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Standard Test Method for High-Strain Dynamic Testing of Piles[1]

This standard is issued under the fixed designation D 4945; 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 procedure for testing vertical or batter piles individually to determine the force and velocity response of the pile to an impact force applied axially by a pile driving hammer to the top of the pile. This test method is applicable to deep foundation units that function in a manner similar to foundation piles, regardless of their method of installation provided that they are receptive to high strain impact testing.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.* For a specific precautionary statement, see Note 5.

NOTE 1—High-strain dynamic testing requires a strain at impact which is representative of a force in the pile having the same order of magnitude, or greater, than the ultimate capacity of the pile.

NOTE 2—This standard method may be applied for high-strain dynamic testing of piles with the use of only force or strain transducers and/or acceleration, velocity or displacement transducers as long as the test results clearly state how the testing deviates from the standard.

NOTE 3—A suitable follower may be required for testing cast-in-place concrete piles. This follower should have an impedance within 10 % of that of the pile. For mandrel driven piles, the mandrel may be instrumented in a similar way to a driven pile.

2. Referenced Documents

2.1 *ASTM Standards:*

C 469 Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression[2]

D 198 Methods of Static Tests of Timbers in Structural Sizes[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 1143 Method of Testing Piles Under Static Axial Compressive Load[4]

3. Terminology

3.1 Except as defined in 3.2, the terminology used in this test method conforms with Terminology D 653.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *capblock*—the material inserted between the hammer striker plate and the drive cap on top of the pile (also called hammer cushion).

3.2.2 *cushion*—the material inserted between the drive cap on top of the pile and the pile (also called pile cushion).

3.2.3 *impact event*—the period of time during which the pile is moving in a positive and/or negative direction of penetration due to the impact force application. See Fig. 1.

3.2.4 *moment of impact*—the first moment of time after the start of the impact event when the acceleration is zero. See Fig. 1.

3.2.5 *pile impedance*—the Young's modulus of the pile material multiplied by the cross-sectional area of the pile and divided by the strain wave speed.

4. Significance and Use

4.1 This test method is used to provide data on strain or force and acceleration, velocity or displacement of a pile under impact force. The data may be used to estimate the bearing capacity and the integrity of the pile, as well as hammer performance, pile stresses, and soil dynamics characteristics, such as soil damping coefficients and quake values. This test method is not intended to replace Test Method D 1143.

5. Apparatus

5.1 *Apparatus for Applying Impact Force:*

5.1.1 *Impact Force Application*—Any conventional pile driving hammer or similar device is acceptable for applying the impact force provided it is capable of generating a net measurable pile penetration, or an estimated mobilized static resistance in the bearing strata which, for a minimum period of 3 ms, exceeds to a sufficient degree the working load assigned to the pile, as judged by the engineer in charge. The device shall be positioned so that the impact is applied

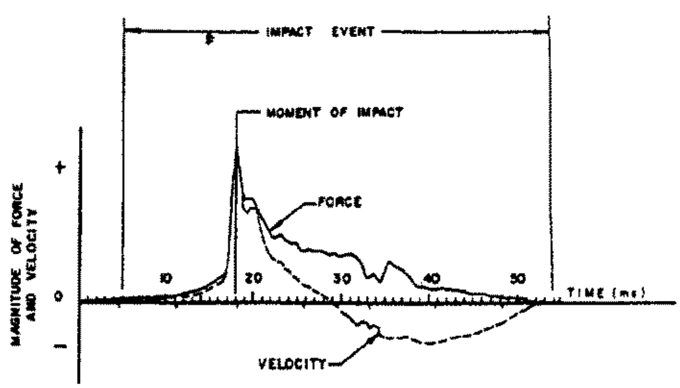

FIG. 1 Typical Force and Velocity Traces Generated by the Apparatus for Obtaining Dynamic Measurements

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

axially to the head of the pile and concentric with the pile.

5.2 *Apparatus for Obtaining Dynamic Measurements:*

5.2.1 *Force or Strain Transducers*—The apparatus shall include transducers, which are capable of independently measuring strain and acceleration versus time at a specific location along the pile axis during the impact event. A minimum of two of each of these devices shall be securely attached on opposite sides of the pile so that they do not slip. Bolt-on, glue-on, or weld-on transducers are acceptable. The strain transducers shall have a linear output over the entire range of possible pile strains. When attached, their natural frequency shall be in excess of 7500 Hz. The measured strain shall be converted to force using the pile cross-section area and dynamic modulus of elasticity at the measuring location. The dynamic modulus of elasticity may be assumed to be 29 to 30 × 10^6 psi for steel. The dynamic modulus of elasticity for concrete and wood piles may be estimated by measurement during a compression test in accordance with Test Method C 469 and Methods D 198. Alternatively, they may be calculated from the wave speed determined as indicated in 6.2.

