Designation: C 1383 – 04

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 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 the 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 597 Test Method for Pulse Velocity Through Concrete

E 1316 Terminology for Nondestructive Examinations

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

[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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[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.

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

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.[3] Fig. 1 shows an example of the surface-wave portion of a waveform and the approximate contact time is indicated.

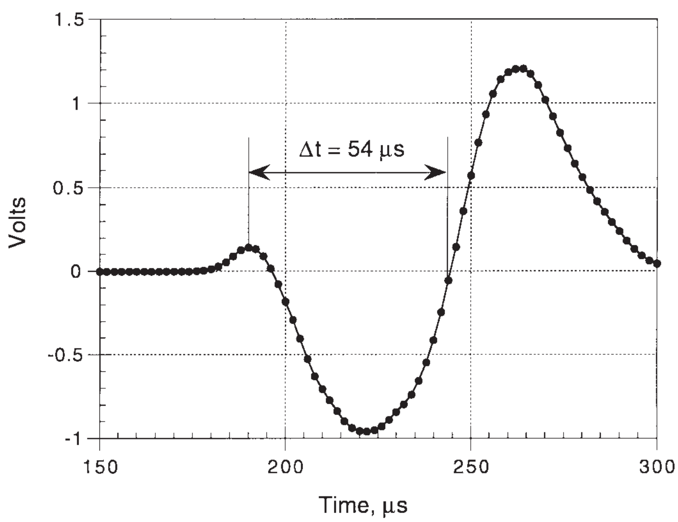

FIG. 1 Expanded View of Surface-Wave Portion of Waveform Showing the Width of the Surface Wave Signal as an Approximation of the Contact Time of the Impact

3.1.6 *P-wave*—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.

3.1.7 *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 frequency*—the rate at which the points that comprise the waveform are recorded; the inverse of the sampling interval, expressed in Hz or samples/s (also referred to as *sampling rate*).

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

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

3.1.11 *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*).

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

3.1.13 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*[3,4]—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, m/s, and
C_p = the P-wave speed in concrete that is obtained from Procedure A, m/s.

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 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.

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[3] 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 11.

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.

[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.

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 air dry as 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[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.

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

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 so forth) 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 [5]

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 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.

[5] Suitable apparatus is available commercially.

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

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.

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. 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 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. 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 the time difference, Δt, between the arrival of the P-wave in

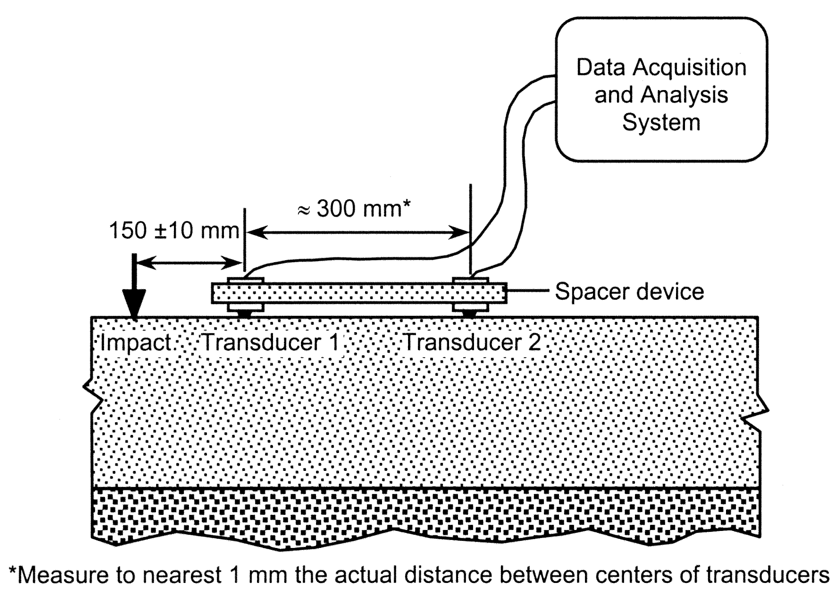

FIG. 2 Schematic of Testing Configuration for Procedure A

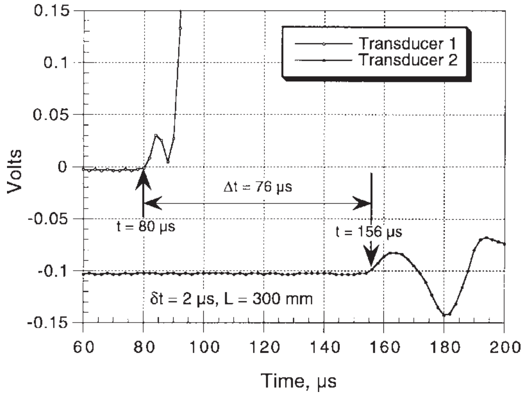

FIG. 3 Example of waveforms obtained using Procedure A (Only Early Part of Waveforms are Plotted)

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.

