**Designation: D8295 − 19**

# Standard Test Method for Determination of Shear Wave Velocity and Initial Shear Modulus in Soil Specimens using Bender Elements[1]

This standard is issued under the fixed designation D8295; 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 the laboratory use of piezo-ceramic bender elements to determine the shear wave velocity in soil specimens. A shear wave is generated at one boundary of a soil specimen and then received at an opposite boundary. The shear wave travel time is measured, which over a known travel distance yields the shear wave velocity. From this shear wave velocity and the density of the soil specimen the initial shear modulus ($G_{max}$) can be determined, which is the result of primary interest from bender element tests.

1.2 This shear wave velocity determination involves very small strains and is non-destructive to a test specimen. As such, bender element shear wave velocity determinations can be made at any time and any number of times during a laboratory test.

1.3 This test method describes the use of bender elements in a triaxial type test (for example, Test Methods D3999, D4767, D5311, or D7181), but a similar procedure may be used for other laboratory applications, like in Direct Simple Shear (Test Method D6528) or oedometer tests (for example, Test Methods D2435 and D4186). Shear wave velocity can also be determined in unconfined soil specimens held together by matrix suction.

1.4 Shear wave velocity can be determined in different directions in a triaxial test, for example vertically and horizontally. Shear waves generated to determine shear wave velocity can also be polarized in different directions, for example a horizontally propagating shear wave with either vertical or horizontal polarization. This test method describes the use of bender elements mounted in the top platen and base pedestal of a triaxial test specimen to measure shear wave velocity in the vertical direction. With additional bender elements mounted on opposite sides of a triaxial specimen, a similar procedure may be used to determine horizontal shear wave velocity.

1.5 A variety of different interpretation methods to evaluate the shear wave travel time in a soil specimen have been proposed and used. This test method only describes two of these, Start to Start and Peak to Peak using a single sine wave signal sent to the transmitter bender element. Other interpretation methods producing similar results may also be used.

1.6 Bender element measurements may not work very well in some situations, like in extremely stiff soils where the generated shear wave amplitude may be exceedingly small.

1.7 This test method does not cover the determination of compressional wave velocity in soil specimens. This measurement requires a different type of piezo-ceramic element configuration, and such determinations are generally not useful in saturated soft soil specimens as the earliest identifiable compressional wave arrival at the receiver end of a saturated specimen will likely have been transmitted through the (relatively incompressible) specimen pore water rather than the (compressible) soil skeleton.

1.8 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.9 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.9.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

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

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*



[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.09 on Cyclic and Dynamic Properties of Soils.

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*Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D3999 Test Methods for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus

D4015 Test Methods for Modulus and Damping of Soils by Fixed-Base Resonant Column Devices

D4186 Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading

D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

D5311 Test Method for Load Controlled Cyclic Triaxial Strength of Soil

D6026 Practice for Using Significant Digits in Geotechnical Data

D6528 Test Method for Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils

D7181 Test Method for Consolidated Drained Triaxial Compression Test for Soils

D7263 Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens



## 3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.1.2 *initial shear modulus, $G_{max}$ or $G_o$, n*—the shear modulus for soils determined at very small strain amplitude (for example, a shear strain of $10^{-3}$ % and below) at a particular stress condition and time, where the shear modulus seems to be constant plotted against the logarithm of strain.

3.1.3 *travel time, n*—in propagating waves, the time interval it takes for a shear wave to propagate through soil from a source to a receiver.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bender element, n*—an electro-mechanical transducer consisting of two thin piezo-ceramic plates with conducting surfaces sandwiched between them and on the outside.

3.2.2 *receiver bender element, n*—a series-connected bender element used to detect the arrival of a shear wave propagating through the soil specimen.

3.2.3 *transmitter bender element, n*—a parallel-connected bender element used to generate a shear wave through the soil specimen.

3.2.3.1 *Discussion*—The receiver bender element can be used as a shear wave transmitter and the transmitter bender element as a shear wave receiver, but they will function less efficiently (i.e., the receiver signal amplitude will be smaller).

## 4. Summary of Test Method

4.1 The test specimen and triaxial equipment are prepared and assembled as for a triaxial test. The specified back pressure, confining pressure and deviator stress are then applied to the triaxial test specimen.

