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A Review of Ultrasonic Application on Non-destructive Testing Method for Concrete Structure

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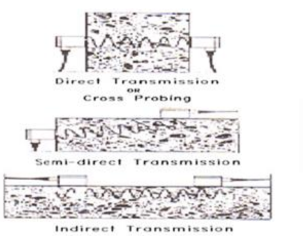
Graphical abstract



Abstract

Although the technique of using ultrasound has reached maturity by given the extent of the development of sensors, but the use of the various areas still can be explore. Many types of ultrasonic sensors are still at conventional in use especially for measurement equipment in the industry. With the advancement of signal processing techniques, high-speed computing, and the latest techniques in image formation based Non-destructive testing (NDT) methods, the usage of ultrasound in concrete NDT testing is very extensive because the technique is very simple and should not damage the concrete structure to be investigated. Many of the parameters need to be tested using ultrasound techniques to concrete can be realized. Starting with the initial process for of concrete mixing until the concrete matured to the age of century old. Various tests are available to test a variety of non-destructive of concrete completely, in which there is no damage to the concrete, through those where the concrete surface is damaged a bit, to partially destructive testing, such as core tests and insertion and pull-off test, which surface to be repaired after the test. Testing parameter features that can be evaluated using non-destructive testing and destructive testing of some rather large and include basic parameters such as density, elastic modulus and strength and surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of the workmanship and structural integrity of the ability to detect voids, cracks and delamination. A review of NDT using ultrasound on concrete are presented in this paper to highlight the important aspect to consider when one to consider the application and development of ultrasound testing on concrete by considering ultrasound signal capturing, processing and presenting.

Keywords: Ultrasonic; concrete; pulse velocity method; pulse echo method; concrete tomography

■1.0 INTRODUCTION

Concrete is a building material that is quite complex in terms of the composition of the material contained uneven nature for the purpose of building the needed durability and strength. The concrete mixture also reinforce with steel bar to add strength of concrete[1]. It mostly found in highways, building foundation, concrete bridges. While the mixture is according to a measure that required by the standard, but the source material such as sand, gravel and cement quality still varies. Certainly a standard model that represents a of concrete block is impossible to be found.

Non-destructive testing (NDT) method is a technique used to obtain information about the properties or objects without damaging the internal state of the object. Non-destructive testing is a descriptive term used for the inspection of materials and components in such way that allows materials to be examined without changing or destroying their usefulness. NDT is a management tool that can provide quality guarantees impressive results when used properly. It requires an understanding of the methods available, their capabilities and limitations, knowledge of standards and specifications for performing the test. NDT techniques can be used to monitor the integrity of the item or structure throughout the design life [2].

The ability and the effectiveness of NDT using ultrasound method on concrete cannot exaggerate. The parameter to be tested can be divided in to two categories; the quality of the concrete and the defect of the concrete structure. The quality of the concrete can be determined by finding the strength of the concrete, the sufficient amount of reinforcing steel [3]. Sometimes initial sample are needed for quality testing. Second parameter is the defect of the concrete where the cases are quite complex and varies with application and aged of the concrete structure. The two major techniques to be apply using ultrasound method, based on the array of ultrasound sensor.

If two sensors are used as pair of sensor one is acting as transmitter and the other acting as receiver. The sound pressure are transmit from the transmitter with sufficient pressure to make sure the sound can penetrate the concrete structure followed the desired thickness, while the receiver will convert the received sound wave to useful electric signal. The differences between transmit and receive sound wave are very obvious in term of magnitude and the time taken for the wave to reach receiver. This technique called Pulse Velocity Method. Second method is using the same sensor for transmit and received the reflected wave or transmitter and receiver at the same position. This method called pulsed echo method[4].

This review focused on application of ultrasound for NDT where the subject is concrete, using simple approach the review can divided based on different categories. In this paper, the review can be divided into 3 section; array of sensor, type of sensor, result representation.

■2.0 ARRAY OF SENSOR

The technique of NDT of ultrasound using at least one sensor to complete the measurement process. The most common application is using a pair of sensor called Pulse Velocity Method (PVM). If only one sensor (acting as transmitter and receiver) used or the transmitter and receiver (dual element transducer) at the same location the reflected wave or echo are necessary to detect. This method called Pulse Echo Method (PEM) technique. When PVM and PEM technique individually or combined are used but with a sufficient point of measurement, the technique can be extend as Concrete Tomography.