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 that a well defined amplitude spectrum is obtained with a single predominant peak. The impact duration, t_c, must be less (see 3.1.5) than the round-trip travel time for a P-wave, that is:

$$t_c < \frac{2T}{C_p} \tag{4}$$

NOTE 10—Hardened steel balls with diameters ranging from 8 to 16 mm in diameter and attached to steel spring rods and spherically tipped mechanical impactors have been used as suitable impactors for typical highway pavements.

11.2 *Transducer*—A broadband transducer that responds to displacements normal to the surface. This transducer is the same as that described under Procedure A.

11.3 *Data-Acquisition System*—For acquiring, recording and processing the output of the transducer. This system can be the same as that described under Procedure A.

11.3.1 The typical sampling frequency is between 500 kHz (2 µs interval) and 250 kHz (4 µs interval).

11.3.2 The typical number of data points in the recorded waveform is 1024 or 2048.

11.3.3 The typical duration of the recorded waveform (the sampling period) is 4096 µs or 8192 µs.

NOTE 11—The sampling period is the product of the number of recorded points and the sampling interval. The inverse of the sampling period establishes the frequency interval in the amplitude spectrum obtained by the fast Fourier transform method. A sampling period of 4096 µs corresponds to a frequency interval of 244 Hz and a sampling period of 8192 µs corresponds to 122 Hz. A smaller frequency interval results in a more accurate thickness measurement. However, the sampling period should be chosen considering the lateral dimensions of the plate relative to the thickness of the plate. If the smaller lateral dimension is at least 20 times the thickness, a sampling period of 8192 µs may be used. If the smaller lateral dimension is at least 10 times the thickness, a sampling period of 4096 µs may be used. For smaller lateral dimensions, a shorter sampling period will have to be used, resulting in a greater uncertainty in the measured thickness. These limitations are necessary to assure that the waveform does not include motion associated with other modes of vibration that would interfere with the ability to identify the thickness frequency of the plate in the amplitude spectrum.

11.3.4 The voltage range for data acquisition shall be such that the amplitude of the waveform is sufficient to permit visual examination of its key features, such as the surface wave signal and the subsequent oscillations.

NOTE 12—A voltage range that is too high may result in a displayed waveform with small amplitude making it difficult to examine. A voltage range that is too low may result in clipping of the transducer signal. A digitizer with at least 12-bit resolution is recommended.

11.3.5 Software shall be provided for acquiring, recording, displaying, and analyzing data. The software shall compute the amplitude spectrum from the recorded waveform. The amplitude spectrum shall be displayed immediately after the waveform has been captured. A cursor for manually determining the thickness frequency shall be included. It is permitted to use software to determine the thickness frequency.

11.3.6 The data-acquisition system shall be operated by a power source that does not produce electrical noise that is detected by the transducer and data acquisition system when the system is set at the voltage range used for testing (see Note 5).

11.4 *Cables and Connectors*, as described under Procedure A.

11.5 *Functionality Check Apparatus*, as described under Procedure A.

12. Preparation of Test Surface

12.1 Remove dirt and debris from the surface where the thickness is to determined.

12.2 If the test surface is extremely rough so that it is difficult to achieve good contact between the transducer tip and the concrete, grind the surface so that good contact is achieved (see Note 7).

13. Procedure

13.1 Fig. 4 is a schematic of an impact-echo test on a plate.

13.2 Position the transducer on the concrete surface where thickness is to be measured. Position the impactor to strike at a distance less than 0.4 of the nominal plate thickness away from the transducer.

13.3 Ready the data-acquisition system with correct data acquisition parameters (sampling frequency, voltage range, triggering level, delay, and so forth). Data acquisition shall be triggered by the transducer signal or by an instrumented impact device. If necessary, establish data acquisition parameters by trial tests.

