REMR TECHNICAL NOTE CS-ES-1.10

NONDESTRUCTIVE TESTING OF CONCRETE WITH ULTRASONIC PULSE-ECHO

PURPOSE: To provide information on the Ultrasonic Pulse-Echo (UPE) system as a nondestructive technique to determine the quality and condition of surface and interior concrete in the dry or underwater.

INTRODUCTION: Scientists at the U.S. Army Engineer Waterways Experiment Station (WES) recently developed a nondestructive technique for "seeing into" concrete. This technique, known as UPE, is an acoustic method based on introducing ultrasonic stress waves into concrete with a piezoelectric element. Both signal generation and detection are accomplished with piezoelectric crystals. For decades, UPE has been routinely used in the fields of metal testing, underwater detection and ranging (sonar), as well as for testing and evaluating other homogeneous and fine-grained materials. At WES, this technology was adapted to concrete through the development of specialized hardware and software. The system works especially well on concrete walls or slabs with a thickness of I ft or less. Structures such as sea walls, pavements, walls, floors, parking garages, bridge decks, etc. are ideally suited for this device. The diagnostic capacity of this device represents a significant breakthrough for evaluating a difficult nonhomogeneous composite material such as concrete.

DEVELOPMENT: A literature search for nondestructive test methods for concretes revealed that more pulse-echo research was needed. A commercial system for making pulse-echo measurements could not be found on the market.

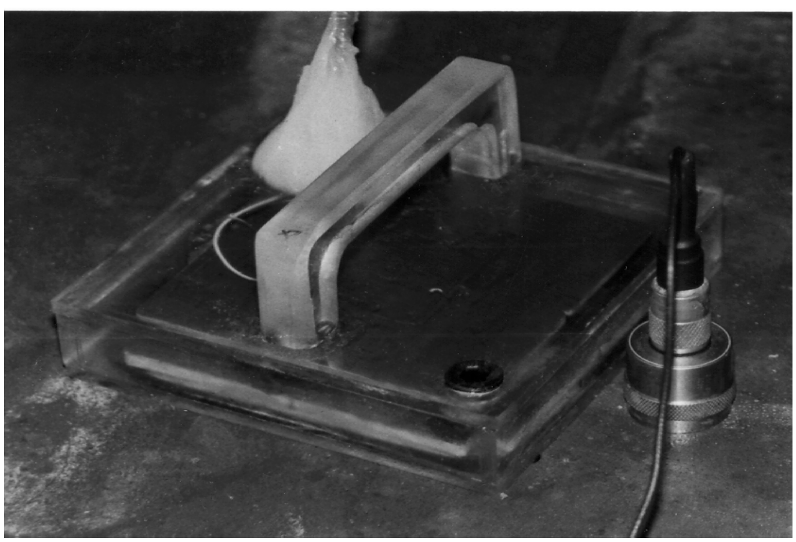

Figure 1. Illustration of the ultrasonic pulse echo technique concrete plate element.

Although investigators had made some progress in understanding the problems associated with the development of pulse echo for concrete, the heterogeneous nature of concrete and the state-of-the-art of ultrasonic materials and techniques had prevented development of a practical system like that used for homogeneous materials. Literature revealed that resolution was poor because of long pulse lengths (high Q value) for the transducers. Investigators had problems with interfering Rayleigh waves at low frequencies. Signal-to-noise ratios (SNR) ranged from only about 2 to 6. An earlier pulse-echo system, the Ohio State University device, had a diameter of 18 in. (457 mm) and a mass of 40 lb (18 kg). Measurements showed extraneous signals other than the desired longitudinal mode because of mode conversion in the transducers. Also, transducers lacked the proper focal length, directivity, and sensitivity. Research at WES resulted in the development of a pitch-catch system that operates at a center frequency of 200 kHz with a signal to noise ratio of 18. The mass and dimensions of the improved system have been reduced 90% from the prior state-of-the-art system. The present system works well for making thickness measurements of portland-cement concrete floors and walls, and it can indicate the presence of voids to a depth of approximately 12 in.

PRINCIPLE OF OPERATION: An ultrasonic (acoustic) wave is generated by exciting a piezoelectric material with a high-amplitude, transient electrical pulse from a high-voltage, high-current pulser. The short burst of ultrasonic energy from the crystal is transmitted into the concrete and impinges upon the various interfaces within. The change in acoustic impedance at the various interfaces, air voids, water-filled voids, reinforcing bars, cracks, delaminations and other interfaces or inclusions within the concrete causes a portion of the input energy to reflect (echo) back to the surface. There the energy is detected by a second piezoelectric element. A larger portion of the energy continues to travel forward, strike other interfaces and return an amount of energy based on (1) the area of the reflecting surface, (2) the angle of the reflecting surface, and (3) the acoustic impedance of the reflecting material. The time for the echo to return is measured with the

