Designation: D7400/D7400M – 19

Standard Test Methods for Downhole Seismic Testing[1]

This standard is issued under the fixed designation D7400/D7400M; 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 These test methods address compression (P) and shear (S) waves propagating in the downward direction in a nearly vertical plane. The seismic waves can be denoted as P_V or P_Z for a downward propagating compression wave and as S_{VH} or S_{ZX} for downward propagating and horizontally polarized shear wave. The S_{VH} or S_{ZX} is also referred to as an S_H wave. These test methods are limited to the determination of the interval velocities from arrival times and relative arrival times of compression (P) waves and vertically (SV) and horizontally (SH) oriented shear (S) seismic waves which are generated near surface and travel down to an array of vertically installed seismic sensors. Two methods are discussed, which include using either one or two downhole sensors (receivers).

1.2 Various applications of the data will be addressed and acceptable procedures and equipment, such as seismic sources, receivers, and recording systems will be discussed. Other items addressed include source-to-receiver spacing, drilling, casing, grouting, a procedure for borehole installation, and conducting actual borehole and seismic cone tests. Data reduction and interpretation is limited to the identification of various seismic wave types, apparent velocity relation to true velocity, example computations, use of Snell's law of refraction, and assumptions.

1.3 There are several acceptable devices that can be used to generate a high-quality P or SV source wave or both and SH source waves. Several types of commercially available receivers and recording systems can also be used to conduct an acceptable downhole survey. Special consideration should be given to the types of receivers used and their configuration to provide an output that accurately reflects the input motion. These test methods primarily concern the actual test procedure, data interpretation, and specifications for equipment which will yield uniform test results.

1.4 All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.4.1 The procedures used to specify how data are collected/recorded and calculated in these test methods are regarded as the industry standard. In addition, they are representative of the significant digits that should generally 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 design.

1.4.2 Measurements made to more significant digits or better sensitivity than specified in these test methods shall not be regarded a nonconformance with this standard.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.5.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

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

1.7 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

D4428/D4428M Test Methods for Crosshole Seismic Testing

D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *seismic wave train*—the recorded motion of a seismic disturbance with time.

4. Summary of Test Method

4.1 The Downhole Seismic Test makes direct measurements of compression (P-) or shear (S-) wave velocities, or both, in a borehole advanced through soil or rock or in a cone penetration test sounding. It is similar in several respects to the Crosshole Seismic Test Method (Test Methods D4428/D4428M). A seismic source is used to generate a seismic wave train at the ground surface offset horizontally from the top of a cased borehole. Downhole receivers are used to detect the arrival of the seismic wave train. The downhole receiver(s) may be positioned at selected test depths in a borehole or advanced as part of the instrumentation package on an electronic cone penetrometer (Test Method D5778). The seismic source is connected to and triggers a data recording system that records the response of the downhole receiver(s), thus measuring the travel time of the wave train between the source and receiver(s). Measurements of the arrival times (travel time from source to sensor) of the generated P- and S- waves are then made so that the low strain ($<10^{-4}$ %) in-situ P-wave and S-wave velocities can be determined. The calculated seismic velocities are used to characterize the natural or man-made (or both) properties of the stratigraphic profile.

5. Significance and Use

5.1 The seismic downhole method provides a designer with information pertinent to the seismic wave velocities of the materials in question (**1**)[3]. The P-wave and S-wave velocities are directly related to the important geotechnical elastic constants of Poisson's ratio, shear modulus, bulk modulus, and Young's modulus. Accurate in-situ P-wave and S-wave velocity profiles are essential in geotechnical foundation designs. These parameters are used in both analyses of soil behavior under both static and dynamic loads where the elastic constants are input variables into the models defining the different states of deformations such as elastic, elasto-plastic, and failure. Another important use of estimated shear wave velocities in geotechnical design is in the liquefaction assessment of soils.

5.2 A fundamental assumption inherent in the test methods is that a laterally homogeneous medium is being characterized. In a laterally homogeneous medium the source wave train trajectories adhere to Snell's law of refraction. Another assumption inherent in the test methods is that the stratigraphic medium to be characterized can have transverse isotropy. Transverse isotropy is a particularly simple form of anisotropy because velocities only vary with vertical incidence angle and not with azimuth. By placing and actuating the seismic source at offsets rotated 90° in plan view, it may be possible to confirm that a more complex model is needed to evaluate the field data.

5.3 In soft saturated soil, where the P-wave velocity of the soil is less than the P-wave velocity of water, which is about 1450 m/s [4750 ft/s], the P-wave velocity measurement will primarily be controlled by the P-wave velocity of water and a direct measurement of the soil P-wave velocity will not be possible.

NOTE 1—The quality of the results produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities. 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 The basic data acquisition system consists of the following:

6.1.1 *Energy Sources*—These energy sources are chosen according to the needs of the survey, the primary consideration being whether P-wave or S-wave velocities are to be determined. The source should be rich in the type of energy required, that is, to produce good P-wave data, the energy source must transmit adequate energy to the medium in compression or volume change. Impulsive sources, such as explosives, hammers, or air guns, are all acceptable P-wave generators. To produce an identifiable S wave, the source should transmit energy to the ground with a particle motion perpendicular or transverse to the axis of the survey. Impulse or vibratory S-wave sources are acceptable, but the source must be repeatable and, although not mandatory, reversible.

[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] The boldface numbers in parentheses refer to a list of references at the end of this standard.