NOTE 13—For some systems, it is advisable to set the data acquisition parameters so that about 100 points are recorded before the trigger point. The initial portion of the waveform provides information on the contact time of the impact and can help identify invalid waveforms due to improper coupling, electrical noise, or other factors.

13.4 Perform the impact. Examine the acquired waveform and corresponding amplitude spectrum. In making a judgment about the validity of the waveform, examine whether the portion of the waveform corresponding to the surface wave is of the correct shape and that the surface wave is followed by periodic oscillations corresponding to multiple reflections between the plate boundaries. The amplitude spectrum of a valid waveform will have a single dominant peak at a frequency corresponding to the plate thickness.

NOTE 14—Fig. 5 shows an example of a valid time domain waveform and its corresponding amplitude spectrum for a test of a concrete slab on grade. The sampling interval is 4 μs and the number of points in the complete waveform (not shown) is 2048.

13.5 If a valid waveform and amplitude spectrum have been obtained, store the waveform and amplitude spectrum. Repeat the test to verify the results. If the results are repeatable and valid, move to the next test point. If the waveform and amplitude spectrum are not valid (see Note 15), check that the test surface is free of dust and debris and that the transducer is coupled properly to the test surface. Also check that the impact point is flat and free of debris, and that the correct size of impactor is being used. Repeat the test until a valid waveform and amplitude spectrum are obtained.

NOTE 15—Fig. 6 shows an example of invalid impact-echo test results. The waveform lacks periodic oscillations and the amplitude spectrum does not contain a single dominant peak.

14. Data Analysis

14.1 Determine the frequency of the high-amplitude peak in the amplitude spectrum.

14.2 Calculate the thickness of the plate using Eq 2.

15. Interpretation of Results (Systematic Errors)

15.1 There are systematic errors in determining the wave speed and the thickness of concrete plates because of the digital

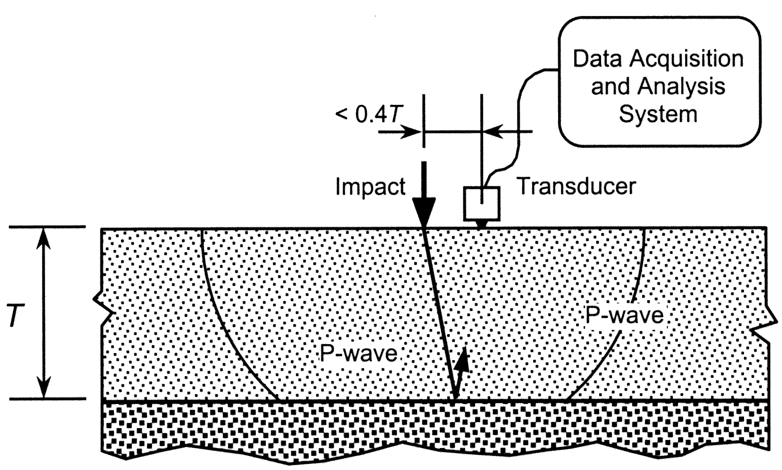

FIG. 4 Schematic of Testing Configuration for Impact-Echo Test (Procedure B)

