

STATE OF PRACTICE OF NDE TECHNOLOGIES IN BRIDGE INSPECTION

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ABSTRACT

Bridges deteriorate due to a variety of environmental and mechanical loads. Most bridges in the United States are in service over several decades or even over a century. Over 30 years since the National Bridge Inspection Standards (NBIS) was adopted, visual inspection remains the major approach to evaluate bridge conditions. The advantages of this method are economical, fast and simple. However, visual inspection is functionally limited, highly operator dependent and inaccessible to unexposed components. The emerging Bridge Management System, used by State Highway agencies, calls for more advanced technologies to obtain detailed and quantitative information on bridge conditions. NDT technologies can play an important role to increase the inspection efficiency and reliability. This paper categorizes the most frequently used NDE technologies for steel, concrete and timber bridges. The advantages and shortcomings of the major NDT technologies for evaluation of concrete bridge are compared. A few emerging trends of these technologies are also discussed. The current status of applying NDT technologies for bridge inspection from results of surveys in State DOTs as well as the future trend is also briefly discussed.

INTRODUCTION

Bridge maintenance and repair is a worldwide problem for agencies responsible for bridge management. There are totally around 580,000 bridges in U.S. most of which were built in the 1930s, and 1950s and 1960s (Hadavi, 1998). After being in service for many years, most of these bridges deteriorate and need rehabilitation or replacement. Causes of bridge failure include corrosion, fatigue, inappropriate design, wind, scour, earthquake, floods, and fire (Harik, et al., 1990). Tremendous amount of costs are needed to keep America's bridges in safe and serviceable condition. "The Federal Highway Administration (FHWA) has estimated that \$50 billion is needed to keep roads and bridges in their current state of repair, and that \$215 billion is needed to repair all the roadways and bridges that are deficient" (Roberts and Shepard, 2000).

The collapse of the 2, 235-ft long Silver Bridge in Point Pleasant, over the Ohio River between West Virginia and Ohio, resulted in 46 fatalities. It was found later that the reason for failure of Silver Bridge was the fracture of an eyebar. This catastrophic disaster speeded the process of making the National Bridge Inspection Standards. The standards require the inspection of all bridges on public roadways in the USA on a periodic basis, normally at least once every two years. Data from the inspections are maintained in the National Bridge Inventory (NBI), a database with information on the size, construction and general conditions of the approximately 590, 000 bridges and culverts in the United States (Chong et al., 2003).

In order to evaluate the safety of a constructed system, it is essential to determine the remaining strength of the system by a performance analysis based upon the strength and inspection data of the materials and the structural system. Currently visual inspection method remains the main approach for bridge evaluation. The advantages of this method are economical, fast and simple. However, visual inspection is functionally limited, highly operator dependent and

inaccessible to unexposed components. The emerging Bridge Management System, used by State Highway agencies, calls for more advanced technologies to obtain detailed and quantitative information on bridge conditions.

NDE technology has been in existence for quiet a long time. Upon properly selected and applied, NDE technology can significantly increase the inspection efficiency and accuracy. Recent advancements in NDE technology arouse broad interest of applying these new technologies in the bridge inspection program. In this paper, the state practice of using NDE techniques is introduced. A few promising NDE techniques for concrete bridge evaluation are also presented.

STATE OF NDE APPLICATIONS FOR BRIDGE INSPECTION

The congressionally mandated National Bridge Inspection program requires States to periodically inventory, inspect, and rate all highway bridges on public roads. The National Bridge Inspection Standards (NBIS), implemented in 1971, prescribe minimum requirements for the inspection of highway bridges in the United States (National Bridge Inspection Standards, 1998). Therefore, according to NBIS requirements all state DOTs have to inspect their bridges regularly (Moore et al., 2001).

During a literature search conducted by the authors, several surveys on the application of NDE to highway structures were identified. These surveys included a 1994 study by the California Department of Transportation (Caltrans), a study by Rens, et al. (1993) for the American Association of Railroads, a follow-up study by Rens and Transue (1997) and a study by Moore et al. (2001) for the Federal Highway Administration.

