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Structural Evaluation of an Existing RC Bridge Using Non-Destructive Tests- A Review

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Abstract
This paper examines the different nondestructive testing (NDT) methods available and gives a series of case studies for the strength assessment of an existing bridge. In general, the cost of remediation is substantially cheaper if a flaw is discovered early rather than allowing the building to deteriorate for months or years. In terms of accuracy, testing practicality, and costs, NDT techniques were evaluated across several performance parameters. Researchers were able to analyze material consistency in three dimensions and find faults or deterioration regions inside structural elements with a new degree of efficiency using the two methods together.
Keywords: *NDT methods; Damage assessment; Concrete bridges;*

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I. INTRODUCTION

A bridge is a structure intended to allow people and vehicles to cross anything (such as water, a low spot, or a train). Because of the considerable growth of the road and railway networks over the last several decades, the number of bridges has expanded significantly. Various sections of them are exposed to severe environments over time, reducing their service life. Some of those constructions now have a wide variety of flaws. Health monitoring is the process of identifying and tracking structural integrity and analysing the degree of deterioration in a structure. The assessment of bridges' long-term condition and safety is critical for effective civil infrastructure maintenance and management. With the ageing of the buildings, operations and maintenance have gotten increasingly complicated. After the concrete has set, it is frequently required to examine the construction to see if it is acceptable for its intended usage. A bridge's deck is one of its most susceptible components. It has a shorter service life than the other parts and is intended to be changed on a frequent basis. In highway bridges, concrete deterioration, steel corrosion, changes in boundary conditions, and the weakening of structural connections with time are all major concerns. The structural integrity and serviceability of a damaged bridge will degrade over time if it is not repaired. The most common non-destructive assessment approach for bridge inspections is visual examination. Because of the rising expense of repairs for ageing bridge networks, the growing backlog of structures in need of renovation, and the greater use of non-destructive testing technology, non-destructive testing for bridges has gained more attention in recent years. Non-destructive and partially destructive tests may measure a wide variety of characteristics, including fundamental parameters like density, elastic modulus, and strength, as well as surface hardness and absorption, and reinforcement position, size, and distance from the surface. In some situations, the capacity to identify voids, cracking, and delamination may also be used to assess the quality of labour and structural integrity. Both ancient and new structures can benefit from non-destructive testing. Visual inspection, half-cell electrical potential method, rebound hammer test, carbonation depth measurement test, permeability test, penetration resistance or Windsor probe test, Covermeter testing, Radiographic testing, Ultrasonic pulse velocity testing, Sonic methods, Impact echo testing, Ground penetrating radar or impulse radar testing, and infrared thermography are some of the most common NDT methods for concrete structures.

The following are some examples of circumstances where non-destructive testing may be useful:

- ❖ Precast unit quality control or on-site construction.
- ❖ Removing any doubts regarding the acceptability of the item provided due to apparent non-compliance with the specifications.
- ❖ Confirming or removing doubts about the quality of concrete batching, mixing, placement, compacting, or curing.
- ❖ Monitoring of strength growth in connection to the removal of formwork, the end of curing, prestressing, the application of load, or other similar purposes.

- ❖ Cracks, voids, honeycombing, and other flaws in concrete structures are located and their extents are determined.
- ❖ Determining the consistency of the concrete, potentially as a prelude to core cutting, load testing, or other more costly or disruptive tests.
- ❖ Identifying the location, quantity, and condition of reinforcement.
- ❖ Increasing the amount of confidence in a limited number of damaging tests[1].

