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Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method[1]

This standard is issued under the fixed designation C 1383; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining the thickness of concrete slabs, pavements, bridge decks, walls, or other plate-like structure using the impact-echo method.

1.2 The following two procedures are covered in this test method:

1.2.1 *Procedure A: P-Wave Speed Measurement*—This procedure measures the time it takes for the P-wave generated by a short-duration, point impact to travel between two transducers positioned a known distance apart along the surface of a structure. The P-wave speed is calculated by dividing the distance between the two transducers by the travel time.

1.2.2 *Procedure B: Impact-Echo Test*—This procedure measures the frequency with which the P-wave generated by a short-duration, point impact is reflected between the parallel (opposite) surfaces of a plate. The thickness is calculated from this measured frequency and the P-wave speed obtained from Procedure A.

1.2.3 Both Procedure A and Procedure B must be performed at each point where a thickness determination is made.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 597 Test Method for Pulse Velocity Through Concrete[2]

E 1316 Terminology for Nondestructive Examinations[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *acoustic impedance*—the product of P-wave speed and density that is used in computations of characteristics of stress wave reflection at boundaries.

3.1.2 *amplitude spectrum*—a plot of relative amplitude versus frequency that is obtained from the waveform using a Fourier transform technique.

3.1.3 *Fourier transform*—a numerical technique used to convert digital waveforms from the time domain to the frequency domain.

3.1.3.1 *Discussion*—The peaks in the amplitude spectrum correspond to the dominant frequencies in the waveform.

3.1.4 *impact-echo method*—a send-receive nondestructive test method based on the use of a short-duration mechanical impact to generate transient stress waves and the use of a broadband receiving transducer placed adjacent to the impact point.

3.1.4.1 *Discussion*—Waveforms are converted to the frequency domain and the resulting amplitude spectra are analyzed to obtain the dominant frequencies in the structure's response to the impact. These frequencies are used to determine the thickness of the structure or the presence of flaws.

3.1.5 *impact duration*—the time that the impactor used to generate stress waves is in contact with the test surface. Also referred to as contact time.

3.1.5.1 *Discussion*—The impact duration is a critical aspect in the success of the two procedures covered by this method. Recommended impact durations are given. In practice, the impact duration will depend on the type of impactor and the condition of the concrete at the point of impact. Smooth, hard surfaces will result in shorter impact durations than rough, soft surfaces. The user should verify that the impact durations are within the recommended ranges. An approximate measure of the impact duration can be obtained from the portion of the waveform corresponding to the surface wave arrival.[4] Fig. 1 shows an example of the surface-wave portion of a waveform and the approximate contact time is indicated.

3.1.6 *P-wave*—the dilatational (longitudinal or primary) stress wave which causes particle displacement parallel to the

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

[4] Sansalone, M. and Streett, W.B., *Impact-Echo: Nondestructive Evaluation of Concrete and Masonry*, Bullbrier Press, Ithaca, NY and Jersey Shore, PA, 1997.

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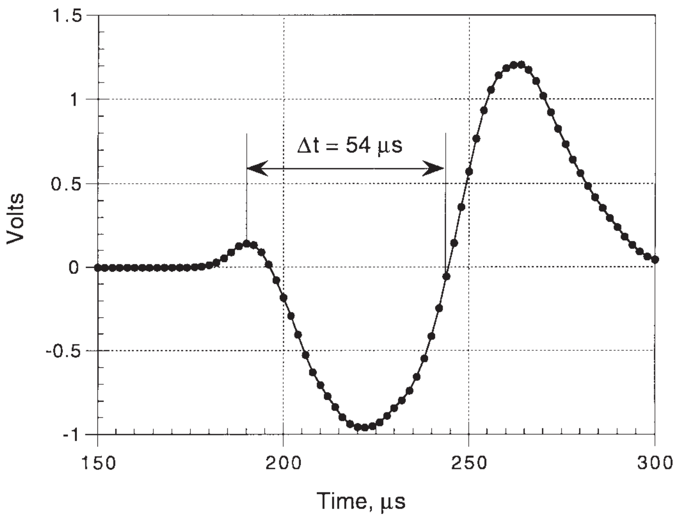

FIG. 1 Expanded View of Surface-Wave Portion of Waveform Showing the Width of the Surface Wave Signal as an Approximation of the Contact Time of the Impact

direction of wave propagation. This wave produces normal stresses (tensile or compressive) as it propagates.

3.1.7 *P-wave speed*—the speed with which the P-wave propagates through a semi-infinite solid.

3.1.7.1 *Discussion*—The P-wave speed is the same as the compressional pulse velocity measured according to Test Method C 597.

3.1.8 *sampling period*—the duration of the waveform which equals the number of points in the waveform multiplied by the sampling interval.