Moore, et al. (2001) conducted a survey focusing on the current NDE method for bridge inspection. Fifty-two surveys were sent to the FHWA State Division Bridge Engineers to be completed in coordination with the State bridge inspection manager. Forty-two responses were received from State DOTs with a response rate of 81 percent. Table 1 summarizes the responses for the question "What NDE techniques are currently utilized on bridges under your jurisdiction".

This table indicates that visual inspection remains one of most commonly used techniques for bridge condition assessment. As discussed earlier, while visual inspection is relatively simple to perform, it has shortcomings in terms of low efficiency, prone to subjective error, and visual inspection under heavy traffic poses adverse unsafe working environment for the field inspectors.

The most popular NDT techniques for steel bridge inspection are Liquid Penetrant and Ultrasonic Method. Mechanical sounding remains the most popular NDE techniques for both concrete and wood bridges. Figure 1 shows evolution of the percentage use of NDT technology for bridge inspection. The average percentage applications of the five most popular NDT techniques have increased over the 5-year span. The use of these advanced techniques indicates the willingness by state agencies to try new technologies to improve the practice of bridge inspections. NDE methods that are effective in assessing bridge conditions rapidly gained popularity; while the application of NDE methods that only applies under certain conditions (such as eddy current method) remains steady. This implies that NDE techniques have to possess demonstrated advantages in order to be widely accepted. This is also a guide for the development of new NDT techniques.

Table 1. NDE techniques used for bridge inspection (compiled from Moore et al., 2001)

Inspection method	Bridge type		
	Steel	Concrete	Timber
Visual Inspection	95.2	90.5	85.7
Liquid Penetrant	81.0	-	-
Ultrasonics	81.0	19.0	-
Magnetic Particle	64.3	-	-
Radiography	16.7	0.0	0
Acoustic Emission	11.9	2.4	0
Vibration Analysis	9.5	0.0	-
Eddy Current	9.5	-	-
Other Electromagnetic Techniques for Steel	2.4	-	-
Mechanical Sounding	0.0	76.2	83.3
Thermal/Infrared	0.0	11.9	-
Other: Sonic Force	2.4	-	-
Other: D-meter	0.0	-	-
Cover Meter	-	50.0	-
Rebound Hammer	-	45.2	-
Electrical Potential Measurements	-	26.2	-
Radar	-	21.4	-
Moisture Meter	-	-	11.9
Stress Wave Analysis	-	-	4.8
Other: Boring/Coring	-	-	9.5
Other: Inspection Pick	-	-	4.8
Other: Timber Decay Detecting Drill	-	-	4.8

Note: "-" means that the NDE is not applicable for this type of bridge

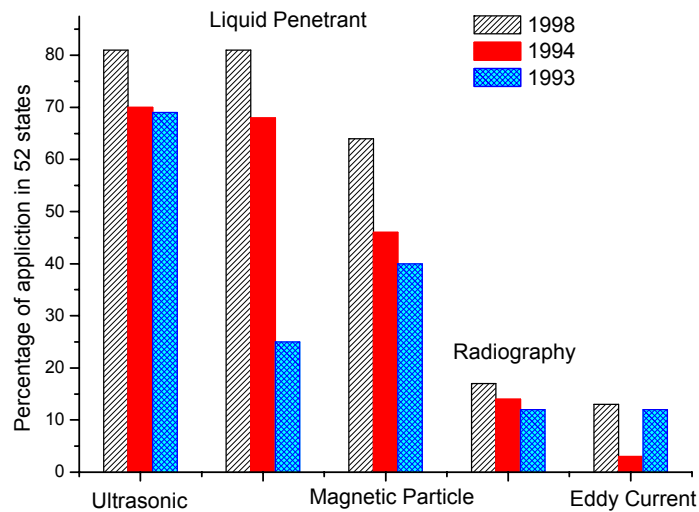


Figure 1. Evolution of NED application in the United States (Generated from data in Moore, 2001)

MERITS ASSESSMENT OF PROMISING NDE TECHNIQUES FOR CONCRETE BRIDGES

Because it is a formidable task to include all the existing NDE techniques for different types of bridges (concrete, steel and timber), this paper emphasizes only concrete bridges. Based on assessment of the survey data, the authors believe the following NDT technologies have good potentials to improve the concrete bridge inspection practice and recommend more research efforts on these techniques. The principle, application and recent progresses of these techniques are summarized below.