Non-destructive Test (NDT) methods

1. Visual inspection

For assessing visible surfaces, visual inspection is a versatile and effective NDT approach. However, its success is dependent on the investigator's expertise and understanding, specifically with respect to structural behaviour, materials, and construction methods. The most common method of inspecting concrete structures for deterioration is visual inspection. One of the first phases in evaluating concrete structures is a visual evaluation. While this procedure is quick and inexpensive, it never provides precise and quantitative information regarding interior faults. Cracking, seepage, spalling, exposed reinforcement, discoloration, moisture ingress, beam delamination, concrete deterioration, and reinforcement corrosion are all commonly detected through visual inspection. Visual examination can be done with a hand-held magnifier, stereo microscope, fiberscopes, and borescopes, among other equipment. Figure 1 shows some of the faults discovered by Gokhan when inspecting a concrete bridge using this approach. The fundamental disadvantage of visual inspection is that it only discovers cracks, degradation, and damage when they start to impact the structure's life or, in certain situations, when they have severely affected the structure's internal layers while only slight cracks appear on the surface. This is especially true in the case of long span bridges, when visual inspection of the whole structure is extremely difficult[2]. Damage condition states based on visual inspection are rated on a four-level scale indicated in Table 1. The worst condition ratings of the components were used to derive the bridge condition rating[3]. Initial Inspection, Routine Inspection, Damage Inspection, In-depth Inspection, Fracture-Critical Inspection, Underwater Inspection and Special Inspection these are the types of inspections[4]. Visual assessment was essential for accurately identifying previous strengthening work[5]. The visual examination was carried out within touching distance of each piece, such as the deck slab soffit, which was inspected for cracking, spalling, exposed reinforcement, seepage, and staining from the footway and carriageway below[6]. The visual inspection resulted in the identification of the geometry, morphology, and notable damages, which were all captured on a quick sketch made on the spot[7]. Visual inspection is a precursor for any intended non-destructive test to determine the likely cause(s) of damage to a concrete structure and, as a result, to determine which of the different NDT techniques available would be most effective for any further assessment of the problem[1].

Figure 1: Concrete deterioration between spans (a) seepage, (b) efflorescence, (c) concrete cover delamination, (d) widen cracks[2]

Table 1: Visual inspection condition rating scale[3].

Rating $CR_{VisInsp}$	Description
1	No deterioration (Like new condition)
2	Low deterioration (Good condition)
3	Medium deterioration (Satisfactory)
4	Heavily deteriorated (Poor condition)

CONCLUSION

Visual examination is usually just one part of a comprehensive assessment method. By this method, only visible cracks can be determined. If there are any flaws present in the structure, it fails to identify them. As a result, it is proposed that this approach be used in combination with other NDT methods to determine the true condition of the building.

2. REBOUND HAMMER

The rebound hammer test is used to determine the hardness of concrete's surface. The compressive strength of concrete is determined by interpreting the rebound value. It is based on the principle that the hardness of the surface against which an elastic mass impinges determines its rebound (IS 13311 (Part-2) 1992). There appears to be minimal theoretical link between concrete strength and hammer rebound number. Empirical relationships between strength parameters and the rebound number have been demonstrated, but only within limitations[1]. Rebound measurements were taken on each specimen's three sides (lateral, bottom, and top) at 16 testing locations with a consistent spacing of 3 cm on each side. The rebound was determined for each concrete mix using measurements taken on the two specimens that were also utilised in the destructive testing (e.g. compressive strength)[8]. The concrete's compressive strength was tested in the laboratory using two methods after the on-site rebound hammer results were collected (for comparison):

1. The compressive strength was determined using the graph in the instrument's handbook.
2. A graph generated by the study team was used to evaluate compressive strength. The corresponding values calculated using the rebound hammer method on the locations where the samples were drilled out were compared to the laboratory-found compressive strength values of the drilled out cores (Figure 2)[7].

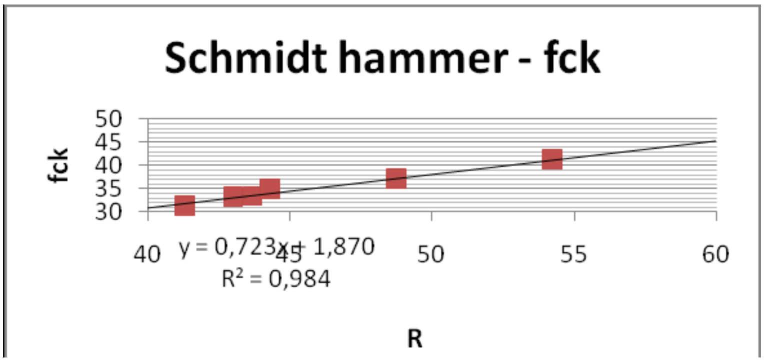

Figure 2: Fck–Nr of rebound hammer plotted on the basis of direct crushing value in compression[7]

Figure 3: Testing of Bridge Pier using Rebound Hammer[1]

CONCLUSION

The strength of concrete, mainly surface hardness and penetration resistance, can be determined using a rebound hammer. By interpreting the rebound value, the compressive strength of concrete is determined.