6.1.1.1 *Shear Beam*—A shear beam is a common form of an SH-wave energy source (**2**). The beam can be metal or wood, and may be encased at the ends and bottom with a steel plate. Strike plates may optionally be provided at the beam ends. The bottom plate may optionally have cleats to penetrate the ground and to prevent sliding when struck. A commonly utilized shear beam has approximate dimensions of 2.4 m [8 ft] long by 150 mm [6 in.] wide. The center of the shear beam is placed on the ground at a horizontal offset ranging from 1 to 4 m [3 to 12 ft] from the receiver borehole (or cone insertion point). This horizontal offset should be selected carefully since borehole disturbance, rod noise, and refraction through layers with significantly different properties may impact the test results. Larger horizontal offsets of 4 to 6 m [12 to 20 ft] for the seismic source may be necessary to avoid response effects due to surface or near-surface features. In this case the possibility of raypath refraction must be taken into account. The ends of the beam should be positioned equidistant from the receiver borehole. The shear beam is typically then loaded by the axle load of vehicle wheels or the leveling jacks of the cone rig. The ground should be level enough to provide good continuous contact along the whole length of the beam to ensure good coupling between the beam and the ground. Beam-to-ground coupling should be accomplished by scraping the ground level to a smooth, intact surface. Backfilling to create a flat spot will not provide good beam-ground coupling and should be avoided. The shear beam is typically struck on a strike plate at one end using a nominal 1- to 15-kg [2- to 33-lb] hammer to produce a seismic wave train. Striking the other end will create a seismic wave train that has the opposite polarity relative to the wave train produced at the first end. Fig. 1 shows a diagram of the typical shear beam configuration that will produce SH-wave trains. Fig. 2 shows an example of an impulse seismic source wave train that contains both P- and S-wave components. Although the shear beam of dimensions 2.4 m [8 ft] long by 150 mm [6 in.] wide is commonly utilized, it may be desirable to implement beams of shorter length so that SH-source more closely approximates a "point source" for tests less than 20 m [60 ft] in depth. The "point source" SH-wave beam allows for the accurate specification of the source Cartesian location (x, y, and z coordinates) which is required for the subsequent interval velocity calculation. For example, if a large SH-hammer beam is utilized, it becomes difficult to specify the exact location of the seismic source. In addition, it is preferable to initially excite a small area if complex stratigraphy exist and shorter SH-hammer beams mitigate problems arising from poor beam-ground coupling.

NOTE 2—The ranges of dimensions and hammer units shown in Fig. 1 are examples of typical energy source configurations but are not the only means to produce acceptable seismic wave trains. In this typical case, heavier hammers and longer pivot arms will generally produce higher energy wave trains and deeper penetration into the soil and rock as long as ground coupling with the shear beam is maintained.

6.1.2 *Receivers*—In the downhole seismic test, the seismic receivers are installed vertically with depth within a borehole or as part of the instrumentation in a cone penetrometer probe. The receivers intended for use in the downhole test shall be

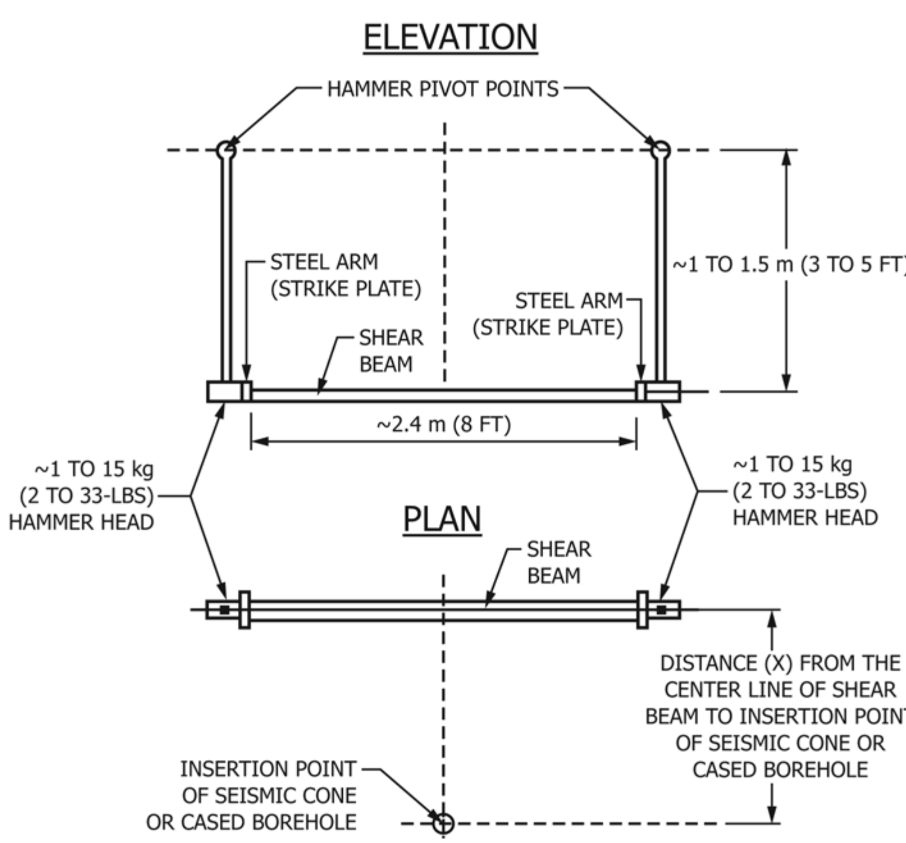

FIG. 1 Typical Downhole Shear Wave Source (Produces SH- Wave Train)