destructiveness	Non-destructive	Non-destructive	Semi-destructive
Accuracy	Moderate	High (for defects)	Very High
Depth assessed	Surface only	Entire cross-section	Full-depth sample
Time required	Quick	Moderate	Long
Equipment cost	Low	Moderate to High	High
Use in field	Excellent	Good	Moderate
Primary limitation	Surface sensitivity	Coupling, interpretation	Structure weakening

3.8 Relevant Indian Standards and Codes

A number of IS codes provide guidelines for performing and interpreting non-destructive tests on hardened concrete. These include:

- **IS 13311 (Part 1): 1992** – *Method of Non-Destructive Testing of Concrete – Ultrasonic Pulse Velocity* This standard lays down the procedure for UPV, interpretation of pulse velocities, and classification of concrete quality.

- **IS 13311 (Part 2): 1992** – *Method of Non-Destructive Testing of Concrete – Rebound Hammer* Covers equipment calibration, method of conducting the test, and indicative strength values.
- **IS 456: 2000** – *Plain and Reinforced Concrete – Code of Practice* Provides general quality control and acceptance criteria for concrete structures.
- **IS 516 (Part 5/Sec 1): 2018** – *Testing of Hardened Concrete – Compressive Strength of Core Specimens* Specifies procedures for obtaining and testing cores for compressive strength.

3.9 Combined Use of NDT Techniques

In professional practice, **multiple NDT methods are used in combination** to improve the reliability of results. This is known as **correlation testing**, where results from one method are verified against another.

Example Strategy:

- Use **Rebound Hammer** for quick surface hardness assessment across a wide area.
- Use **UPV** in zones where hammer results are low or inconsistent to check for internal defects.
- Use **Core Cutting** only at critical or suspicious locations for strength validation.

Benefits of Combined Testing:

- Reduces uncertainty and error
- Allows cross-verification
- Enhances confidence in decision-making (repair/strengthening vs. demolition)

3.10 Field Testing Best Practices

When performing NDT in the field, several best practices should be followed to ensure reliability and safety.

Before Testing:

- Review structural drawings for reinforcement layout
- Select accessible and representative areas

- Calibrate instruments with standard blocks

During Testing:

- Avoid wet or dirty surfaces (especially for rebound hammer)
- Ensure proper contact and alignment of transducers (for UPV)
- Maintain consistent spacing and layout
- Record environmental conditions

After Testing:

- Analyze variations statistically
- Document location, readings, photos, and core sample positions
- Use GIS or digital tools to map NDT zones and results

3.11 Case Study: Structural Audit of a 10-Year-Old School Building

Background: A government school building constructed in 2013 began showing signs of surface cracking and efflorescence. A structural audit was ordered.

Tests Conducted:

- Rebound Hammer: 60 readings across columns and beams
- UPV: Direct and indirect method at 15 strategic locations
- Core cutting: 3 locations (1 from beam, 2 from slab)

Findings:

- Average rebound numbers ranged from 22 to 30, indicating fair to good concrete.
- UPV results varied from 3.2 to 4.1 km/s, indicating non-uniform internal quality.
- Core compressive strengths: 20.4 MPa, 22.1 MPa, and 18.9 MPa (specified: 25 MPa)

Action Taken:

- Local repairs recommended in low-strength zones
- Waterproofing membrane applied to prevent further moisture ingress
- Load-bearing capacity deemed satisfactory for current use

3.12 Emerging Trends in NDT of Concrete

With advancements in technology, newer and more precise NDT techniques are being developed:

- **Ground Penetrating Radar (GPR):** Used to detect reinforcement, voids, and delamination.
- **Impact Echo and Tomography:** Help assess delaminations and thickness in large slabs or tunnel linings.
- **Infrared Thermography:** Detects subsurface voids and moisture using temperature differentials.
- **AI-Powered NDT Analysis:** Emerging software solutions use machine learning for pattern recognition and interpretation of NDT results.

These techniques are **augmenting traditional methods** and are particularly valuable for heritage structures, large infrastructures (bridges, dams), and post-disaster assessments.

3.13 Safety and Ethical Considerations in NDT

While NDT is generally safe, certain safety and ethical aspects must be upheld:

- Ensure **authorized access** to test locations, especially in functioning buildings.
- Avoid **drilling near high-stress or high-load zones** during core extraction.
- Maintain **data confidentiality** and avoid misuse of test results.
- Ensure all readings are taken by **qualified and certified technicians**.
- Report limitations and uncertainties transparently in the final report.