3. ULTROSONIC PULSE VELOCITY TEST

Ultrasonic pulse velocity test is primarily used to determine the concrete's sound velocity and also its compressive strength[1]. The density and elastic properties of concrete influences the velocity of ultrasonic pulses travelling through it[9]. This approach has been effectively used to assess material homogeneity, void identification, depth of surface crack, internal qualities of fill material or structure, average compressive strength, internal dimensions, and shape of the structure[2][10]. One of the oldest non-destructive testing (NDT) methods for detecting the relative quality of concrete is to measure the time of pulse of ultrasonic waves across a known path length. It may be used to identify anomalous areas in a member[10]. An electrical pulse generator, a pair of transducers, an amplifier, and an electronic timing device for measuring the time interval between the beginning of a pulse generated at the transmitting transducer and its arrival at the receiving transducer comprise the majority of the equipment[1][2][5]. The surface of the concrete should be smooth and dust-free. The transducers must be pushed against the concrete until a consistent reading occurs. Before beginning the measurements, double-check the reference value, and do so every hour[9]. The ultrasonic wave transmitter was placed on one side of the concrete structure to be studied, while the receiver was placed on the opposite side in direct transmission of ultrasonic waves[5]. Plasticine, petroleum jelly or grease was used to provide acoustic connection between the transducers and the concrete surface[2][5]. The longitudinal waves are the first waves to reach the receiving transducer, and a second transducer converts them to an electrical signal[1]. The transmitting transducer generates a stress pulse, which travels through the member. The receiving transducer receives the signal and displays the data in the form of travel time. A little portion of the radiated energy is reflected back to the surface when the wave approaches a flaw. In this case, defects are determined as any acoustical impedance anomaly that differs from the concrete element being inspected. When compared to concrete in intact regions, concrete in areas where there is severe degradation or micro cracking will have a considerably lower velocity[2]. The pulse's travel time T may be measured using electronic timing circuits. The following equation calculates the longitudinal pulse velocity (in km/s or m/s):

$v = L / T$[1]

where v is the longitudinal pulse velocity, L is the path length, and T is the pulse's duration to cross that length.

Transducers should be in the 20 to 150 kHz range, however frequencies as low as 10 kHz for extremely long concrete route lengths and as high as 1 MHz for mortars and grouts or short path lengths can be adopted. For short path lengths, high frequency transducers are used, whereas low frequency transducers are preferred for long distance lengths[1].Ultrasonic pulse velocity (UPV) was measured using direct, indirect, and semi-direct transmission of ultrasonic waves at a maximum frequency of 200 kHz[2][8][10]. Because it gives a specified path length across the structure, it is widely accepted that the direct transmission arrangement is a suitable method to implement in the NDT of structures. Furthermore, because the arrival time of the initial wave is the most important factor, the analysis does not require any effort to detect complicated wave frequencies and reflections. A flaw can be detected because sonic waves cannot pass through an air gap, which could be caused by a fracture, void, or delamination at the brick or stone-mortar interface. A propagating wave must find a way around the emptiness, which causes signal loss and increases travel time[10]. Direct transmission is the most efficient method of testing if the bridge part is accessible from opposite sides, such as a girder or pier column, since the transducer gets the highest energy from the transmitted pulse. Semidirect transmission (transducers on neighbouring faces) or indirect transmission (transducers on the same face) can be employed for an abutment wall[3]. Semi-indirect transmission is an improved form of direct transmission. The semi-indirect transmission method, also known as sonic tomography, is employed on routes that are not parallel to the structure's wall surfaces. The signal generator and receiver are situated on the same face of a structure in the indirect approach, also known as sonic reflection or sonic-echo method. The inner discontinuities or the rear face echo recorded stress waves (direct stress waves). Due to the poor resolutions obtained from the low frequency energy, this approach is not suggested[2]. Figures 3b and 3c show direct and indirect transmission modes respectively, which are commonly utilised in tomographic surveys. [10]. For each cubic specimen, direct UPV was computed by averaging three measurements taken on three pairs of opposite faces. With a gap of 7 cm in between transmitter and the receiver, indirect UPV was adopted for both the laboratory slabs and the on-site tests. In each testing location, nine measurements were taken with a consistent spacing of 10 cm[8]. When compared to mechanical testing on control samples such as cubes or cylinders, pulse velocity measurements have the benefit of directly relating to the concrete in the structure rather than samples, which may or may not be actually representative of the concrete in situ[1]. It was discovered that the pulse velocity recorded on drilled cores is consistently higher than that measured on the structure itself[9].