5.2.1.1 Force measurements also can be made by force transducers placed between the pile head and the driving hammer, although it should be recognized that such a transducer may alter the dynamic characteristics of the driving system. Force transducers shall have an impedance between 50 % and 200 % of the pile impedance. The output signal must be linearly proportional to the axial force, even under eccentric load application. The connection between the force transducers and the pile shall have the smallest possible mass and least possible cushion necessary to prevent damage.

5.2.2 *Acceleration, Velocity or Displacement Transducers*—Velocity data shall be obtained with accelerometers, provided the signal can be processed by integration in the apparatus for reducing data. A minimum of two accelerometers with a resonant frequency above 7500 Hz shall be at equal radial distances on diametrically opposite sides of the pile, attached to the pile securely so that they do not slip. Bolt-on, glue-on, or weld-on transducers are acceptable. The accelerometers shall be linear to at least 1000 g and 7500 Hz for satisfactory results on concrete piles. For steel piles, it is advisable to use accelerometers that are linear up to 5000 g. Either a-c or d-c accelerometers can be used. If a-c devices are used, the time constant shall be at least 0.2 s. Alternatively, velocity or displacement transducers may be used to obtain velocity data, provided they are equivalent in performance to the specified accelerometers.

5.2.3 *Placement of Transducers*—The transducers shall be placed, diametrically opposed and on equal radial distances, at the same axial distance from the bottom of the pile so that the measurements are not affected by bending of the pile. When near the upper end, they shall be attached at least one and one-half pile diameters from the pile head. This is illustrated in Figs. 2 through 7. Care shall be taken to ensure that the apparatus is securely attached to the pile so that slippage is prevented. The transducers shall have been calibrated to an accuracy of 2 % throughout the applicable measurement range. If damage is suspected during use, the transducers shall be re-calibrated (or replaced).