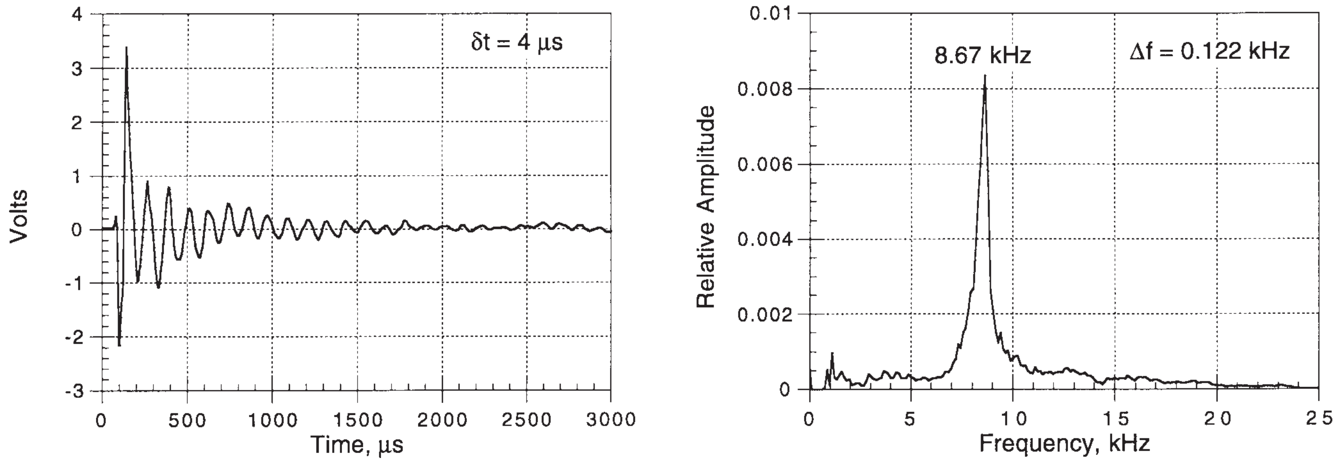

FIG. 5 Waveform and Amplitude Spectrum for a Valid Impact-Echo Test of 250-mm Thick Concrete Slab

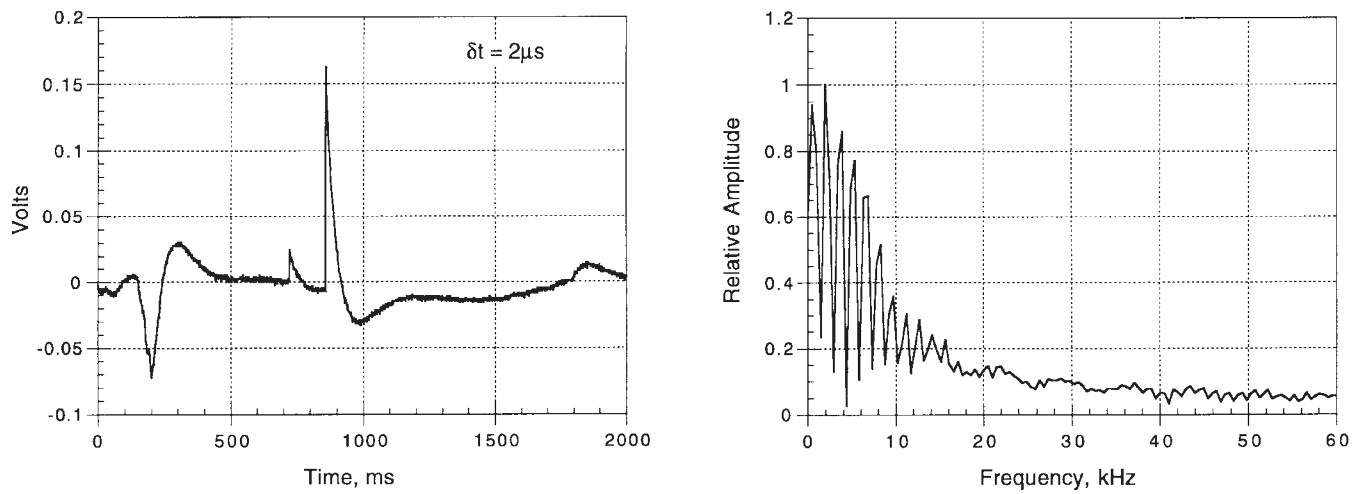

FIG. 6 Example of an Invalid Impact-Echo Test, the Waveform Does Not Display Periodic Oscillations and the Amplitude Spectrum does not have a Single Dominant Peak

nature of the waveforms and amplitude spectra. Thus there is an inherent systematic error in the computed P-wave speeds and plate thicknesses. The appendix provides derivations of the expressions for maximum systematic errors.

15.2 *Systematic Error in Procedure A*—The maximum systematic error in the calculated P-wave speed is given by:

$$e_p = \pm \frac{\delta t}{\Delta t} \tag{5}$$

where:

δt = sampling interval, and
Δt = measured P-wave travel time.