Ground-Penetration Radar Imaging

Principle:

GPR is an impulse echo technology using electromagnetic wave. The interactions of electromagnetic field with the surrounding materials are recorded by GPR electronics (Davis & Annan, 1989). Typically electromagnetic impulses have a pulse duration of ≤ 1 ns (1×10^{-9} s). Figure 2 is a schematic of the proposition of emitted impulses due to inhomogeneities in the testing material.

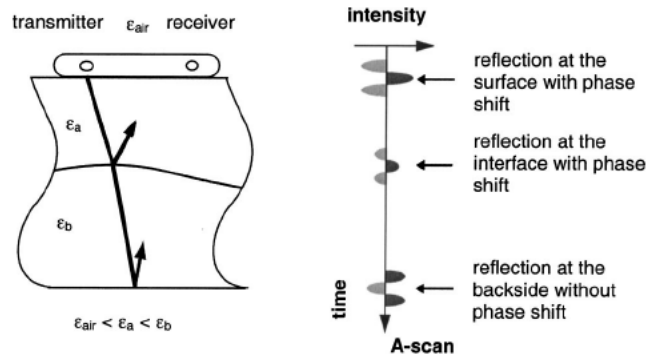


Figure 2. Schematic of GPR principles (Maierhofer, 2003)

Both the propagation velocity of the pulses and the intensity of the reflections are a function of the dielectric properties of the materials, which are defined by their complex permittivity, ε (Maierhofer, 2003):

$$\varepsilon = \varepsilon' - i\varepsilon'' \quad (1)$$

where ε complex permittivity; ε' = real part of complex permittivity; and ε'' = imaginary part of complex permittivity.

Materials with very low electric conductivity are called lossless materials. Concrete and masonry in a dry condition are lossless, thus the imaginary part ε'' can be neglected. Then the following relation between the propagation velocity v of the electromagnetic impulses and the permittivity ε can be established by approximation:

$$v = \frac{c}{\sqrt{\varepsilon}} \quad (2)$$

where v =propagation velocity of electromagnetic impulse; and c =speed of light in vacuum (33108 m/s).

With known permittivity of measured material, the position of interfaces can be determined from the location of reflections in the propagation time plot. Errors can arise due to the fact that the permittivity is influenced by a variety of parameters such as temperature of material, moisture content of material, salt content of material, and pore structure and pulse frequency (Maierhofer, 2003).

GPR works in either reflection/scattering mode or transillumination mode. In both cases, it measures one of electromagnetic field component (generally the electric field component). The intensity of electric field component is then converted to a time varying voltage signal (or in some cases it is converted to a frequency domain signal). The measured signal is determined by the transfer function of the GPR electronics as well as the surrounding materials. The reflection/scattering mode is generally used to detect changes in the surrounding environment. The original GPR signals generally need to be migrated to obtain meaningful interpretation. This is a complex process that needs special expertise.

Application

GPR is perhaps one of the most attractive NDE methods available for the detection of deteriorations in concrete bridge decks. GPR gains its popularity in concrete bridge inspection since hardened concrete is relatively low loss which is ideal for GPR surveys. Concrete is primarily composed of sand and gravel, which both have low electrical conductivity values (i.e. lossless media) and can be penetrated by GPR easily. Vast amounts of data can be collected by GPR systems at high speed. The information collected by GPR can be used to determinate delaminations and bulk concrete deterioration in the concrete structure.

GPR is a very efficient tool to determine the delamination in concrete bridge decks, asphalt-covered decks and thickness of asphalt cover. Although GPR measurements subject to the influence of moisture, it is independent of weather conditions. This method can also be used to examine the condition of the top flange of box beams. The use of dual frequency radar allows more accurate characterization of these defects (Rens et al., 2005).

