VICROADS INTERNATIONAL CONFERENCE ON NO-DESTRUCTIVE TESTING, DECEMBER 10-12, 2015

Non-destructive Testing (NDT) of Concrete in Structures

Fred Andrews
Principal Engineer,
Concrete Technology, GeoPave

Apeh, Abah Joseph
Department of Building, Federal University of Technology,
Minna, Nigeria.

INTRODUCTION

Non-Destructive Testing (NDT) methods are used to determine the condition and quality of concrete or to locate objects embedded in concrete, without damaging or destroying the concrete. Some NDT methods may be used to identify the location and development of cracks and voids which are not visible at the concrete surface but which may affect the structural or durability performance of concrete.

Due to the specialised nature of NDT methods and the specific equipment required for each method, operators must be well trained and familiar with all factors affecting the test conditions and the readings or responses obtained. Also, the results must be properly evaluated and interpreted by experienced personnel who are familiar with the particular NDT technique.

Each NDT method has its advantages and limitations for certain assignments, and none can be used alone to give an effective and unambiguous diagnosis. It is important to avoid any negative influences such as weather conditions, and to be aware of the limits of the technique in response to various objects. Some NDT methods are comparative and rely on a control or reference sample such as a defect-free item or a series of test cylinders to establish the base response.

This Technical Note provides an overview of the different NDT methods available and nominates suitable applications for their use[1,2,3].

INFRARED THERMOGRAPHY

The presence of flaws within the concrete affects the heat conduction properties. The presence and location of hidden defects (such as delaminations or voids) is indicated by the differences in surface temperature between sound and unsound concrete. The technique is considered suitable for providing an assessment of flaws in concrete, particularly delaminations in bridge decks, and can provide a fair indication of the location of reinforcing bars, cables and cable ducts and concrete surface cracking. Infrared thermography allows for more rapid data collection and greater accuracy when used on asphalt covered decks compared to conventional sounding methods. Testing is not viable during periods of adverse weather (rain or wind). Testing can be adversely affected by several surface conditions such as: debris, water, wearing, discolouration, crack sealant, strong wind, etc. These issues are discussed in standard recommendations such as ACI 228.2R[2] and ASTM D4788 - *Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography*.

GROUND PENETRATING RADAR (GPR)

Ground penetrating radar (GPR) provides subsurface reflection images of structures. GPR operates by transmitting pulses of ultra high frequency radio waves (microwave electromagnetic energy) into the subsurface object through an antenna, which is part of a portable control unit and recorder (Fig 1). The transmitting antenna is excited by repetitive high voltage pulses with repetition rates typically of the order of 10,000 Hertz. The proportion of the wave which penetrates from the air into the concrete depends on the moisture content, penetration being lower for wetter concrete. A part of the penetrating wave is reflected by interfaces or objects with dielectric properties different from that of the general medium. These reflections are detected by the receiving antenna and converted into electrical signals. The recorded reflections can be analysed in terms of shape, travel time and signal amplitude to provide information about the size, depth and properties in relation to the material object. This enables a good identification of reinforcing bars, prestressing cables, cable ducts, zones of varying moisture content and thickness of slabs, different concrete, asphalt-concrete overlay interface, plastic spacers and a fair assessment of delaminations and large voids in concrete. Some guidance on the GPR testing method is given in ASTM D6087 - *Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar*, and ASTM D6432 - *Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation*.