15.2.1 Eq 5 is based on the assumption that there is no electrical noise in the waveforms, so that the P-wave arrival can be identified easily. Fig. 7 shows the maximum systematic error due to the sampling interval as a function of the travel time. Report the P-wave speed calculated according to Eq 3 as follows:

$$C_p \pm e_p C_p \tag{6}$$

15.3 *Systematic Error in Procedure B*—The maximum systematic error in the calculated thickness due to frequency resolution is given by the following equation:

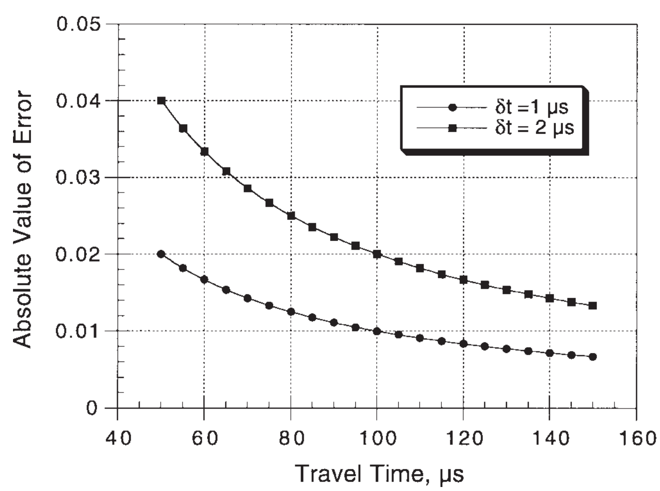

FIG. 7 Maximum Systematic Error Due to Sampling Interval as a Function of the Travel Time

$$e_f = \pm \frac{\Delta f}{2f} \tag{7}$$

where:

Δf = the frequency interval in the amplitude spectrum, and
f = the frequency corresponding to the high amplitude peak in the amplitude spectrum.

15.3.1 Fig. 8 shows the maximum systematic error in the calculated thickness due to the frequency resolution as a function of the measured frequency. A higher frequency corresponds to a lower thickness, and there is less systematic error in the computed thickness as the thickness decreases.

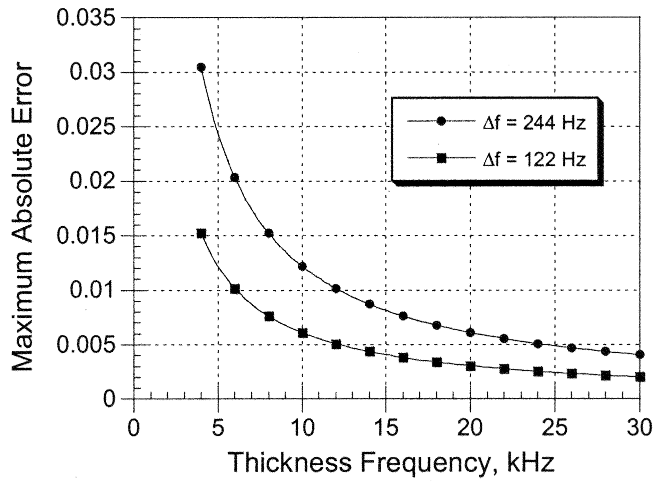

FIG. 8 Maximum Systematic Error Due to Frequency Interval as a Function of Thickness Frequency

15.4 *Combined Systematic Error*—An estimate of the maximum expected systematic error in the calculated thickness that accounts for both sources of error is given by the following equation:[7]

$$e = \sqrt{e_p^2 + e_f^2} \tag{8}$$

15.5 *Reporting Thickness*—Report plate thickness, which is calculated according to Eq 2, as follows:

$$T \pm eT \tag{9}$$

16. Report

16.1 Report the data acquisition parameters that were used. These include the sampling interval, the voltage range, the voltage resolution, the number of points in the waveform, and the frequency interval in the amplitude spectrum.

16.2 The location of each test point on the structure, a description of the condition of the test surface, and whether grinding was required.

16.3 For concrete slabs on grade, report the type of material supporting the slab, if known.

16.4 The P-wave speed in accordance with 15.2.1.

16.5 The plate thickness in accordance with 15.5.

16.6 If the alternative procedure in 9.6 was used to establish the apparent P-wave speed, provide the calibration data and report how the data were used to estimate concrete thickness.

17. Precision and Bias

17.1 The precision and bias of this test method are unknown at this time. Data comparing core lengths with pavement thicknesses obtained by an earlier version of this test method are given in the reference cited in footnote 3. That reference indicates that the differences in pavement thickness by measurement of cores and by this test method were within ±3 % for pavement thickness varying from 200 to 290 mm.