More advanced processing of GPR data involves GPR imaging. GPR imaging can be used to locate and map subsurface deck features such as reinforcing steel and delaminations. It is assumed that the embedded element, such as rebar and damaged areas, represents an impedance contrast to the surrounding concrete. GPR apparatus emits electromagnetic radar waves into the bridge deck from an antenna placed on the deck surface. A GPR image is generated as waves are reflected back to the antenna after they come in contact with electrical interfaces between two media having different dielectric values. Damaged concrete causes an attenuation of the radar signal as the signal travels through the bridge deck and is reflected back from the damaged areas (Tuttle, 2005).

Limitation

GPR penetration depth is strongly dependent on the electrical conductivity of the materials to be investigated. For highly conductive materials, penetration depth is shallow. The frequency usage is a compromise between resolution and penetration. High frequency is required to produce high resolution, while low frequency is needed to obtain deep penetration. The resolution of the current GPR equipments are generally not sufficiently high for crack or dislamination detection.

Recent progress

A noteworthy development of radar system for bridge inspections is the HERMES (high-speed electromagnetic roadway measurement and evaluation system). Joint evaluation by the Lawrence Livermore National Laboratories (LLNL) and FHWA has found HERMES promising to meet the need for rapid and reliable assessment of concrete bridge decks. The target of HERMES is to develop a GPR system that can reliably detect, quantify, and image delaminations in bridge decks. So it can be operated without lane closure. The HERMES system includes a computer workstation and storage device, survey wheel, control electronics, and an array of 64 antenna modules or transceivers mounted in a towable trailer (Figure 3). The trailer can be pulled by a vehicle at traffic speeds over a bridge deck to collect information about the roadway subsurface. Its low power radar sensors gathering data 30 centimeters or more into concrete. The

most unique design feature of HERMES is the antenna array. The prototype system was delivered to FHWA in October 1998. Field testing of this system was conducted in cooperation with state transportation agencies. The field-testing program evaluated the prototype system and identified the required improvements for a second-generation system. A project to begin the development of the second generation system was initiated in October 2000 (Chong et al., 2003).

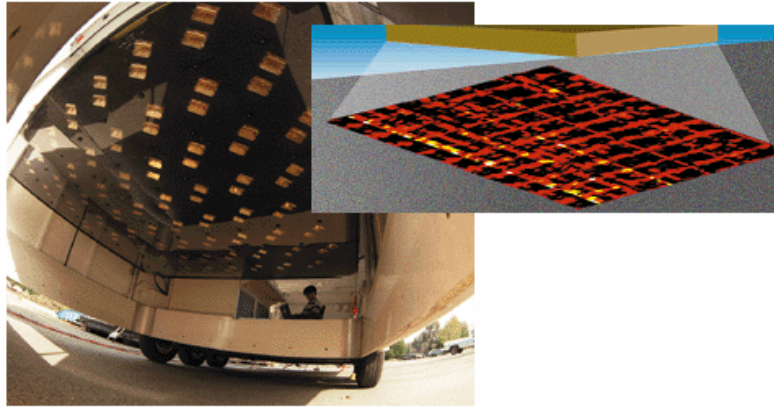


Figure 3. Trailer used for HERMES and the array of 64 radar modules (<http://www.llnl.gov/str/Hernandez.html>)

Ultrasound Method

Principles

Ultrasound Method is an impulse echo technology using ultrasound. Ultrasound refers to the high frequency wave that is too highly pitched for human ear to hear. The configuration of a typical ultrasonic testing system is shown in Figure 4. When ultrasound waves travel through media of interest, they are reflected at interfaces where there are differences in the acoustic impedances of the materials on each side of the interfaces. The difference in acoustic impedance is commonly referred to as the impedance mismatch. The greater the impedance mismatch, the greater the percentage of energy that will be reflected at the interface or boundary between one medium and another. The reflection coefficient is given in Equation (NDT Resource Center webpage, ultrasound)

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \quad (3)$$

where Z_1 and Z_2 are acoustic impedance of materials on each side of a boundary.

