Designation: D 2845 – 05

Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock[1]

This standard is issued under the fixed designation D 2845; 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 describes equipment and procedures for laboratory measurements of the pulse velocities of compression waves and shear waves in rock (**1**)[2] and the determination of ultrasonic elastic constants (Note 1) of an isotropic rock or one exhibiting slight anisotropy.

NOTE 1—The elastic constants determined by this test method are termed ultrasonic since the pulse frequencies used are above the audible range. The terms sonic and dynamic are sometimes applied to these constants but do not describe them precisely (**2**). It is possible that the ultrasonic elastic constants may differ from those determined by other dynamic methods.

1.2 This test method is valid for wave velocity measurements in both anisotropic and isotropic rocks although the velocities obtained in grossly anisotropic rocks may be influenced by such factors as direction, travel distance, and diameter of transducers.

1.3 The ultrasonic elastic constants are calculated from the measured wave velocities and the bulk density. The limiting degree of anisotropy for which calculations of elastic constants are allowed and procedures for determining the degree of anisotropy are specified.

1.4 The values stated in inch-pounds are to be regarded as the standard. The SI values given in parenthesis are provided for information purposes only.

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:* [3]

D 653 Terminology Relating to Rock, Soil, and Contained Fluids
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D 6026 Practice for Using Significant Digits in Geotechnical Data
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *compression wave velocity*—the dilational wave velocity which is the propagation velocity of a longitudinal wave in a medium that is effectively infinite in lateral extent. It is not to be confused with bar or rod velocity.

4. Summary of Test Method

4.1 Details of essential procedures for the determination of the ultrasonic velocity, measured in terms of travel time and distance, of compression and shear waves in rock specimens include requirements of instrumentation, suggested types of transducers, methods of preparation, and effects of specimen geometry and grain size. Elastic constants may be calculated for isotropic or slightly anisotropic rocks, while anisotropy is reported in terms of the variation of wave velocity with direction in the rock.

5. Significance and Use

5.1 The primary advantages of ultrasonic testing are that it yields compression and shear wave velocities, and ultrasonic values for the elastic constants of intact homogeneous isotropic rock specimens (**3**). Elastic constants are not to be calculated for rocks having pronounced anisotropy by procedures described in this test method. The values of elastic constants often do not agree with those determined by static laboratory methods or the *in situ* methods. Measured wave velocities likewise may not agree with seismic velocities, but offer good approximations. The ultrasonic evaluation of rock properties is

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.
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[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] 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.

useful for preliminary prediction of static properties. The test method is useful for evaluating the effects of uniaxial stress and water saturation on pulse velocity. These properties are in turn useful in engineering design.

5.2 The test method as described herein is not adequate for measurement of stress-wave attenuation. Also, while pulse velocities can be employed to determine the elastic constants of materials having a high degree of anisotropy, these procedures are not treated herein.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—The testing apparatus (Fig. 1) should have impedance matched electronic components and shielded leads to ensure efficient energy transfer. To prevent damage to the apparatus allowable voltage inputs should not be exceeded.

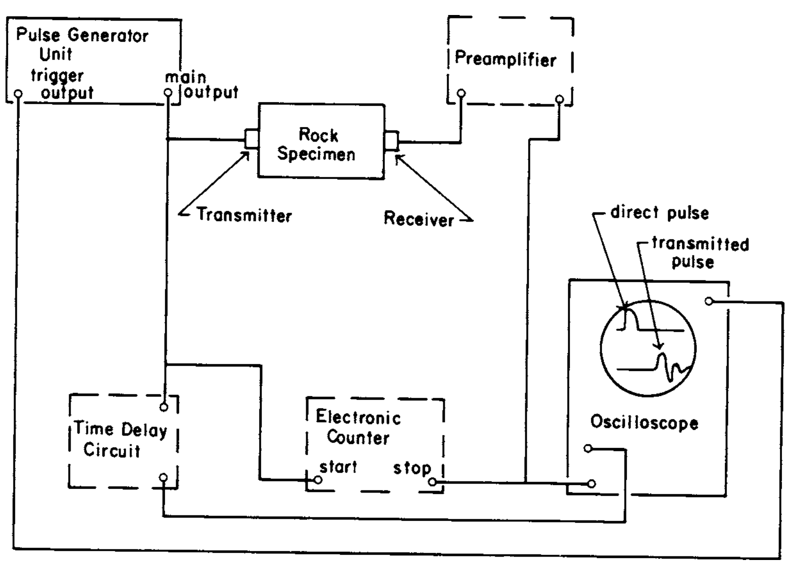
6.2 *Pulse Generator Unit*—This unit shall consist of an electronic pulse generator and external voltage or power amplifiers if needed. A voltage output in the form of either rectangular pulse or a gated sine wave is satisfactory. The generator shall have a voltage output with a maximum value after amplification of at least 50 V into a 50-Ω impedance load. A variable pulse width, with a range of 1 to 10μ *s* is desirable. The pulse repetition rate may be fixed at 60 repetitions per second or less although a range of 20 to 100 repetitions per second is recommended. The pulse generator shall also have a trigger-pulse output to trigger the oscilloscope. There shall be a variable delay of the main-pulse output with respect to the trigger-pulse output, with a minimum range of 0 to 20 μ*s*.