Figure 1 - Ground Penetrating Radar (GPR) testing utilising high frequency impulse radar

RADIOGRAPHIC METHODS

Radiographic methods for concrete inspection include gamma-ray radiography, X-ray radiography, and X-ray radioscopy (and backscatter radiometry which is discussed separately). These methods use radioactive materials and involve hazardous radiation, and test personnel require specialised training and accreditation. A radiographic image is taken through a concrete component to reveal a picture of the interior. Radiography is a reliable method to "see through" a concrete component, and can detect interior flaws such as voids in post tensioning ducts and locating cables and cable ducts, reinforcing bars and cover thickness. It provides a fair assessment of other flaws and defects in concrete. The most important advantage of radiography over other NDT techniques is that it is highly reliable and shows a "see-through" picture of the inspected area. The disadvantages are mainly related to operational safety through use of trained operators and exclusion zones during exposures, and the fact that the operation of radiographic techniques in bridge inspection is comparatively complicated and slow. Exposures of large member thickness can take several hours. Also, both sides of the component must be accessible. Guidance on radiography test methods is given in BS 1881: Part 205 – *Testing concrete – Recommendations for radiography of concrete*.

BACKSCATTER RADIOMETRY (BSR) (Nuclear surface moisture density gauge)

The BSR method determines the in-place density of the outer 100 mm of hardened concrete. The equipment has a concentrated gamma ray source and a detector fixed in a frame. A nuclear surface moisture density gauge has appropriate configuration with a gamma ray source. In operation, the gauge is placed on the concrete surface and it measures the intensity of reflected (backscattered) radiation that has passed through the concrete component. The gauge requires calibration for backscatter density, and density adjustments must be made using cores from sites that have been tested using the gauge. The method can be used when only one face of a component is accessible. There are a number of instruments which are commercially available. The technology is rapid and simple, although it requires a radiation safety program and accreditation to operate the rugged portable equipment. Refer to ASTM C 1040 - *Test Methods for Density of Unhardened and Hardened Concrete in Place by Nuclear Methods*.

ULTRASONIC PULSE VELOCITY (UPV)

The UPV method involves measuring the speed of travel of an ultrasonic pulse through concrete. This speed is influenced by the density and elastic modulus of the concrete. It is often used for relative strength assessments. The technique is most effective and economic for comparative assessments of quality (density) and detection of voids, delaminations, and under compacted and honeycombed areas because the pulse takes longer to travel around defective areas. The method is most effective when sound is transmitted directly between transducers placed on opposite faces. The method is less effective but possible when transducers are positioned at right angles over a corner or on the same surface. Low frequency ultrasonic pulses (about 30 kHz) are sent by the transmitting transducer and received by the second transducer with the time taken for the ultrasonic pulse to travel recorded by a timer. The pulse velocity is determined by dividing the path length between the two transducers by the pulse travel time. Generally higher pulse velocity is associated with higher strength of concrete. The pulse velocity can be affected by concrete mix composition, concrete density and compaction, moisture condition and age of concrete. It is important that testing and interpretation of the data generated is carried out by an experienced operator. Effectiveness can be improved with concrete core calibration to relate speed of sound in concrete to concrete density and strength. Refer to ASTM C597 - *Standard Test Method for Pulse Velocity Through Concrete*.

IMPACT-ECHO

The impact-echo technique is based on generating a short duration impact (sound) wave onto the test surface. These waves propagate into the concrete and are reflected by the opposite face of the concrete, or from internal flaws or other objects back to a receiver or transducer. The signals received are converted into a frequency, are analysed to determine the existence and depth of defects and are displayed onto a screen. The impact-echo technique is effective in determining the thickness of a component (particularly when only one face is accessible), and the presence of delaminations or large cracks, particularly if they run parallel to the surface, and voids. Compared with the sounding techniques in determining delamination (i.e: hammer, chain, rebound hammer), impact-echo is more reliable when relatively small areas are delaminated so as to indicate early signs of deterioration. Compared with GPR, impact-echo has the advantage that the test results are not influenced by weather conditions, or by moisture or chloride in concrete. The effectiveness and accuracy can be improved by calibrating with a known thickness of concrete and assessment made by taking several readings, particularly in the case of thicker and longer concrete elements. The equipment provides for rapid data collection and the data should be interpreted by an experienced operator. Refer to ASTM C 1383 - *Test Method for Measuring P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method*.