The acoustic impedance (Z) of a material is defined as the product of density (ρ) and acoustic velocity (V) of that material (Equation (4)).

$$Z = \rho V \quad (4)$$

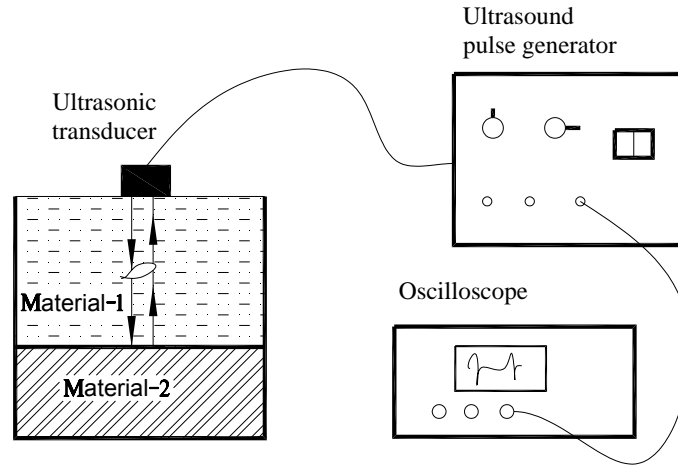


Figure 4. Schematic explanation of Ultrasonic principles

The traditional method of ultrasonic testing is called pulse echo. In the pulse-echo system, the transmitting transducer introduces a wide-band acoustic signal into the test object. The pulse propagates in the material and is scattered or reflected by the interfaces or inhomogeneities (such as cracks and voids etc.) within the object. Because of the impedance mismatch, the interfaces or the boundaries of the inhomogeneities will cause a large amount of acoustic energy to be scattered or reflected. The reflections are picked by the receiving transducer where the returning signal can be displayed as amplitude versus time (an A-scan). The depth of the interface (inhomogeneities) can be determined by sending the impulse on the surface of water and recording the transit time between the pulse reflections. A new testing method called direct-sequence, spread-spectrum, ultrasonic evaluation (DSSSUE) was recently introduced. This new method has advantages of better sensitivity and larger scan area compared to the traditional method. More details about the ultrasound method can be found in literature (Rens et al., 1997).

Application

Ultrasound Method has been used to thickness measurement of concrete members. This is particularly helpful for examine the covered structural elements to avoid the destructive method of taking cores. It can be used for internal crack detection, which is inaccessible to visual inspection. Ultrasonic imaging can be used to evaluate grouted post-tensioned tendons (Iyer, 2002). This is important as chloride-induced corrosion of reinforcing steel is the most important factor affecting the durability of reinforced concrete structures.

Limitations

The tradition ultrasonic devices require that ultrasonic transducers be bonded to the test material with an acoustical impedance matching coupling medium, such as water. The coupling medium can cause transit time errors on the order of one percent. Due to partial transmission and partial reflection of the ultrasonic energy in the couplant layer, there may be a change of shape of the waveform which can further affect velocity measurement accuracy. This can also lead to serious errors in absolute attenuation measurements, which is the reason that so few reliable absolute measurements of attenuation are reported in the scientific literature. Another important factor affecting the measurement accuracy is the piezoelectric transducer itself. Since conventional transducers do not respond as a simple vibrating piston but instead have their own frequency, amplitude, and directional response, they exert a major influence on the components of the generated ultrasonic signals (Green, 2000).

New Progress

In order to avoid the coupling problems of conventional contact transducers, a method of non-contact generation and detection of ultrasound is of great practical importance. Several such techniques are presently available in various stages of development, these include capacitive pick-ups, electromagnetic acoustic transducers (EMAT's), laser beam optical generators and detectors, and more recently air-coupled ultrasonic systems. The non-contact type ultrasonic method can potentially significantly increase the testing efficiency.

Impact Echo

Principle

The impact-echo method is a technique for flaw detection in concrete based on stress wave propagation. When a stress wave travels through an interface of different materials on each side, a portion of the incident wave is reflected. The amplitude of the reflection is a function of the angle of incidence and is a maximum when this angle is 90°. For normal incidence the reflection coefficient, R , is given by the following:

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (5)$$

where Z_2 = specific acoustic impedance of material 2 and Z_1 = specific acoustic impedance of material 1.

Similar as for the ultrasonic method, the acoustic impedance is the product of the wave velocity and material density.