4.2 For any bender element measurement, a shear wave is generated by the transmitter bender element at one specimen boundary, that propagates through the soil specimen and is picked up by the receiver bender element at the opposite specimen boundary. The known shear wave travel length (bender element tip-to-tip distance) divided by the shear wave travel time (measured on the recorded transmitter and receiver bender element traces) is the resulting shear wave velocity. The small-strain initial shear modulus, $G_{max}$, of the soil specimen is determined from the measured shear wave velocity and specimen bulk density.

## 5. Significance and Use

5.1 The initial shear modulus ($G_{max}$) of a soil specimen under particular stress and time conditions is an important parameter in small-strain dynamic analyses such as those to predict soil behavior or soil-structure interaction during earthquakes, explosions, and machine or traffic vibrations. $G_{max}$ can be equally important for small-strain cyclic situations such as those caused by wind or wave loading. Small-strain $G_{max}$ is also vital for non-linear analyses of large strain situations, where the larger strain soil stiffness results could come from torsional shear tests, for example. Shear wave velocity and $G_{max}$ can be used to compare different soil specimens in a laboratory testing program, and also for comparing laboratory and field measurements of these parameters.

5.2 Torsional resonant column tests (Test Method D4015) are often used to determine properties of a soil specimen at small shear strains up to and possibly slightly beyond 0.01%. Resonant column test results can include $G_{max}$ versus time, shear modulus versus strain, damping ratio versus time and damping ratio versus strain. Bender element tests can only provide the first of these, $G_{max}$ versus time. The strain level in bender element tests is small (constant $G_{max}$ strain levels), but the strain magnitude is not known and the strain is not constant along the shear wave travel path due to material and geometric damping. Bender elements can therefore not be used to evaluate shear modulus versus strain and do not provide information about damping ratio. However, bender elements can be incorporated in a variety of different laboratory testing

[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.

devices, allowing the measurement of small-strain and large-strain stiffness on the same specimen at the particular conditions of the test and possibly eliminating the need for additional resonant column tests.

NOTE 1—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

## 6. Apparatus

6.1 *Triaxial Testing Equipment*—The triaxial equipment and ancillary equipment is the same as in the triaxial standard method being followed.

6.2 *Transmitter Bender Element*—A parallel-connected bender element having a wire connected to both outer surface electrodes and another wire is connected to the center electrode. The polarizations of the two ceramic plates in this bender element (sandwiched between the three electrode surfaces) are in the same direction, towards one side. The transmitter bender element is permanently mounted in the end platen opposite of the receiver bender element. The wires and connections to the transmitter bender element should be shielded to reduce any ambient electrical noise that could be included in the driving signal sent to the transmitter element.

6.3 *Receiver Bender Element*—A series-connected bender element having a wire connected to one outer surface electrode and another wire connected to the opposite outer surface electrode. The polarizations of the two ceramic plates in this bender element (sandwiched between the three electrode surfaces) are in opposite directions, towards the center electrode. The wires and connections to the receiver bender element should be shielded to reduce any ambient electrical noise that could be picked up in the recorded receiver signal.

6.3.1 Fig. 1 shows an example of a receiver bender element permanently mounted in a triaxial cell pedestal. Approximately one third of its length is rigidly glued into a slot in the pedestal, one third passes through a clear slot filled with soft silicone in the filter stone, and one third protrudes into the soil specimen. Other bender element configurations may be used.

6.3.2 It can be advantageous to have the receiver bender element mounted in the end platen with least mechanical vibrations (most stationary). With an actuator situated in the top of a load frame connected to the triaxial piston and top platen, the receiver bender element would preferably be mounted in the base platen (pedestal) of the triaxial cell.

6.4 *Function Generator*—A device used to generate a driving signal to the transmitter bender element. It must be able to generate a single-period sine wave pulse with an adjustable frequency typically within the range from 1 kHz to 50 kHz. The amplitude of the generated sine wave should be sufficient that a clearly recognizable received signal is apparent. It is advantageous if this function generator can be programmed to automatically send single-period sine wave pulses with a specified time delay between them in order to use an averaging function in the recording equipment. The time delay should be long enough for all the movements in the receiver bender element from the previous shear wave pulse to have completely died out. For typical triaxial testing, a conservative time delay could be about 0.1 second.

