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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 C1383; 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 at 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 Unless specified otherwise, 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 standard. No other units of measurement are included in this standard.

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

1.5 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

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***A Summary of Changes section appears at the end of this standard**

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C125 Terminology Relating to Concrete and Concrete Aggregates
C597 Test Method for Pulse Velocity Through Concrete
E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology C125 and Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *P-wave, n*—the dilatational (longitudinal or primary) stress wave that causes particle displacement parallel to the direction of wave propagation: this wave produces normal stresses (tensile or compressive) as it propagates.

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

3.2.3.1 *Discussion*—
The P-wave speed is the same as the compressional pulse velocity measured according to Test Method C597.

3.2.4 *apparent P-wave speed in a plate*[3,4], *n*—a wave speed that is equal to 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, m/s, and
C_p = the P-wave speed in concrete that is obtained from Procedure A, m/s.

3.2.4.1 *Discussion*—
This wave speed is used in thickness calculations in impact-echo measurements on plates. The P-wave speed measured using Procedure A is converted to the apparent P-wave speed in a plate that is used to calculate the plate thickness by the following equation:

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

where:

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

If the alternative procedure in 9.6 is used to determine the apparent P-wave speed, the 0.96 factor is not applied to the determined P-wave speed for calculating the thickness.

3.2.5 *surface wave, n*—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*).

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,

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
[3] Sansalone, M. and Streett, W.B., *Impact-Echo: Nondestructive Evaluation of Concrete and Masonry*, Bullbrier Press, Ithaca, NY and Jersey Shore, PA, 1997.
[4] 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.

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 This test method is a pplicable to plate-like structures with lateral dimensions at least six times the thickness. These minimum lateral dimensions are necessary to prevent other modes[3] of vibration from interfering with the identification of the thickness mode frequency in the amplitude spectrum. As explained in Note 12, the minimum lateral dimensions and acceptable sampling period are related.

4.4 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.

4.5 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.

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

4.7 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[3] 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 amplitude 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.

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

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

4.10 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[5]

6.1 *Impactor*—The impactor shall be spherical or spherically tipped. It shall produce an impact duration of 30 µs ± 10 µs with

[5] Suitable apparatus is available commercially.

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~~150 mm ± 10 mm from the first transducer.

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

6.2 *Transducers*—Two broadband transducers that respond to displacements normal to the surface. 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.[6] 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 frequency 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 acquisition 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.

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

NOTE 6—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 7—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.

8. Procedure

8.1 Fig. 1 shows a schematic of the test set-up for Procedure A.

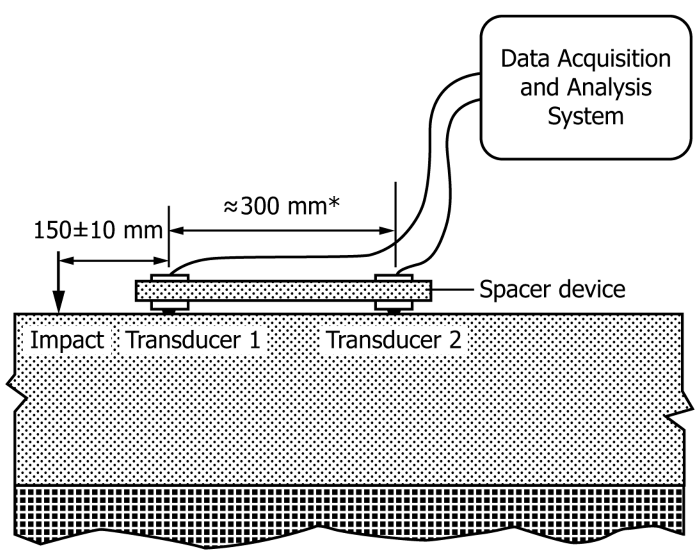
8.2 Assemble the apparatus (transducers, spacer device, impactor). Verify that the test system is functioning properly. Position the apparatus on the concrete surface, and position the impactor to strike on the line passing through the two transducers and at a distance of 150 mm ± 10 mm from the first (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 frequency, voltage range, triggering level, delay, and so forth).

NOTE 8—For some systems, it is advisable to set the data acquisition parameters so that about 100 points are recorded before the trigger point. This pre-trigger information permits an assessment of the baseline value in the waveform before P-wave arrival. Due to electrical noise, the signal may fluctuate before P-wave arrival, and knowing the amplitude of those fluctuations assists in identifying P-wave arrival.

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 9—Fig. 2 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.



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

FIG. 1 Schematic of Testing Configuration for Procedure A

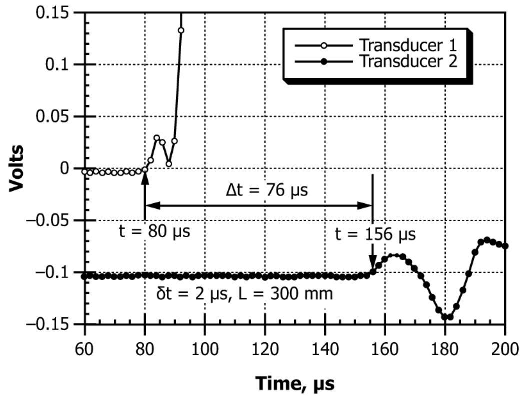


FIG. 2 Example of Waveforms Obtained Using Procedure A (Only Early Part of Waveforms Are Plotted)

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. 2). Use the cursors to display the voltage and time readings at the points corresponding to the P-wave arrivals. Determine the time difference, Δt, between the arrival of the P-wave in each waveform. This time difference is the travel time. Automated detection of the P-wave arrivals in the waveforms is permitted provided the waveforms are stable (do not contain noise) before the P-wave arrivals.

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

$$C_p = \frac{L}{\Delta t} \tag{3}$$

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.

9.6 *Alternative Procedure*—Under circumstances where maximum accuracy in measured thickened is not critical, the apparent P-wave speed in the concrete is permitted to be determined by direct calibration with measured thickness at points in the structure. Determine the thickness of the structure, determine the thickness frequency at the same point in accordance with Procedure B, and use Eq 2 to solve for the apparent wave speed. The purchaser of testing services and the testing agency shall agree on whether this alternative is permitted. They shall agree further on the number and location of calibration points and the method of determining concrete thickness. When this alternative procedure is used, the interpretation procedure in Section 15 is not applicable.

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.