The basic principle of impact echo method is illustrated in Figure 5. A transient stress wave impulse is generated by a mechanical impact on the surface. P-wave, S-wave and R-wave are generated by the impact. P-waves and S-waves propagate into the object along spherical wavefronts, and are reflected by the internal interfaces or the external boundaries. The surface wave, R-wave, travels along the surface away from the impact point. The arrivals of the reflected waves generate displacements that are recorded by receiving transducers amounted on the impact surface. Because of the natures of wave propagation, the displacement waveforms recorded will be dominated by P-waves if the receiver is put close to the impact point. Thus the recorded waveform can be used to determine the travel time, which the time needed for P-wave travel from the initiation surface, to the reflection interface and back to the receiver. Velocity of P-wave is dependent on the material properties. Thus the distance from initiation surface to the reflection interface can be determined (Carino, weblink).

The recorded signals can also be analyzed in the frequency domain. The recorded surface displacement waveform is transformed into the frequency domain by using the fast Fourier transform technique (Bracewell 1978). The computed amplitude spectrum shows the dominant frequency components in the waveform. For slab-like structures, the frequency corresponding to the thickness of slab will usually be the dominant peaks in the spectrum.

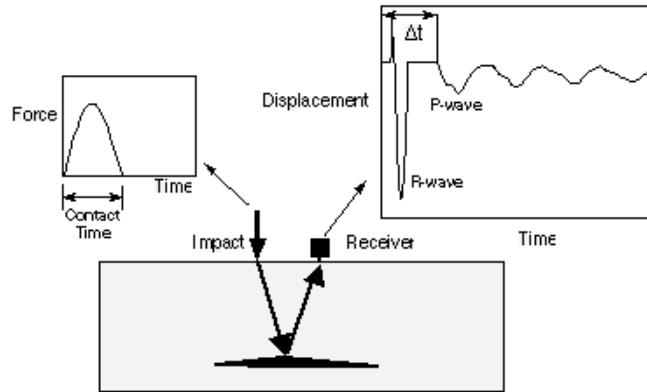


Figure 5. Schematic explanation of impact echo method (Carino, weblink)

Application

The impact-echo method has been successfully used in detecting a variety of defects, such as voids and honeycombed concrete in members, delaminations in bare and overlaid slabs, and voids in tendon ducts. Experimental studies have been supplemented with analytical studies to gain a better understanding of the propagation of transient waves in bounded solids with and without flaws. Application of the method has been extended to prismatic members, such as columns and beams. The method has also been applied to evaluate the quality of the bond between an overlay and base concrete (Chong et al., 2003).

New Progress

During the initial development of the impact-echo technique, interpretation of the recorded waveforms was performed in the time domain. This required establishing the time of impact initiation and the arrival time of the first echoed P-wave. While this was feasible, it was found to be challenging and time-consuming under non-ideal circumstances. The alternative approach of using the frequency domain analysis works under certain circumstances. However, both analyses in time domain and in frequency domain fail to detect the miniature details. For example, the amplitude spectra, based on fft, can only provide global information and lose important local effects of the frequency components, which correspond to the details of concrete flaws. There have been progresses in applying wavelet analyses to provide multiscale images of concrete internal structures. The wavelet image combines the advantage of time and frequency domain analyses to achieve high accuracy and high resolution for concrete internal crack determination.

Infrared Thermography

Principle

Infrared thermography is a technique of mapping the surface temperature. Infrared is an invisible electromagnetic wave with a wavelength range from 0.75~1000 μm , which is longer than that of visible light and shorter than that of microwave. A typical infrared system is shown in Figure 6. Infrared thermography basically includes a camera, equipped with a series of changeable optics, and a computer. The core of the camera is the infrared detector, which absorbs the IR energy emitted by the object (whose surface temperature is to be measured) and converts it into electrical voltage or current. Any object emits energy proportional to its surface temperature as governed by Stefan-Boltzman law (Meola and Carlomagno, 2004):

$$E_{\lambda} = \varepsilon_{\lambda} \sigma T^4 \quad (6)$$

where E_λ = total emitted energy (W/m^2); T = absolute temperature of the body (K^4); σ = Stefan-Boltzman constant (W/m^2K^4); ε_λ = the spectral emissivity coefficient;

So, the energy really detected (by the infrared detector) depends on the emissivity coefficient of the surface under measurement and also on the environment. More detailed information of emissivity can be found in the cited reference (Meola and Carlomagno, 2004).