6.3 *Transducers*—The transducers shall consist of a transmitter that converts electrical pulses into mechanical pulses and a receiver that converts mechanical pulses into electrical pulses. Environmental conditions such as ambient temperature, moisture, humidity, and impact should be considered in selecting the transducer element. Piezoelectric elements are usually recommended, but magnetostrictive elements may be suitable. Thickness-expander piezoelectric elements generate and sense predominately compression-wave energy; thickness-shear piezoelectric elements are preferred for shear-wave measurements. Commonly used piezoelectric materials include ceramics such as lead-zirconate-titanate for either compression or shear, and crystals such as a-c cut quartz for shear. To reduce scattering and poorly defined first arrivals at the receiver, the transmitter shall be designed to generate wavelengths at least 3 × the average grain size of the rock.

NOTE 3—Wavelength is the wave velocity in the rock specimen divided by the resonance frequency of the transducer. Commonly used frequencies range from 75 kHz to 3 MHz.

6.3.1 In laboratory testing, it may be convenient to use unhoused transducer elements. But if the output voltage of the receiver is low, the element should be housed in metal (grounded) to reduce stray electromagnetic pickup. If protection from mechanical damage is necessary, the transmitter as well as the receiver may be housed in metal. This also allows special backings for the transducer element to alter its sensitivity or reduce ringing **(4)**. The basic features of a housed element are illustrated in Fig. 2. Energy transmission between the transducer element and test specimen can be improved by (*1*) machining or lapping the surfaces of the face plates to make them smooth, flat, and parallel, (*2*) making the face plate from a metal such as magnesium whose characteristic impedance is close to that of common rock types, (*3*) making the face plate as thin as practicable, and (*4*) coupling the transducer element to the face plate by a thin layer of an electrically conductive adhesive, an epoxy type being suggested.

6.3.2 Pulse velocities may also be determined for specimens subjected to uniaxial states of stress. The transducer housings in this case will also serve as loading platens and should be



NOTE 1—Components shown by dashed lines are optional, depending on method of travel-time measurement and voltage sensitivity of oscilloscope.

FIG. 1 Schematic Diagram of Typical Apparatus

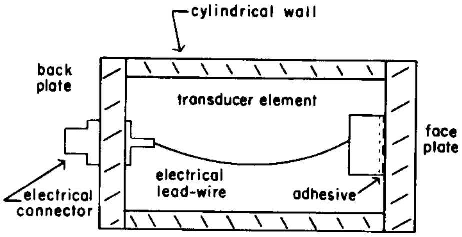


FIG. 2 Basic Features of a Housed Transmitter or Receiver

designed with thick face plates to assure uniform loading over the ends of the specimen (5).

NOTE 4—The state of stress in many rock types has a marked effect on the wave velocities. Rocks *in situ* are usually in a stressed state and therefore tests under stress have practical significance.

6.4 *Preamplifier*—A voltage preamplifier is required if the voltage output of the receiving transducer is relatively low or if the display and timing units are relatively insensitive. To preserve fast rise times, the frequency response of the preamplifier shall drop no more than 2 dB over a frequency range from 5 kHz to 4 × the resonance frequency of the receiver. The internal noise and gain must also be considered in selecting a preamplifier. Oscilloscopes having a vertical-signal output can be used to amplify the signal for an electronic counter.