18. Keywords

18.1 concrete plate; impact-echo; nondestructive testing; P-wave speed; thickness measurement

[7] Ku, H.H., "Notes on the Use of Propagation of Error Formulas," *Journal of Research of the National Bureau of Standards—C. Engineering and Instrumentation,* Vol 70C, No.4, October-December 1966.

APPENDIX

(Nonmandatory Information)

X1. SYSTEMATIC ERRORS

X1.1 General

X1.1.1 This test method is based on using digital sampling and digital signal analysis methods. As a result, the time-domain waveforms and amplitude spectra are composed of discrete points with fixed spacings that depend upon the data acquisition parameters. This results in systematic errors between the measured travel times or thickness frequencies and their true values. The following sections explain how to determine the maximum values of these systematic errors. Because of these systematic errors, the P-wave speeds and plate thicknesses obtained from this test method are reported as ranges of values.

X1.2 Systematic Error in P-Wave Speed

X1.2.1 Fig. X1.1 shows a schematic of the early part of the waveforms (voltage versus time) obtained from the two transducers in Procedure A. The solid circles represent the points recorded by the data acquisition system. The solid lines represent the true surface displacements as a function of time. The travel time is measured as the time difference Δt between the two points at which the voltages rises above the background values. The measured travel time differs from the true travel time $\Delta t'$. From Fig. X1.1, it can be shown that:

$$\Delta t = \Delta t' - \epsilon_1 + \epsilon_2 \qquad \text{(X1.1)}$$

$$\Delta t' - \Delta t = \epsilon_1 - \epsilon_2 \qquad \text{(X1.2)}$$

The relative error in the calculated P-wave speed due to the differences between the measured and true travel time can be expressed as follows:

$$e_p = \frac{C_p - C'_p}{C'_p} = \frac{\frac{L}{\Delta t} - \frac{L}{\Delta t'}}{\frac{L}{\Delta t'}} = \frac{\Delta t'}{\Delta t} - 1 = \frac{\Delta t' - \Delta t}{\Delta t} = \frac{\epsilon_1 - \epsilon_2}{\Delta t} \qquad \text{(X1.3)}$$

The maximum absolute value of the error e_p occurs when either $\epsilon_1 = 0$ and $\epsilon_2 = \delta t$; or when $\epsilon_1 = \delta t$ and $\epsilon_2 = 0$. When $\epsilon_1 = 0$ and $\epsilon_2 = \delta t$:

$$e_p = \frac{-\delta t}{\Delta t} \qquad \text{(X1.4)}$$

When $\epsilon_1 = \delta t$ and $\epsilon_2 = 0$:

$$e_p = \frac{+\delta t}{\Delta t} \qquad \text{(X1.5)}$$

Therefore, the maximum systematic error in the P-wave speed due to sampling in the time domain is:

$$e_p = \pm \frac{\delta t}{\Delta t} \qquad \text{(X1.6)}$$

X1.2.2 The above derivation assumes that the two waveforms are obtained by simultaneous sampling of the two channels. Fig. X1.2 is a schematic of the waveforms obtained by a data acquisition system that alternately samples the two channels. It can be shown that the maximum systematic error