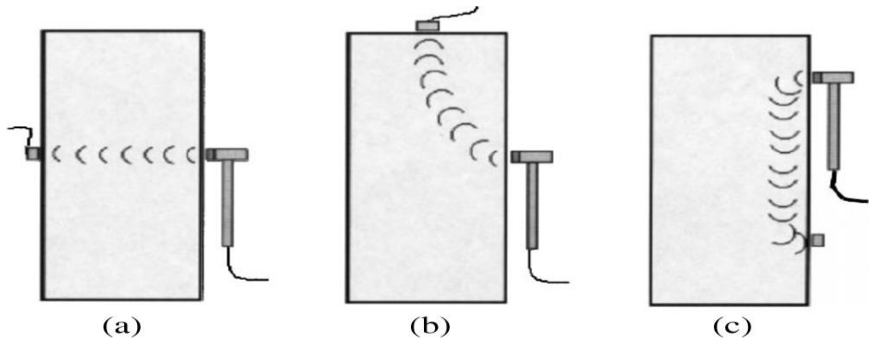

Figure 4: Transmission modes for sonic wave tests: (a) direct; (b) semi-direct; (c)indirect[10]

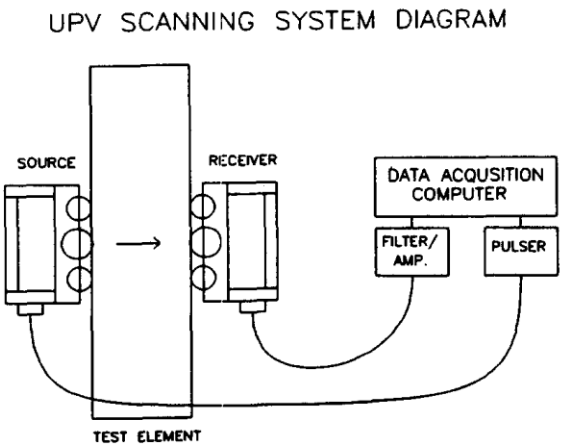

Figure 5: UPV scanner system[11]

Table 2: Classification of the Quality of Concrete on the Basis of Pulse Velocity (IS 13311-Part-1-1992)[1].

Longitudinal pulse velocity km/s	Quality of concrete
>4.5	Excellent
3.5-4.5	Good
3.0-3.5	Medium
2.0-3.0	Poor
< 2.0	Very poor

CONCLUSION

Ultrasonic tests are a reliable method of determining the compressive strength, modulus of elasticity and density of existing concrete structures. Whenever possible, go with the direct method. The indirect approach produces less accurate and dispersed ultrasonic measurements. The velocity recorded on cores or samples in the laboratory is higher than the velocity observed in in-situ[9].

4. COVERMETER

The diameter of the reinforcement and its distance from the concrete surface can be determined using a covermeter. The covermeter consists of two coils placed on an iron-cored inductor. When one of the cores receives an alternating current, a current is produced in the other, which is subsequently amplified and measured. Steel has a non-linear relationship with concrete thickness and is also affected by rod diameter. The higher electrical conductivity of the concrete above the reinforcing rods may impact the accuracy of the findings measured on the covermeter if the concrete has been penetrated by saltwater water[10].

II. CONCLUSION

Visual inspection and various NDT methods were carried out to know the strength and section properties of concrete bridge. Location and determination of the extent of cracks, voids, honeycombing and other defects within a concrete structure can be determined. And also, it Can determine the position, quantity or condition of reinforcement. Vibration analysis according to present loading conditions. Based on NDT values bridge structure can be analyzed and retrofitted. By the combination of two or more NDT methods, researchers were able to find flaws or regions of degradation inside structural elements and to analyse material consistency in three dimensions with a new degree of efficiency.

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