5.3 *Signal Transmission*—The signals from the trans-

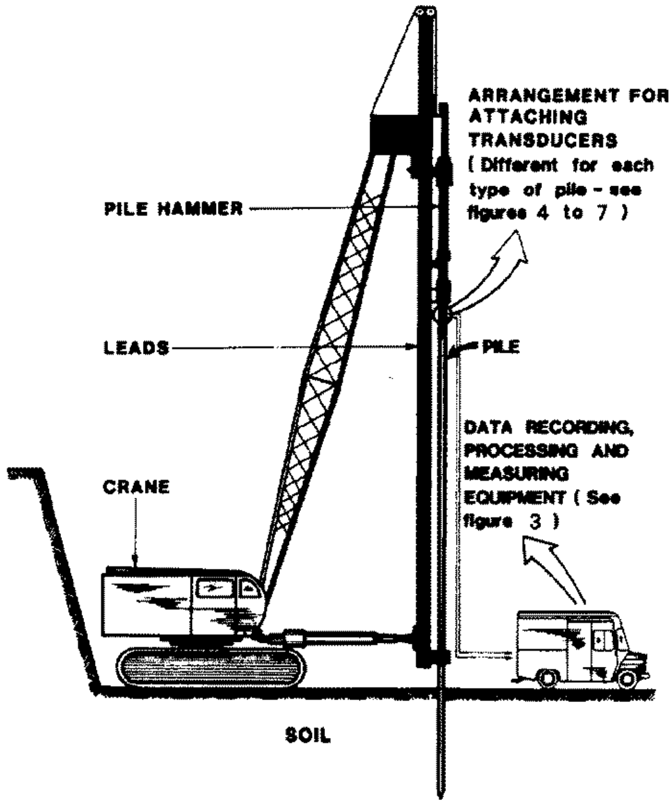


FIG. 2 Typical Arrangement for High Strain Dynamic Testing of Piles

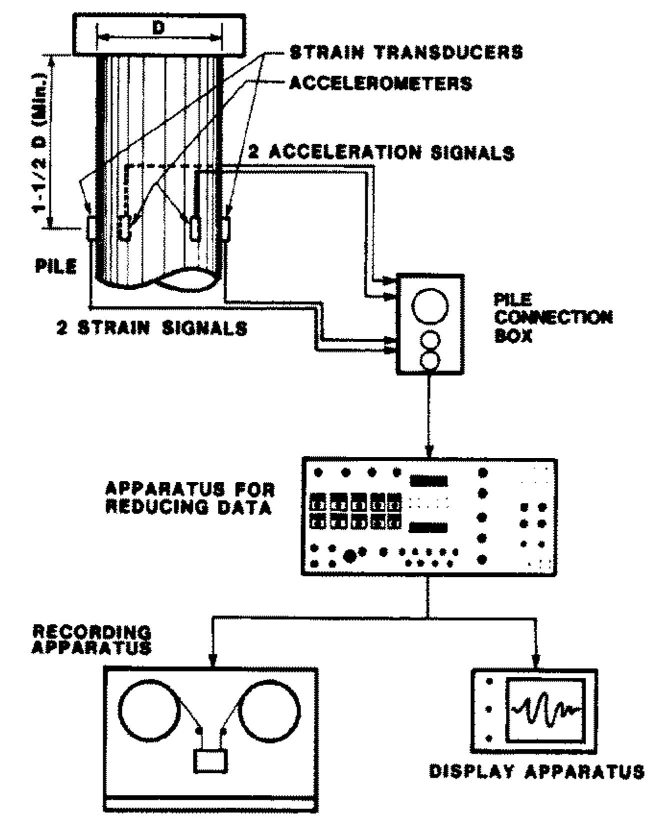


FIG. 3 Schematic Diagram for Apparatus for Dynamic Monitoring of Piles

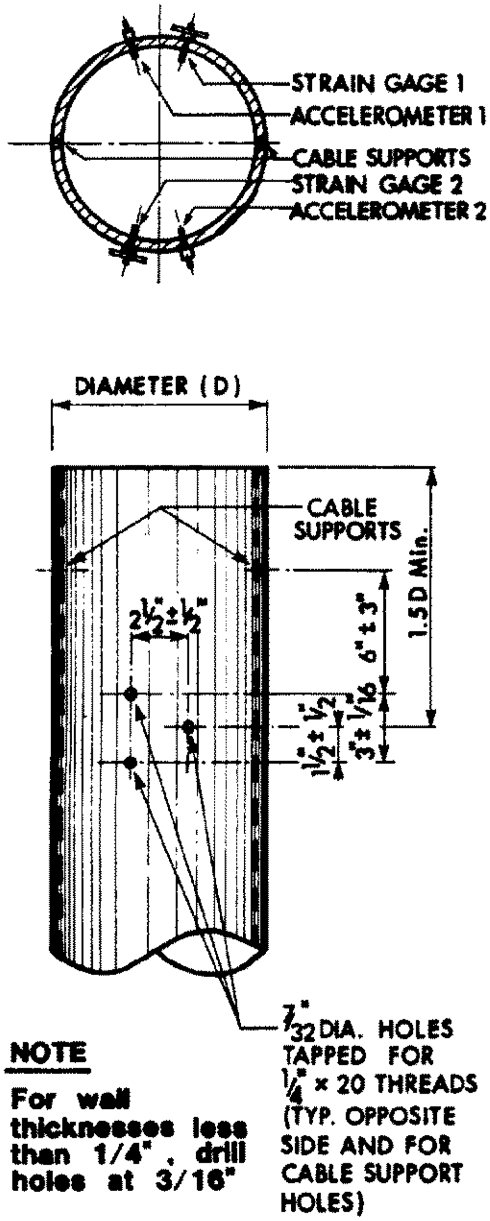


FIG. 4 Typical Arrangement for Attaching Transducers to Pipe Piles

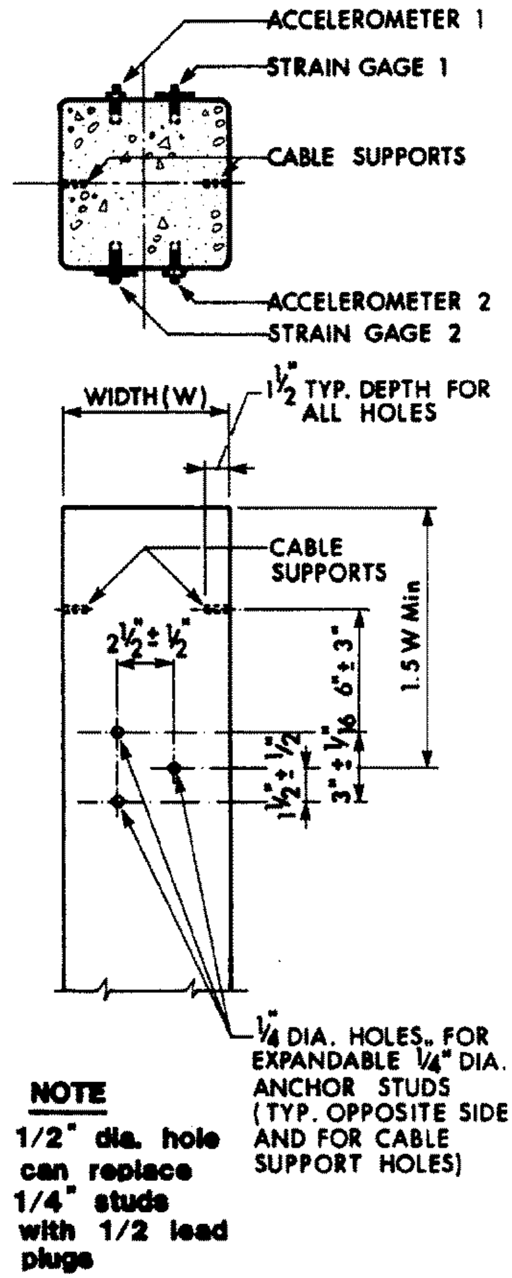


FIG. 5 Typical Arrangement for Attaching Transducers to Concrete Piles

ducers shall be transmitted to the apparatus for recording, reducing, and displaying the data (see 5.4) by means of a cable or equivalent. This cable shall limit electronic or other interferences to less than 2 % of the maximum signal expected. The signals arriving at the apparatus shall be linearly proportional to the measurements at the pile over the frequency range of the equipment.

5.4 *Apparatus for Recording, Reducing and Displaying Data:*

5.4.1 *General*—The signals from the transducers (see 5.2) during the impact event shall be transmitted to an apparatus for recording, reducing, and displaying data to allow determination of the force and velocity versus time. It may be desirable to also determine the acceleration and displacement of the pile head, and the energy transferred to the pile. The apparatus shall include an oscilloscope or oscillograph for displaying the force and velocity traces, a tape recorder or equivalent for obtaining a record for future analysis, and a means to reduce the data. The apparatus for recording, reducing, and displaying data shall have the capability of making an internal calibration check of strain, acceleration, and time scales. No error shall exceed 2 % of the maximum signal expected. A typical schematic arrangement for this apparatus is illustrated in Fig. 3.

5.4.2 *Recording Apparatus*—Signals from the transducers shall be recorded electronically in either analog or digital form so that frequency components have a low pass cut-off frequency of 1500 Hz (−3 dB). When digitizing, the sample frequency shall be at least 5000 Hz for each data channel.