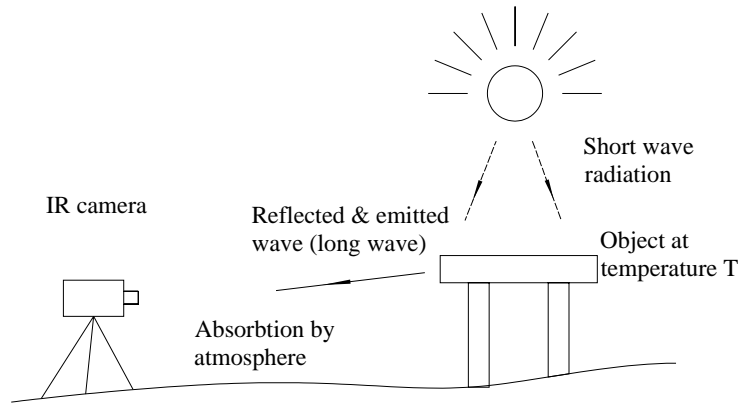


Figure 6. Measuring temperature of a object using IR camera

Infrared radiography of stress pattern analysis is based on the thermoelastic effect in structural materials. Compression and tension cycles (fatigue) produce heating or cooling of the solids. Pressures in an area of a solid show up as a stressed region where heat is generated or absorbed. This is known as the thermoelastic effect, i.e., the change of temperature that accompanies elastic deformation of a body. Thus stress concentrations in joints or areas of high fatigue show up as "hot spots" in IR scans (Rens et al., 1997).

Thermal effects can be monitored in two ways; both ways involve heating the structure or specimen and measuring the flux change. Thermal effects can be obtained by physically heating the structure with lamps (until thermal equilibrium is reached) or applying stress reversals to fatigue the structure or part. In each of these methods, the change in heat can be related to stress or areas of deterioration. Thermal properties can be measured during the day or night as long as heat transfer is taking place on the structure, i.e., the surrounding environment has a different temperature from that of the part or structural system (Rens et al., 1997).

Applications

IR emission has been used in a variety of applications. In bridge engineering, it can be used to inspect concrete bridge decks for debonding and delamination conditions and for determining the corrosion levels of reinforcing steel. Detailed information of detecting delamination in concrete deck using infrared thermography can be found in ASTM D 4788-88.

A project was performed by Kansas Department of Transportation in 1996 to evaluate conditions of asphalt concrete overlaid concrete bridge decks using infrared thermography and GPR. The targets are to find subsurface anomalies, delaminations and de-bonding as the traditional method of mechanical sounding is a less effective option for finding subsurface defects after an overlay is in place. The infrared thermograph and ground penetrating radar study did find a significant amount of the subsurface anomalies that were not identified using traditional methods. But there was no clear answer of the accuracy the infrared thermography and GPR method (Alt and Meggers, 1996).

An extensive field application of IR emissions on concrete structures is being performed by Greiner consultants of Baltimore, Md. (Commentary 1988). The project team has used IR scanning to inspect concrete bridge decks for debonding and delamination conditions and for determining the corrosion levels of reinforcing steel (Rens, et al., 1997). This study showed that structural problems can be identified and located quickly, causing minimal disruption to traffic since the system is remote. Thermal techniques have been used to analyze steel corrosion levels. Louisiana State University has used infrared spectroscopy to identify developing rust phases and weathering characteristics of steel coupons taken from deteriorating bridge spans.

Merits and Limitations

Highway agencies find the infrared thermography technique very attractive because it is an area testing method rather than point method. Data analysis is simple and the results of the surveys can be obtained in real time. The advantages include: fast data acquisition, minimal surface preparation, works good on complex geometries, high sensitivity, no contact needed, portable, and usable during the day or evening. Infrared thermography is suitable for composite structure such as fiber reinforce polymer (FRP) composite. In the study of NCHRP Project 10-64, thermography along with ultrasonic testing are rated as most practical NDE techniques for inspection of FRP bridge deck.