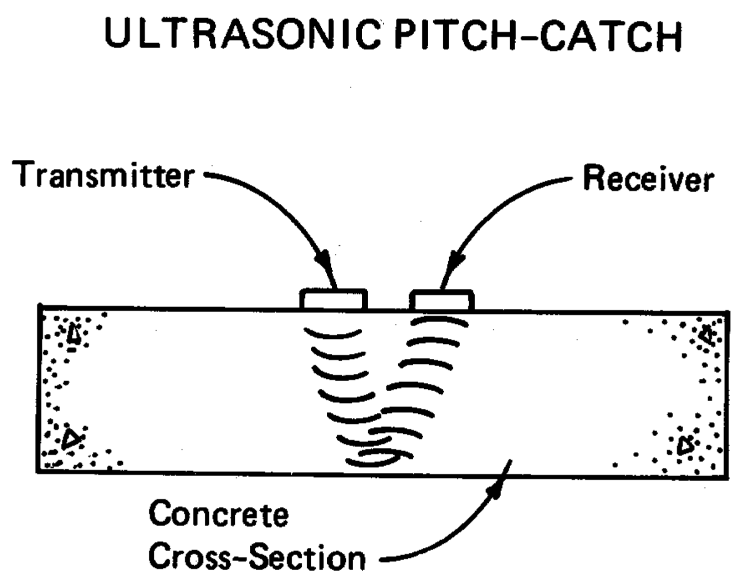

Figure 2. Measurement of time-of-arrival (TOA) of backwall echo using lead metoniabate as transmitter and polyvinyldene fluoride (PVDF) as receiver.

accurate time base of an oscilloscope. The complete signal is stored on magnetic disc and can be retrieved at any time for further analysis.

It is a well-known fact that the ultrasonic pulse velocity of concrete is a very good indicator of its condition. For a known thickness of concrete (such as a bridge deck for example), the velocity (v) of the concrete can be determined by the equation v " 21/t where I = thickness of the concrete, and 21 is the two-way travel distance of the ultrasonic pulse and t = time of arrival of backwall (BW) echo.

Generally the concrete in the structure will have a very narrow range of velocity when it is sound because the structure generally consists of one concrete design mixture. In localities where deterioration or microcracking has taken place, the concrete will have a noticeably reduced velocity.

APPLICATION: Preliminary tests with the UPE system on a concrete sea wall indicated that the system will pinpoint locations where the concrete is sound or deteriorated. It was found that the presence or absence of the BW echo is significant in determining the condition of the concrete. Typical SNR's of the BW echo from the nominally 9-in. thick concrete wall was about 3 to 6. Unsound concrete produced backscattering and dissipation of the introduced energy to the extent that the noise in front of the BW echo obscured or eliminated it altogether. In some places where the concrete surface is pitted, chipped, corroded with barnacles, or otherwise deteriorated, surface preparation is necessary to obtain a flat surface. Even in sound concrete the BW echo can be absent (for dry surface measurements) unless the small air voids between the transducer face and the concrete surface can be squeezed out with couplant grease to bring about the necessary intimate contact. This is not a problem in underwater measurements.

Although about 60 to 70 percent of the available information can be extracted from the raw signal measured in the field, subtle information hidden by the noise in the signal can be restored by the process of Digital Signal Processing (DSP) at the laboratory. DSP is a high-technology operation used by NASA and others to recover information hidden in noise from communications with space vehicles, submarines, satellite communications, etc. Plans are underway to develop a real-time system with the DSP performed almost instantaneously in the field. Some of the noise is an inherent part of the measurement hardware and cannot be eliminated at the current time until the state-of-the-art of piezoelectric materials can be improved. However, that particular noise has been analyzed in terms of its frequency components, and its characteristics have been defined. With the known information about the noise, digital filters can be built that are capable of attenuating the noise while retaining the valid signal information hidden in the raw signal.

ADVANTAGES: An important benefit of UPE is that it is nondestructive and can be used in the dry or underwater. Also, significant savings are gained by eliminating the bulk of coring that normally is needed. The information gained from UPE evaluation makes it possible to precisely map the regions of quality concrete and those regions that have deterioration. Because faulty zones can be pinpointed, repairs can be localized less expensively.

Another important feature of UPE is its ability to monitor the condition of a structure over time. The first set of measurements (original construction and restored areas) can serve as baseline data that can be compared with a set of data measured later (1 yr, 5 yr, etc.) The baseline data is stored on magnetic discs (fixed or floppy) and can be retrieved and plotted either over or adjacent to the new signals for comparison purposes. This ability to monitor the condition of a structure for years to come is important in investigating the causes of deterioration, the effectiveness of remedial repairs and the prevention of future problems.

LIMITATIONS: Considerable engineering judgment is needed to properly evaluate a measurement. Misinterpretation is possible when poor contact is made. For example, in some cases it may not be possible to identify severely corroded reinforcing bar in poor quality concrete. However, it is possible to identify poor quality concrete which could be the cause of reinforcing bar problems. The poor quality concrete allows the ingress of moisture and oxygen to the reinforcing bars, and hence corrosion occurs. Presently the system is limited to penetration depths of 1 ft. Research is ongoing to develop a system that can penetrate to a depth of 10 ft or more.