5.4.3 *Apparatus for Reducing Data*—The apparatus for

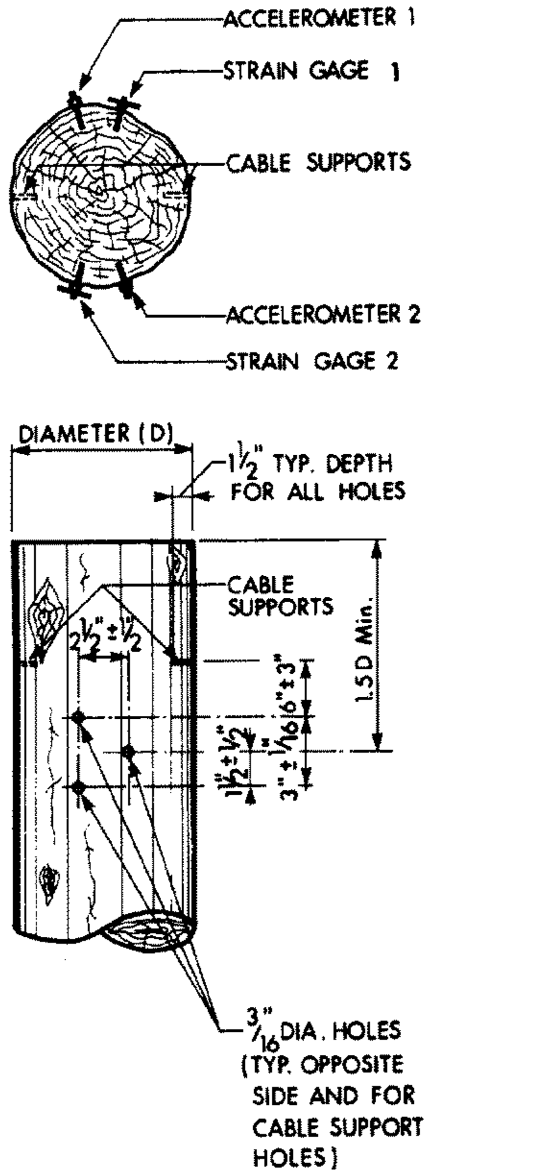
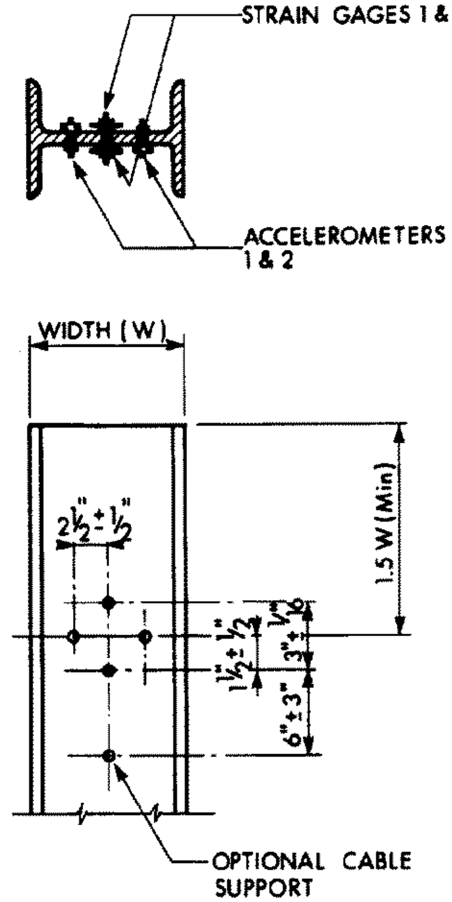


FIG. 6 Typical Arrangement for Attaching Transducers to Wood Piles



NOTE : All holes at 5/16" dia.

FIG. 7 Typical Arrangement for Attaching Transducers to H-Piles

reducing signals from the transducers shall be an analog or digital computer capable of at least the following functions:

5.4.3.1 *Force Measurements*—The apparatus shall provide signal conditioning, amplification and calibration for the force measurements system. If strain transducers are used (see 5.2.1), the apparatus shall be able to compute the force. The force output shall be continuously balanced to zero except during the impact event.

5.4.3.2 *Velocity Data*—If accelerometers are used (see 5.2.2), the apparatus shall integrate the acceleration over time to obtain velocity. If displacement transducers are used, the apparatus shall differentiate the displacement over time to obtain velocity. If required, the apparatus shall zero the velocity between impact events and shall adjust the velocity record to account for transducer zero drift during the impact event.

5.4.3.3 *Signal Conditioning*—The signal conditioning for force and velocity shall have equal frequency response curves to avoid relative phase shifts and relative amplitude differences.

5.4.4 *Display Apparatus*—Signals from the transducers specified in 4.2.1 and 4.2.2 shall be displayed by means of an apparatus, such as an oscilloscope or oscillograph, on which the force and velocity versus time can be observed for each hammer blow. This apparatus may receive the signals from the transducers directly or after they have been processed by the apparatus for reducing the data. The apparatus shall be adjustable to reproduce a signal having a range of duration of between 5 and 160 ms. Both the force and velocity data can be reproduced for each blow and the apparatus shall be capable of holding and displaying the signal from each selected blow for a minimum period of 30 s.

6. Procedure

6.1 *General*—Record applicable project information (Section 7). Attach the transducers (see 5.2) to the pile, perform the internal calibration check, and take the dynamic measurements for the impacts during the interval to be monitored together with routine observations of penetration resistance. Determine properties from a minimum of ten impact records during initial driving and, when used for soil resistance computations, normally from one or two representative blows at the beginning of restriking. The force and velocity versus time signals may be reduced by computer or may be reduced manually to calculate the developed force, velocity, acceleration, displacement, and energy over the impact event.