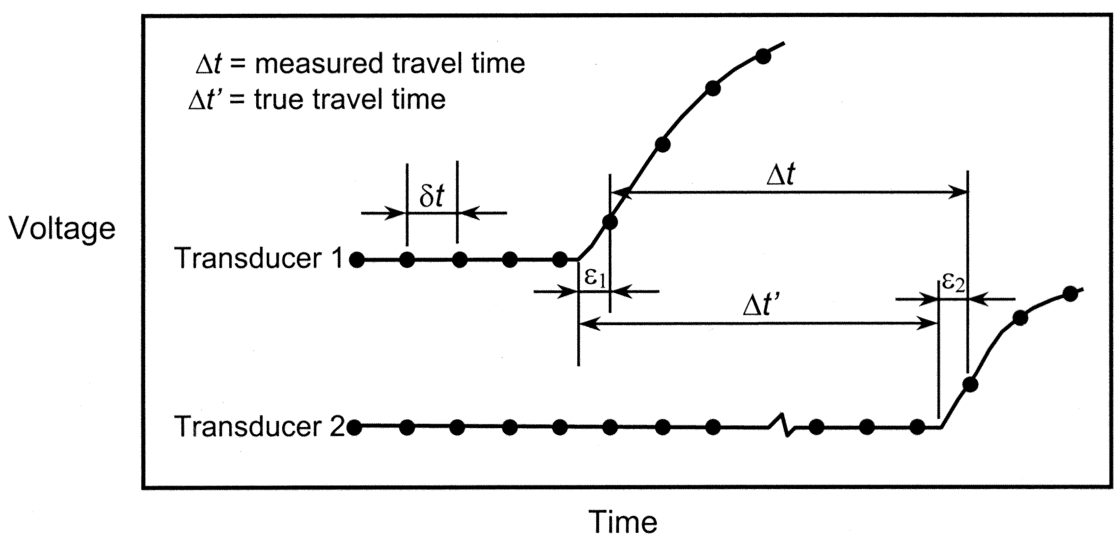

FIG. X1.1 Schematic of Early Part of Waveforms Obtained from Procedure A

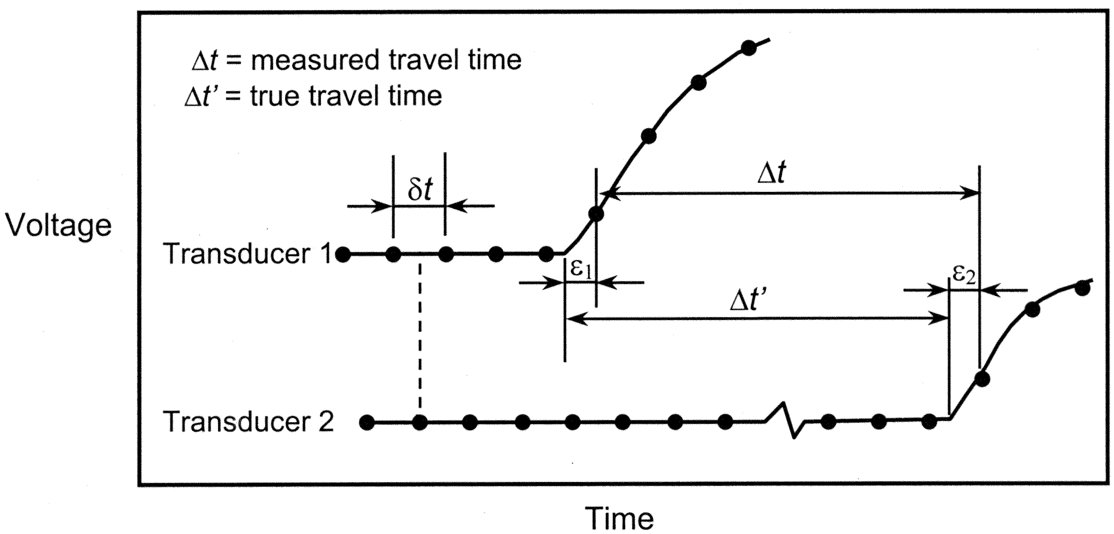

FIG. X1.2 Schematic of Early Part of Waveforms Obtained from Procedure A With a Data Acquisition System That Samples Each Channel Alternately

is the same as given by Eq X1.6 provided the sample interval δt is the time interval between adjacent points in each of the waveforms.

X1.3 Systematic Error in Thickness Due to Frequency Interval in the Amplitude Spectrum

X1.3.1 Fig. X1.3 is a schematic of the amplitude spectrum obtained from an impact-echo test of a solid plate. The high amplitude peak corresponds to the thickness frequency of the plate. The solid circles are the digital values displayed on the computer display, and the solid curve represents the true amplitude spectrum. The measured frequency f differs from the true frequency f'. This difference leads to a systematic error in plate thickness computed using the measured frequency.

X1.3.2 The relative error in the calculated plate thickness is related to the measured frequency and the true frequency as follows:

$$e_f = \frac{T - T'}{T'} = \frac{\frac{0.96\,C_p}{2f} - \frac{0.96\,C_p}{2f'}}{\frac{0.96\,C_p}{2f'}} = \frac{f'}{f} - 1 = \frac{f' - f}{f} \quad \text{(X1.7)}$$

where:

T = calculated thickness based on measured thickness frequency, f, and

T' = calculated thickness based on true thickness frequency, f'.