3.1.9 *sampling interval*—the time difference between any two adjacent points in the waveform.

3.1.10 *surface wave*—a stress wave in which the particle motion is elliptical and the amplitude of particle motion decreases rapidly with depth. Also known as *Rayleigh wave* (or *R-wave*).

3.1.11 *waveform*—a recorded signal from a transducer that is a plot of voltage versus time.

3.1.12 Refer to Terminology E 1316 for additional definitions, related to nondestructive ultrasonic examination, that are applicable to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent P-wave speed in a plate*[4,5]—a parameter that is 0.96 of the P-wave speed:

$$C_{p,\,plate} = 0.96\, C_p \tag{1}$$

where:

$C_{p,\,plate}$ = the apparent P-wave speed in a plate, and
C_p = the P-wave speed in concrete that is obtained from Procedure A.

3.2.1.1 *Discussion*—This parameter is used in thickness calculations in impact-echo measurements on plates. The P-wave speed in a material (concrete) is converted to the apparent P-wave speed that is related to the plate thickness through the following equation:

$$T = \frac{C_{p,\,plate}}{2f} \tag{2}$$

where:

T = the thickness of the plate, and
f = the frequency of the P-wave thickness mode of the plate obtained from the amplitude spectrum.

3.2.2 *plate*—any prismatic structure where the lateral dimensions are at least six times the thickness.

3.2.2.1 *Discussion*—Minimum lateral dimensions are necessary to prevent plate modes[4] of vibration from interfering with the identification of the thickness mode frequency in the amplitude spectrum. The minimum lateral dimensions and acceptable sampling period are related, as explained in Note 9.

4. Significance and Use

4.1 This test method may be used as a substitute for, or in conjunction with, coring to determine the thickness of slabs, pavements, decks, walls, or other plate structures. There is a certain level of systematic error in the calculated thickness due to the discrete nature of the digital records that are used. The absolute systematic error depends on the plate thickness, the sampling interval, and the sampling period.

4.2 Because the wave speed can vary from point-to-point in the structure due to differences in concrete age or batch-to-batch variability, the wave speed is measured (Procedure A) at each point where a thickness determination (Procedure B) is required.

4.3 The maximum and minimum thickness that can be measured is limited by the details of the testing apparatus (transducer response characteristics and the specific impactor). The limits shall be specified by manufacturer of the apparatus, and the apparatus shall not be used beyond these limits. If test equipment is assembled by the user, thickness limitations shall be established and documented.

4.4 This test method is not applicable to plate structures with overlays, such as a concrete bridge deck with an asphalt or portland cement concrete overlay. The method is based on the assumption that the concrete plate has the same P-wave speed throughout its depth.

4.5 Procedure A is performed on concrete that is dry as a high surface moisture content may affect the results.

4.6 Procedure B is applicable to a concrete plate resting on a subgrade of soil, gravel, permeable asphalt concrete, or lean portland cement concrete provided there is sufficient difference in acoustic impedance[4] between the concrete and subgrade or there are enough air voids at the interface to produce measurable reflections. If these conditions are not satisfied, the waveform will be of low amplitude and the spectrum will not include a dominant peak at the frequency corresponding to the thickness (Eq 2). If the interface between the concrete and subgrade is rough, the amplitude spectrum will have a rounded peak instead of a sharp peak associated with a flat surface.

4.7 The procedures described are not influenced by traffic noise or low frequency structural vibrations set up by normal movement of traffic across a structure.

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[5] Sansalone, M., Lin, J. M., and Streett, W. B., "A Procedure for Determining P-wave Speed in Concrete for Use in Impact-Echo Testing Using P-wave Speed Measurement Technique," *ACI Journal*, Vol. 94, No. 6, November-December 1997, pp. 531–539.

4.8 The procedures are not applicable in the presence of mechanical noise created by equipment impacting (jack hammers, sounding with a hammer, mechanical sweepers, and the like) on the structure.

4.9 Procedure A is not applicable in the presence of high amplitude electrical noise, such as may produced by a generator or some other source, that is transmitted to the data-acquisition system.

PROCEDURE A—P-WAVE SPEED MEASUREMENT

5. Summary of Procedure

5.1 An impact on the concrete surface is used to generate transient stress waves. These waves propagate along the surface of the concrete past two transducers, placed on a line through the impact point and at a known distance apart.

5.2 The time difference between the arrival of the P-wave (stress wave with highest speed) at each transducer is used to determine the P-wave speed by dividing the time difference (travel time) by the known distance between the transducers.

6. Apparatus [6]

6.1 *Impactor*—The impactor shall be spherical or spherically tipped. It shall produce an impact duration of 30 ± 10 µs with sufficient energy to produce surface displacements due to the P-wave that can be recorded by the two transducers (see Note 1). The impactor shall be positioned to strike on the centerline passing through the two transducers at a distance of 150 ± 10 mm from the first transducer.