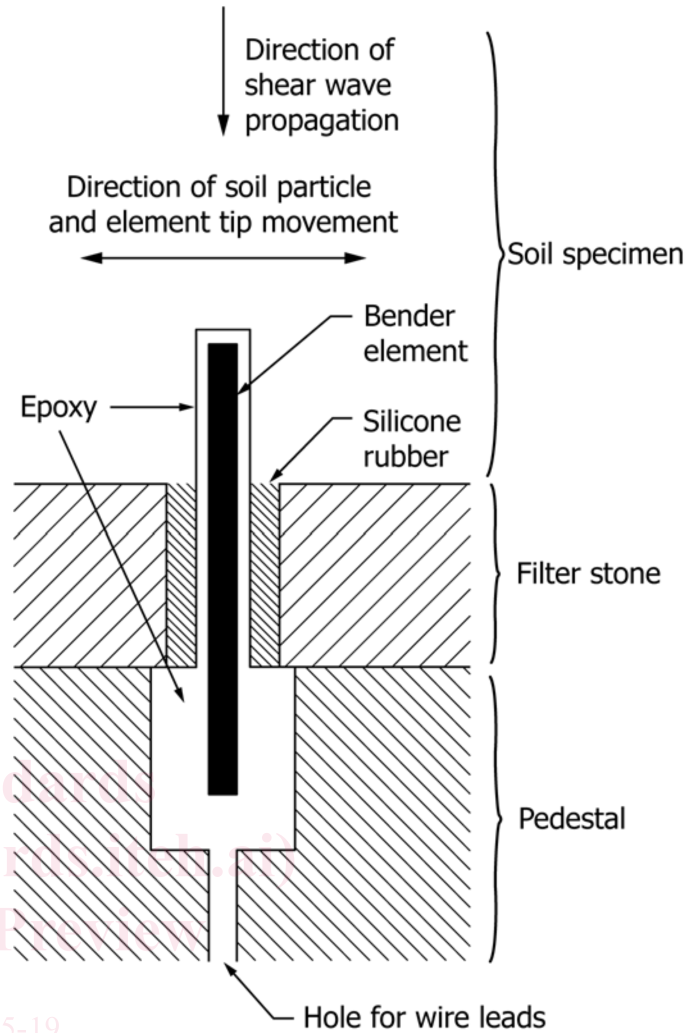


FIG. 1 Receiver Bender Element Mounted in a Triaxial Cell Pedestal

6.5 *Data Recorder*—Either a stand-alone digital storage oscilloscope or an oscilloscope interface connected to a computer. It must have two input channels, one for each of the bender element cables. Single-ended (common ground) devices are often used, but there can be instances where differential inputs are advantageous. For typical measurements on triaxial specimens, the unit must have a time resolution of at least one microsecond (1 µs = $10^{-6}$ s) and an amplitude resolution of at least ten microvolt ($10^{-5}$ V) for the receiver signal. The unit must be able to display the superimposed time traces from both bender elements as a measurement is taken, and preferably have movable cursors in order to interpret the measured shear wave travel time. The unit should have a delayed trigger function, such that the very start of the transmitter signal is recorded. The unit should preferably have an averaging function, where the measurements from several consecutive shear wave pulses can be averaged in order to remove random noise components from the receiver signal.

6.6 *Additional Power Amplifiers and Signal Filters*—Such units should be avoided in the connections between the bender elements and the data recorder, as they can distort the signals and introduce errors in the shear wave travel time measurements. If a power amplifier is absolutely necessary between the function generator and the transmitter bender element, it should be placed prior to the connection to the data recorder. If the receiver signal contains excessive random electrical noise making interpretation difficult, it is preferable to eliminate this noise by using the averaging function of the data recorder instead of using a separate signal filter that could adversely affect the measurements.