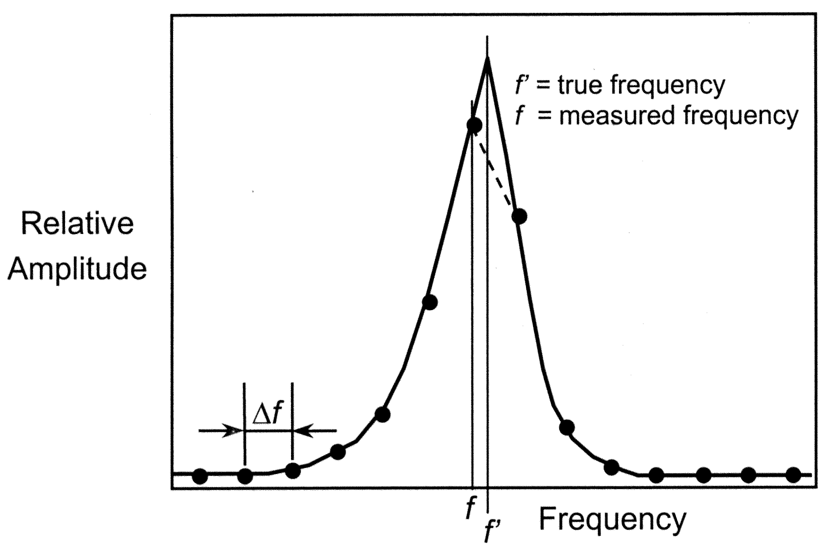

FIG. X1.3 Schematic of Amplitude Spectrum Resulting from an Impact-Echo (Procedure B) Test on a Solid Plate

The absolute value of the maximum difference between f and f' is $\Delta f/2$. Therefore, the maximum systematic error in the calculated thickness due to the frequency interval in the amplitude spectrum is:

$$e_f = \pm \frac{\Delta f}{2f} \quad \text{(X1.8)}$$

X1.3.3 Eq X1.8 shows that systematic error in the calculated frequency is reduced by reducing the frequency interval Δf. As explained in Note 11 of this test method, the frequency interval is controlled by the duration of the waveform, that is, the record length. Thus, when doing the impact-echo test to measure plate thickness, use the longest record length that is practicable. However, the record length must not be too long, otherwise motions due to other plate modes, set up by reflections of the lateral boundaries, may contribute to the waveform. This is the intent of the guidelines in Note 11.

X1.4 Systematic Error in Calculated Thickness

X1.4.1 The thickness calculated from the P-wave speed and peak frequency includes two sources of systematic errors. The approach taken in this test method is to obtain the combined systematic error, e, as follows:

$$e = \sqrt{e_p^2 + e_f^2} \quad \text{(X1.9)}$$

X1.4.2 The relative error in the plate thickness due to the two sources of systematic error is as follows:

$$\frac{T - T'}{T'} = \pm e \quad \text{(X1.10)}$$

that can be rearranged as follows:

$$T' = \frac{T}{1 \pm e} \quad \text{(X1.11)}$$

For small values of $|e|$:

$$\frac{1}{1 \pm e} \approx 1 \pm e \quad \text{(X1.12)}$$

Therefore to account for the systematic error that is inherent in this test method, report the thickness calculated according to Eq 2 as follows:

$$T \pm T e \quad \text{(X1.13)}$$

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue, C 1383 – 98a, that may impact its use. (Approved June 2004)

(1) Added the term "sampling frequency" under 3.1.
(2) Moved the last sentence in 6.6 to new Note 6.
(3) Added new Note 8 to explain the usefulness of pre-trigger data and removed mandatory requirement for pre-trigger data.
(4) Added a sentence to 9.2 to permit automated detection of P-wave arrivals when waveforms are not contaminated with noise.
(5) Added a new 9.6 to permit an alternative procedure for determining apparent P-wave speed when there is agreement between the seller and the purchaser of testing services.
(6) Added new Note 13 to explain the usefulness of pre-trigger data and removed mandatory requirement for pre-trigger data.
(7) Added 16.6 on reporting results when the alternative procedure is used.
(8) Provided information on reported differences between core lengths and slab thicknesses determined by this method.