2.1 Pulse Velocity Method (PVM)

Ultrasonic pulse velocity is one of the most popular non-destructive techniques used in the assessment of concrete properties[5].When electrical pulses are applied to transmitter, the electro-acoustical transducer will produced longitudinal wave of sound pressure. If the arrangement for transmitter and receiver shown in Figure 1, ultrasonic pulses will propagate through the concrete.

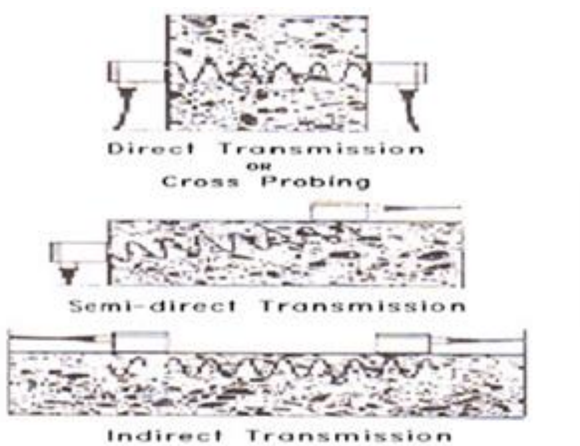


Figure 1 Transmitter and receiver arrangement (a) direct, (b) semi-direct and (c) indirect

There are three possible ways of measuring pulse velocity through concrete:

a. **Direct Transmission (Cross Probing) through Concrete**: In this method transducers are held on opposite face of the concrete specimen under test as shown in Figure 1. The method is most commonly used and is to be preferred to the other two methods because this results in maximum sensitivity and provides a well defined path length.

b. **Semi-direct Transmission through Concrete :** Sometimes one of the face of the concrete specimen under test is not accessible, in that case we have to apply semi-direct method as shown in fig. In this method, the sensitivity will be smaller than cross probing and the path length is not clearly defined.

c. **Indirect Transmission (Surface Probing) through Concrete :** This method of pulse transmission is used when only one face of concrete is accessible. Surface probing is the least satisfactory of the three methods because the pulse velocity measurements indicate the quality of concrete only near the surface and do not give information about deeper layers of concrete. The weaker concrete that may be below a strong surface cannot be detected. Also in this method path length is less well defined. Surface probing in general gives lower pulse velocity than in the case of cross probing and depending on number of parameters.

Comparisons were made between direct and indirect wave velocity direct and indirect wave velocity measurements using statistical analysis. The statistical analysis revealed that direct and indirect wave velocities could be used interchangeably in evaluating the properties of the concrete [6].

A complex of sound pressure wave develops and reaches the receivers which includes both longitudinal and shear waves. The first waves reach the receiver are the longitudinal waves which are directly converted to electrical signal. A simple formula can be used to calculate the transit time of the pulse using the below formula;

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

Where v is the longitudinal pulse velocity, L is the path length and T is the time taken by pulse to traverse that length. When a pulse apply to ultrasound transmitter, an energy is radiated from the source will form as three main distinct types of wave propagation; longitudinal wave, transverse wave and surface wave. The fastest of these waves have the same medium particle displacement is longitudinal wave or P-wave. The nature of ultrasonic wave travel by compression and decompression of medium particle, then ultrasound wave can be measure as compression wave velocity. The wave velocity V_P, is a function of Young's modulus E, Possion's ratio u and the mass density ρ; and the equation is given by:

$$V_P = \sqrt{\frac{E(1-u)}{\rho(1+u)(1-2u)}}$$

The above equation stated that stiffness, elastic properties, density of materials is related with wave velocity. The quality of the concrete can be comparatively obtained based on higher velocity, V_P will determined the quality of concrete in term of homogeneity, uniformity and density.

Most of studies are utilizing this formula to find strength of concrete[5][7][5][8][6]. When ultrasonic pulse propagate through concrete it will hit various media such as cement, gravel, sand, steel and the unwanted medium is air or some porosity material resulted from low quality of concrete ingredient. This will affected the time for the pulse to arrive at the receiver. There are two parameter that can be evaluate whether the air bubble in the concrete or a crack within the concrete slab.