## 7. Preparation of Apparatus

7.1 The preparation of the triaxial equipment is the same as in the standard method being followed.

7.2 A function check of both the transmitter and receiver bender elements should be performed before each use. This can be done by sending a square wave signal to either bender element while holding this close to one's ear. If functioning properly, a slight clicking sound should be heard. Alternatively, both bender elements can be tapped lightly on the sides, for example with a finger or pencil. If functioning properly, the signals on the recording device should show responses each time the bender elements are tapped.

7.3 The shear wave travel distance is the tip-to-tip distance between the transmitter and receiver bender elements within the soil specimen. Because the lengths of each bender element protrudes into the specimen, this must be subtracted from the height of the soil specimen. Measure and record several lengths using a caliper along and to either side of the bender elements. Average the readings for each bender element and add them to determine the total bender element protrusion, $H_b$.

7.4 The transmitter and receiver bender elements must be parallel to each other to function properly. Alignment marks can be made on the triaxial top platen and base pedestal to assist in orienting them correctly during equipment assembly.

7.4.1 Bender element measurements in the form of plots (time traces seen on the screen of the data recording device) are usually presented with the same polarity. For example, if the transmitter trace first starts in the upwards direction (positive voltage), the first significant movement of the receiver trace is also upward. The alignment marks in 7.3 are made such that the top platen orientation relative to the base pedestal will produce the same polarity in the resulting bender element traces. Otherwise, if one of the bender elements happens to be oriented 180° from this, the recording equipment may have a function by which one of the traces can be inverted to get similar polarity in the two traces.

7.5 Fig. 2 shows an example of how the bender elements and electronics are connected for taking shear wave velocity determinations. The function generator sends a driving signal (also called the transmitter signal) to the transmitter bender element and one channel of the data recorder. This driving signal causes the transmitter bender element to move, which generates a shear wave. The cable from the receiver bender element is connected to a second input channel of the data recorder. The receiver signal is generated by the receiver bender element and is proportional to the movement it experiences upon arrival of the shear wave.

## 8. Calibration

8.1 The bender elements themselves may have a time delay, $T_c$, that should be corrected for in the measured shear wave travel time. Such a time delay is usually very small, but can be important when measuring shear wave travel time over short distances in a soil. Using exactly the same test equipment and electronics that will be used to measure shear wave travel time in a soil specimen, place the tips of the transmitter and receiver bender elements in direct contact with each other (no soil specimen). The bender element tips are held together with light pressure by hand or by the test equipment itself (for example, top platen attached to the triaxial piston). Take readings as in



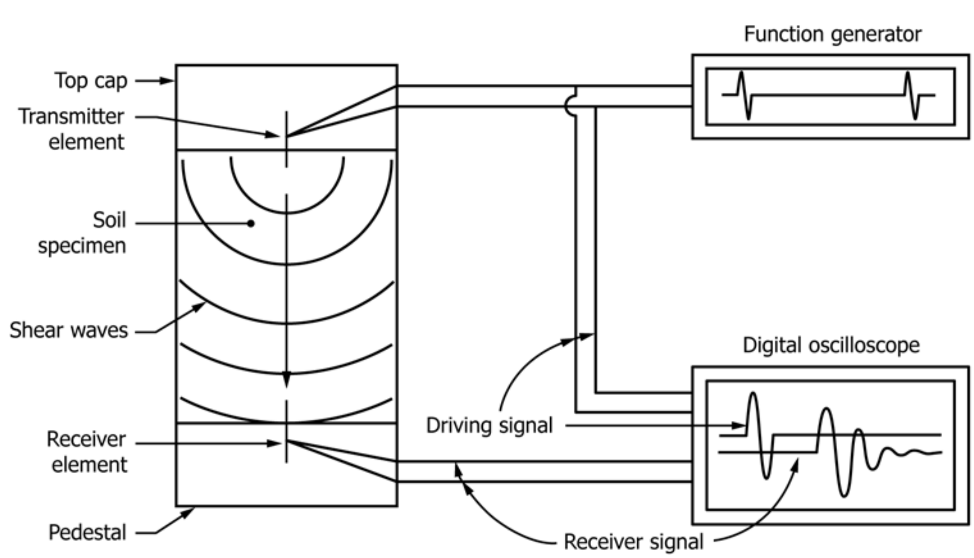


**FIG. 2 Schematic Diagram of Bender Element Test Setup**