However, the efficiency of the technique is a function of the environmental conditions as well as of the decks' conditions. Its first cost is high. Structures need to be fatigued or heated prior to the thermal testing. A major disadvantage of the technique is that the depth of defects cannot be determined. As a consequence, it is not possible to determine if a subsurface void is near the surface, at the asphalt-concrete interface, or farther down at the level of the reinforcing bars. In addition, the resolution of the technique decreases significantly as the asphalt coating thickness increases. Infrared thermography is often used in combination with the ground penetrating radar technique to improve the reliability of bridge deck condition assessments.

Radiography

Principle

Radiography typically involves positioning a radiographic energy source on one side of an object and a recording medium such as film on the other side. Radiation travels through the object and exposes the film. Local material density controls how much radiation passes through the material resulting in a two-dimensional picture of density variation in the object under inspection. The radiation sources are typically x-ray or gamma ray.

X-rays and gamma rays differ only in their source of origin. X-rays are produced by an x-ray generator and gamma radiation is the product of radioactive atoms. Both rays are parts of the electromagnetic spectrum similar as light rays, microwaves, and radio wave. X-rays and gamma rays cannot be seen, felt, or heard. They possess no charge and no mass and, therefore, are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light due to variation of certain material properties in the propagation path (NDT Resource Center webpage, Radiography).

When x-rays or gamma rays are directed into an object, some of the photons interact with the particles of the matter and their energy can be absorbed or scattered. This absorption and scattering is called attenuation. Other photons travel unaffected through the object without interacting with any of the materials particles. The number of photons transmitted through a material depends on the thickness, density and atomic number of the material, and the energy of the individual photons. Thus the photo generated on film is a reflection of the properties of the scanned object. The existence of cracks or corrosion will generate distinctive patterns on the X-ray or gamma rays radiography.

Application

Radiography is suitable to investigate locations of rebar, voids and ducts, and density of concrete. Gama rays are routinely used for measuring the soil densities. In gamma radiography, the reflected intensity of backscatter of the rays is related to the density of the concrete and can, therefore, be used to locate voided and poorly compacted concrete. The equipment is portable and comparatively easy to use. Long exposure times are not needed for gama rays in contrast to the X-ray photography. The backscatter method has a shortcoming in that it only examines the range of concrete within around 50mm from the surface. The X-ray technique provides an internal picture of the concrete. The method can determine the voids in the concrete, but is not frequently used due to the high cost and long exposure times required (Al-Ostaz, 2004).

Limitations

Conventional radiographic techniques perform well in the laboratory and show promise for field use, but the equipment is generally heavy and the power consumption is large. Power sources of continuous 250 kV–4 MV are often needed to penetrate the thick and dense materials used in civil infrastructure applications. Portability of the equipment and access to the location to be evaluated are two major problems encountered during field implementation. Besides, the cost of radiographic tests are generally high.

The main drawback of using conventional radiographic techniques for inspecting structural members is that they utilize photoelectric absorption to produce an internal image of the member. Photoelectric absorption inherently requires access to two opposite sides of the object being inspected. Devices based on Compton scattering rather than photoelectric absorption measures reflected gamma rays. The scattering method requires access from one side and this can be a major advantage if the object is part of a large structure.

New Progress

Advanced technique called computed tomography (CT) could be used to produce a three-dimensional representation of the internal structure of an object. The object is essentially radiographed at various orientations and then computer analyses are used to construct the three-dimensional (3D) image. Civil Engineering applications often require high spatial resolution. However, the finite width of radiography (x-ray) sampling limits its spatial resolution. NSF has invested in research to improve the efficiency of computational methods to deconvolve the beam width from the projection data without increasing the noise in the reconstructed image. The progresses in this area could potentially provide improved imaging tool for diagnose infrastructures.

SUMMARY

This paper provides a general overview on the trend of using NDE technologies for bridge inspection. Results of several surveys were compiled and discussed, which indicated that there is increased interest of using NDE technologies to improve the bridge inspection practice. State DOTs generally take an open-minded attitude for the adoption of NDE technologies. However, these technologies must show appreciable amount of advantages to gain widely acceptance. This paper then briefly discusses a few NDE technologies that are promising to assist the performance evaluation of concrete bridges. The basic principle, the major applications and limitations are provided. The new trends in developing these technologies are also highlighted.

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