NOTE 1—Hardened steel balls ranging from 5 to 8 mm in diameter and attached to steel spring rods have been found to produce suitable impacts.

6.2 *Transducers*— Two broadband, piezoelectric transducers that respond to normal surface displacements. These transducers must be capable of detecting the small displacements that correspond to the arrival of the impact-generated P-wave traveling along the surface. A small contact area between the piezoelectric element and the concrete surface is required to record accurately the arrival of the P-wave (see Note 2). Use a suitable material to couple the transducer to the concrete.

NOTE 2—A commercially available displacement transducer made from a conical piezoelectric element with a tip diameter of 1.5 mm and the larger end attached to a brass backing block has been found suitable.[7] A lead sheet approximately 0.25 mm thick is a suitable coupling material for such a transducer.

6.2.1 Acceptable transducers shall be previously documented to produce accurate results for plate thicknesses similar to those being measured by this test method.

6.3 *Spacer Device*— A spacer device shall be provided to hold the transducers a fixed distance apart. It shall not interfere with the ability of the transducers to measure surface displacement. It shall be manufactured to minimize the possibility of P-wave transmission through it so as to prevent interference with measurement of the P-wave travel time. The transducer tips shall be placed about 300 mm apart. Measure and record to the nearest 1 mm the actual distance between the centers of the transducer tips.

NOTE 3—The accuracy of the measurement is affected if the distance between the tips of the two transducers is not known accurately. The materials and design of the spacer device should be chosen to minimize the change in separation of the transducers due to changes in temperature.

6.4 *Data-Acquisition System*—Hardware and software for acquiring, recording, and processing the output of the two transducers. This system can be a portable computer with a two-channel data-acquisition card, or it can be a portable two-channel waveform analyzer.

6.4.1 The sampling rate for each channel shall be 500 kHz or higher (sampling interval of 2 µs or less). The system shall be capable of triggering on the signal from one of the recording channels.

6.4.2 The voltage range and voltage resolution of the data aquisition system shall be matched with the sensitivity of the transducers so that the arrival of the P-wave is determined accurately.

NOTE 4—For example, a computer data acquisition card with a voltage range of ± 2.5 V and 12-bit resolution has been found to be suitable for the transducer described in Note 2.

6.4.3 The display system shall include cursors, including a corresponding readout of time and voltage, that can be positioned at the point in each waveform corresponding to the P-wave arrival.

6.4.4 The data-acquisition system shall be operated by a power source that does not produce electrical noise detectable by the transducers and data acquisition system when the system is set at the voltage sensitivity required to detect the arrivals of the P-wave.

NOTE 5—Battery-powered data acquisition systems have been found suitable.

6.5 *Cables and Connectors*—To connect the transducers to the data acquisition system. Connectors shall be high quality and tightly connected to the cables. The cables shall be shielded to reduce electrical noise.

6.6 *Functionality Check Apparatus*—Apparatus to verify that all components of test system are functioning properly prior to the start of testing. This may include a reference test specimen whose impact response has been determined and can be compared with the output of the test system.

7. Preparation of Test Surface

7.1 The test surface shall be dry. Remove dirt and debris from the surface where the P-wave speed is to determined.

7.2 If the test surface is extremely rough so that it is difficult to achieve good contact between the transducer tips and the concrete, grind the surface so that good contact is achieved. Remove loose material prior to coupling the transducers to the surface.

NOTE 6—Surface roughness may be a problem when testing highway pavements with roughly textured or grooved surfaces. On new construction, curing compounds may have to be removed at test locations to permit proper coupling of the transducers and to obtain short duration impacts.

[6] Suitable apparatus is available commercially.

[7] Proctor, T.M., Jr., "Some Details on the NBS Conical Transducer," *J. of Acoustic Emission*, Vol 1, No. 3, pp. 173–178.

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8. Procedure

8.1 Fig. 2 shows a schematic of the test set-up for Procedure A.

8.2 Assemble the apparatus (transducers, spacer device, impactor). Verify that the test system is functioning properly. Position the apparatus on the concrete surface, and position the impactor to strike on the line passing through the two transducers and at a distance of 150 ± 10 mm from the first (triggering) transducer. If testing on a grooved surface, test parallel to the grooves, so that the line through the transducers and the impactor does not cross a groove. If cracks are present, position the apparatus so that no cracks intersect the line passing through the impact point and the two transducers.

8.3 Ready the data-acquisition system with correct data acquisition parameters (sampling rate, voltage range, triggering level, delay, and so forth). To ensure that initial portions of the waveforms are captured, set the data acquisition parameters so that about 100 data points are recorded prior to the trigger point.