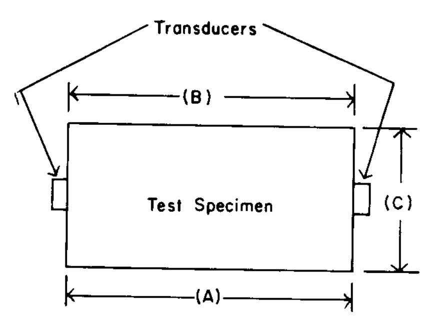
6.5 *Display and Timing Unit*—The voltage pulse applied to the transmitting transducer and the voltage output from the receiving transducer shall be displayed on a cathode-ray oscilloscope for visual observation of the waveforms. The oscilloscope shall have an essentially flat response between a frequency of 5 kHz and 4 × the resonance frequency of the transducers. It shall have dual beams or dual traces so that the two waveforms may be displayed simultaneously and their amplitudes separately controlled. The oscilloscope shall be triggered by a triggering pulse from the pulse generator. The timing unit shall be capable of measuring intervals between 2 µs and 5 ms to an accuracy of 1 part in 100. Two alternative classes of timing units are suggested, the respective positions of each being shown as dotted outlines in the block diagram in Fig. 1: (*1*) an electronic counter with provisions for time interval measurements, or (*2*) a time-delay circuit such as a continuously variable-delay generator, or a delayed-sweep feature on the oscilloscope. The travel-time measuring circuit shall be calibrated periodically with respect to its accuracy and linearity over the range of the instrument. The calibration shall be checked against signals transmitted by the National Institute of Standards and Technology radio station WWV, or against a crystal controlled time-mark or frequency generator that can be referenced back to the signals from WWV periodically. It is recommended that the calibration of the time measuring circuit be checked at least once a month and after any severe impact that the instrument may receive.

7. Test Specimens

7.1 *Preparation*—Exercise care in core drilling, handling, sawing, grinding, and lapping the test specimen to minimize the mechanical damage caused by stress and heat. It is recommended that liquids other than water be prevented from contacting the specimen, except when necessary as a coupling medium between specimen and transducer during the test. The surface area under each transducer shall be sufficiently plane that a feeler gage 0.001 in. (0.025 mm) thick will not pass under a straightedge placed on the surface. The two opposite surfaces on which the transducers will be placed shall be parallel to within 0.005 in./in. (0.1 mm/20 mm) of lateral dimension (Fig. 3). If the pulse velocity measurements are to be made along a diameter of a core, the above tolerance then refers to the parallelism of the lines of contact between the transducers and curved surface of the rock core. Moisture content of the test specimen can affect the measured pulse velocities. Pulse velocities may be determined on the velocity test specimen for rocks in the oven-dry state (0 % saturation), in a saturated condition (100 % saturation), or in any intermediate state. If the pulse velocities are to be determined with the rock in the same moisture condition as received or as exists underground, care must be exercised during the preparation procedure so that the moisture content does not change. In this case it is suggested that both the sample and test specimen be stored in moisture-proof bags or coated with wax and that dry surface-preparation procedures be employed. If results are desired for specimens in the oven-dried condition, refer to Test Method D 2216. The specimen shall remain submerged in water up to the time of testing when results are desired for the saturated state.

7.2 *Limitation on Dimensions*—It is recommended that the ratio of the pulse-travel distance to the minimum lateral dimension not exceed 5. Reliable pulse velocities may not be measurable for high values of this ratio. The travel distance of the pulse through the rock shall be at least 10 × the average grain size so that an accurate average propagation velocity may be determined. The grain size of the rock sample, the natural resonance frequency of the transducers, and the minimum lateral dimension of the specimen are interrelated factors that affect test results. The wavelength corresponding to the dominant frequency of the pulse train in the rock is approximately related to the natural resonance frequency of the transducer and the pulse-propagation velocity, (compression or shear) as follows:

$$\Lambda \approx V/f, \tag{1}$$



NOTE 1—(A) must be within 0.1 mm of (B) for each 20 mm of width (C).

FIG. 3 Specification for Parallelism