COVER METER

The cover meter technique is the least complicated and least expensive of all the NDT techniques (Fig. 2). The meter applies a low frequency alternating magnetic field into the concrete surface. The presence of steel in this magnetic field induces eddy currents and a voltage change that can be detected and displayed by the meter. The cover meter has the ability to locate reinforcing steel and other metal objects, measure the depth of concrete cover and estimate the size of the reinforcing bar. The accuracy of a cover meter can be affected by the amount of steel reinforcement present, particularly by the amount of congestion and the presence of multiple layers or other metallic inclusions. Its accuracy can be improved by calibrating against reinforced concrete with known dimensions and size of reinforcing bars. A cover meter is generally reliable to a depth of 100 mm to 125 mm and should be used by an experienced operator. Refer to BS1881-204 - *Testing concrete - Recommendations on the use of electromagnetic cover meters*.

REBOUND HAMMER TESTING

The rebound hammer (such as the Schmidt Hammer) is a simple device that is used to measure the hardness and predict the strength of the concrete. This is a spring-loaded impacting device that incorporates a scale to measure the energy of the rebound following the impact. The extent of rebound gives an indication of the strength of the concrete at the surface position tested. The average of about 10 to 20 impacts would give an approximate indication as to the compressive strength of concrete at that location. The device is sensitive to a number of factors such as the surface finish, striking aggregate or mortar, the age, the moisture content and hardness, and these factors can influence the predicted strength concrete. The rebound hammer can be used on horizontal, vertical or inclined concrete surfaces provided a correction is made for the angle of inclination. Prior to testing, the rebound hammer should be calibrated using a calibration test anvil supplied by the manufacturer for that purpose. Correlations of rebound number should be developed where possible with the strength of partially destructive core testing and/or concrete cylinder strength results if they are available for the particular concrete mix. Rebound hammer testing should be undertaken in accordance with ASTM C805 - *Test Method for Rebound Number in Concrete*.

VOLUME OF PERMEABLE VOIDS (VPV)

The VPV method provides the ability to determine the water porosity or permeability (and density) of the concrete microstructure in accordance with AS 1012.21 - *Determination of water absorption and apparent volume of permeable voids in hardened concrete*. Although it is a semi-destructive method, as it requires the extraction of concrete cores, it nevertheless provides a very cheap and a non-specialised way of establishing the quality and longterm performance of concrete. VPV test limits are given in VicRoads Standard Specification Section 610 - *Structural Concrete*[4] for both concrete cores and test cylinders.

Figure 2- Cover meter measurements, concrete column (Left) and concrete deck overlaid with asphalt (Right)

SUMMARY

Most of the methods discussed in this technical note are indirect tests, such as impact-echo and radar, which infer the concrete characteristics or dimension from the measured response. A few methods are direct, such as radiography, for observation of the condition of internal components. NDT results can sometimes be ambiguous, and direct observation - by removing concrete - may be necessary to confirm or verify the NDT results. In practice, the combined use of two or more NDT techniques would provide complementary information and result in a more reliable diagnosis. Most techniques require a high level of expertise to interpret results and operators generally should have considerable training in the use of the equipment and in condition assessment of concrete structures.

REFERENCES

1. ARRB TR Contract Report No. RC2071 for VicRoads, A. Shayan and A. Xu, *Investigation of Non-destructive Methods of Determining Details of Components Cast into Concrete Bridge Components*, January 2002. 2. ACI 228.2R *"Non-destructive Test Methods for Evaluation of Concrete in Structures"*

3. BUNGEY, J.H. (1994). *The Testing of Concrete in Structures*, Second Edition.

4. VicRoads Standard Specification Section 610 - *Structural Concrete*.

CONTACT

For further information on Non-Destructive Testing of Concrete in Structures, please contact:

Fred Andrews-Phaedonos

Phone: (03) 9881 8939

Email: fred.andrews-phaedonos@roads.vic.gov.au

Mobile: 0419 597 277