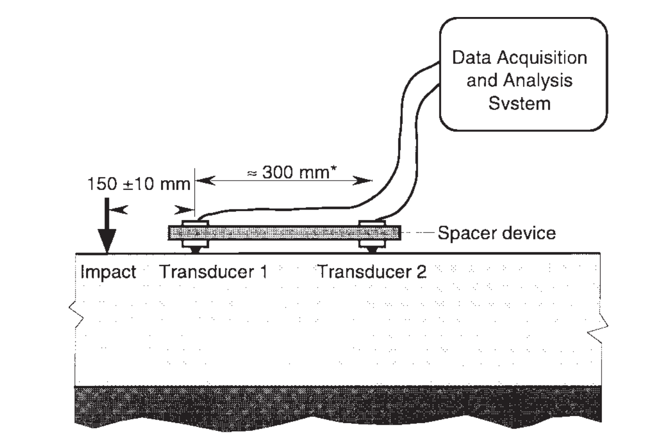
8.4 Perform the impact. Examine the acquired waveforms. If the waveforms from both transducers are valid, store the data for subsequent analysis. If the P-wave arrivals cannot be identified with certainty, repeat the test at the same position or move to a different position to achieve good coupling between the transducers and concrete.

NOTE 7—Fig. 3 is an example to illustrate a valid set of waveforms with the arrows positioned at the points corresponding to the P-wave arrivals in each waveform. In this case the arrivals of the P-wave at the transducer locations are clearly identified by the rise of the waveforms above background levels. The calculated P-wave speed is 0.3/(0.000076) = 3950 m/s, which is a reasonable value.

9. Data Analysis and Calculations

9.1 Display on the screen of the data acquisition system the waveforms from the two transducers so that they are plotted against the same time axis.

9.2 Identify the arrival time of the direct P-wave in each waveform. The arrival of the P-wave is identified as the first point where the voltage changes from the base line value (see Fig. 3). Use the cursors to display the voltage and time readings at the points corresponding to the P-wave arrivals. Determine



*Measure to nearest 1 mm the actual distance between centers of transducers

FIG. 2 Schematic of Testing Configuration for Procedure A

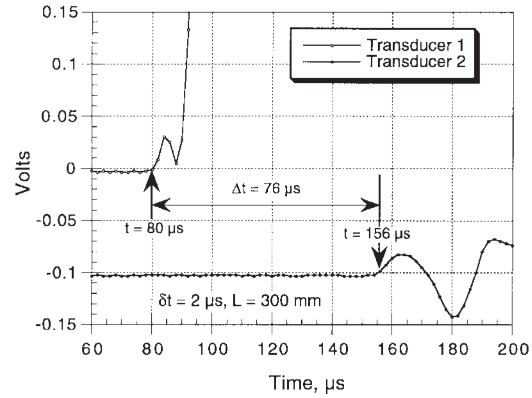


FIG. 3 Example of waveforms obtained using Procedure A (Only Early Part of Waveforms are Plotted)

the time difference, Δ t, between the arrival of the P-wave in each waveform. This time difference is the travel time.

9.3 Use the measured travel time, Δ t, and known spacing between the transducers, L, to calculate the P-wave speed:

$$C_p = \frac{L}{\Delta t} \quad (3)$$

9.4 Perform two replicates of the test at each test location. If the measured travel time is the same in both cases, then proceed to other test points. If the two travel times differ by one sampling interval or more, perform a third test and accept that travel time that repeats as the correct value. If two of the three measurements do not agree, ensure that the transducers are making good contact with the surface, and repeat the test.

9.5 Calculate the apparent P-wave speed in a plate using Eq 1.

PROCEDURE B—IMPACT-ECHO TEST

10. Summary of Test Method

10.1 Impact on the surface of the concrete generates stress waves, of which the P-wave is of primary importance. The P-wave propagates into the plate and is reflected from the opposite surface.

10.2 Multiple reflections of the P-wave between the plate surfaces give rise to a transient thickness resonance with a frequency related to the plate thickness.

10.3 A receiving transducer, located adjacent to the impact point, records the surface displacement caused by the arrival of the reflected waves. The output of the transducer is captured as a time domain waveform.

10.4 The recorded waveform is transformed into the frequency domain using a Fourier transform technique and an amplitude spectrum is obtained. The thickness resonance produces one dominant peak in the spectrum, which can be readily identified. The frequency value of this peak is used in conjunction with the apparent P-wave speed obtained from Procedure A to calculate the thickness of the plate by using Eq 2.

11. Apparatus

11.1 *Impactor*—The impactor shall be spherical or spherically tipped. It shall deliver sufficient energy to a solid plate so

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