2.1 Pulse Echo Method (PEM)

Ultrasonic pulse-echo techniques involve introduction of a stress pulse into concrete at an accessible surface by a transmitter. The pulse propagates into concrete and is reflected by cracks, voids, delamination or material interfaces. The reflected waves, or echoes, are recorded at the surface, and the receiver output is either displayed on an oscilloscope or stored for further processing. There are several methods of examining a test specimen using the pulse-echo technique. The advantage using this technique is only one point needed to apply the sound wave propagation and the reflected wave will give the needed information such as crack, location of steel bar and back wall. The technique

2.3 Ultrasound Based Tomography

Experimental results indicated successful identification for the location of a defect that was embedded in concrete, thus implying the potential of attenuation tomography as a complementary method to the travel time tomography to enhance soundness evaluation of concrete.

Imaging of concrete structures presents many challenges due to the fact that concrete is a non-homogeneous material. Variable grain size distribution and different properties of the constituent materials make it difficult to produce accurate images. In addition, the generally complex physical geometry of the structure, restricted accessibility, and existence of reinforcement and prestressing tendons further complicate the problem**.**

Several examples of ultrasonic tomography applied to concrete elements can be found in the literature [9][10][11][12]. A laboratory experiment was conducted to examine the feasibility of attenuation tomography for visualizing defect in concrete. A concrete slab of $1500 \times 1500 \times 300mm^3$ was used. Styrofoam plates of 300mm diameter were included at specific locations. Tomography measurements were carried out with both the measured portions discretized into 8 uniform solid cells of $100 \times 100 \times 150mm^3$. This resulted in a total of 9 nodes on each of the two measurements[13].

Experimental results indicated successful identification for the location of a defect that was embedded in concrete, thus implying the potential of attenuation tomography as a complementary method to the travel time tomography to enhance soundness evaluation of concrete.

3.0 TYPE OF THE SENSOR

Sensor is the key factor for the successful of NDT on concrete structure. Most of researcher use frequency in the range 30khz to 250khz. Transducers with natural frequencies between 20 kHz and 150 kHz are the most suitable for use with concrete, and these may be of any type, although the piezoelectric crystal is most popular. Piezoelectric transducers are the most common types used for generating ultrasonic waves. Ultrasonic waves are generated by exciting the piezoelectric element in one transducer by an electrical voltage signal in the shape of a spike, which causes it to vibrate at its resonant frequency.

Ultrasound transducer can be categorized into type of operation; contact and non-contact. Contact transducers are used for direct contact inspections, and are generally hand manipulated. They have elements protected in a rugged casing to withstand sliding contact with a variety of materials. These transducers have an ergonomic design so that they are easy to grip and move along a surface. They often have replaceable wear plates to lengthen their useful life. Coupling materials of water, grease, oils, or commercial materials are used to remove the air gap between the transducer and the component being inspected. Dry contact ultrasound offer only dry point contact and normally requiring no surface treatment or couplant offers advantages. Time savings may be considerable and path length accuracy for indirect readings may be increased, but this type of transducer is unfortunately more sensitive to operator pressure.

Non-contact transducer utilizing air or gas as a medium to transfer the sound wave energy from transducer to the testing specimen [14]. Since the early 1970s attention has been focused on developing Non-Destructive Characterization (NDC) methods by utilizing electro-magnetic, thermal, and mechanical waves as the characterizing tools[15]. An electromagnetic acoustic transducer (EMAT), is a type of non-contact ultrasound that generates an ultrasonic pulse which reflects off the sample and induces an electric current in the receiver.

4.0 DATA AND RESULT REPRENSANTATION

The signal received from transducer can be identified as the sound wave pass through the specimen or the reflected wave from the crack, reinforced steel, concrete back wall. The data representation can be simple as numerical value to the complex imaging data as 3D image of the testing concrete specimen.

The A-scan or A-scope method is a one-dimensional view of the defects in concrete. The B-scan or B-scope method involves a series of parallel A-scans and produces a two-dimensional view of the defects in concrete. The C-scan or C-scope method involves a series of parallel A-scans performed over a surface. For high frequency ultrasound imaging applications which can be used for NDT of metals, display of B- or C-scans can provide significant information about the interior defects due to the high directivity of the waves.

5.0 CONCLUSION

The application of ultrasound technique on NDT for concrete structure are briefly described. The consideration of sensor selection are quite crucial decision, from frequency ranging, transducer operating whether contact mode; dry or couplant contacted or non-contact transducer. The objective parameter such as concrete strength, depth of crack, the presence of reinforced bar will determined how the measurement technique can be applied pulse velocity method, pulse echo method or by arranging a few transducer to form tomography system where image of subject can be display by manipulating image reconstruction method.

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