6.2 *Determination of Strain Wave Speed (optional)*—Place the pile on supports or level ground free and clear from neighboring piles and obstructions. Attach accelerometer to one end of the pile and strike the other end of the pile with a sledge hammer of suitable weight. Take care not to damage or dent the pile. Record (see 5.4.2) and display (see 5.4.4) the accelerometer signal. Measure the time between acceleration peaks for as many cycles of reflection as possible. Divide this time by the appropriate travel length of the strain waves during this interval to determine the wave speed.

6.3 *Preparation*—Mark the piles clearly at appropriate intervals. Attach the transducers securely to the piles by bolting, gluing, or welding. For pile materials other than steel, determine the wave speed (see 6.2). Position the apparatus for applying the impact force so that the force is applied axially and concentrically with the pile. Set up the apparatus for recording, reducing, and displaying data so that it is operational and the force and velocity signals are zeroed.

6.4 *Taking Measurements*—Record the number of impacts for a specific penetration. For drop hammers and single acting diesel and steam hammers, record the drop of the ram or ram travel length. Record the number of blows per minute delivered by the hammer. For double acting diesel hammers, measure the bounce pressure, and, for double acting steam or compressed-air hammers, measure the steam or air pressure in the pressure line to the hammer. Take, record, and display a series of force and velocity measurements. Compare the force and the product of velocity and impedance (see 3.2.1) at the moment of impact.

NOTE 4—If the dynamic measurements are to be used for bearing capacity computations, take the dynamic measurements during restriking of the pile at time periods sufficiently long after the end of initial driving to allow pore water pressure and soil strength changes to occur. Further geotechnical conditions, such as underlying compressible layers, need always be considered, as they should be in any type of bearing capacity computation.

NOTE 5: **Warning**—Before approaching a pile being driven, check that no material or other appurtenances can break free and jeopardize the safety of persons in the vicinity.

NOTE 6—If set-rebound measurements are required, attach a removable sheet to the pile and install a horizontal reference beam in the ground adjacent to the pile. Draw a baseline on the sheet from the reference beam before and after each impact.

6.5 *Data Quality Checks*—For confirmation of data quality, periodically compare the force and the product of the velocity and pile impedance at the moment of impact for proportionality agreement and the force and velocity versus time over a series of selected and generally consecutive impact events for consistency. Consistent and proportional signals from the force or strain transducers and the acceleration, velocity or displacement transducers are the result of the transducers systems and the apparatus for recording, reducing and displaying data being properly calibrated. If the signals are not in proportionality agreement, investigate the cause and correct the situation. If the cause is determined to be a transducer, it must be recalibrated before further use. Perform internal calibration checks at the beginning and end of each data set.

NOTE 7—It is generally recommended that all components of the apparatus for obtaining dynamic measurements and the apparatus for recording, reducing and displaying data be calibrated at least once a year.

6.6 *Analysis of Measurements:*

6.6.1 Obtain force and velocity from the readout of the apparatus for reducing data (see 5.4.3) or from the display apparatus (see 5.4.4). Record the impact force and velocity and the maximum and minimum forces for the selected representative blows. Obtain the maximum acceleration directly from the accelerometer signal or by differentiation of the velocity versus time record. Obtain the displacement from the pile driving record, the set-rebound curve, and from the displacement transducer, if used in accordance with 5.2.2 or by integration of the velocity versus time record. Obtain the maximum energy transferred to the location of the transducers.

6.6.2 The recorded data may be subjected to analysis in a computer. The results of the analysis may include an assessment of integrity of the pile, the driving system performance, and the maximum dynamic driving stresses. The results may also be used for evaluation of static soil resistance and its distribution on the pile at the time of the testing. Such further use of the data is a matter of proper engineering judgment.

NOTE 8—Normally, there is better correlation between mobilized resistance and bearing capacity where there is a measurable net penetration per impact.

NOTE 9—Evaluation of static soil resistance and its distribution can be based on a variety of analytical methods and is the subject of individual engineering judgment. The input into the analytical methods may or may not result in the dynamic evaluation matching static load test data. It is desirable and often necessary to calibrate the result of the dynamic analysis with those of a static pile load test carried out according to Method D 1143.

7. Report

7.1 The report of the dynamic testing shall include the following information when applicable:

7.1.1 *General:*

7.1.1.1 Project identification,

7.1.1.2 Project location,

7.1.1.3 Test site location,

7.1.1.4 Owner,

7.1.1.5 Structural engineer,

7.1.1.6 Geotechnical engineer,

7.1.1.7 Pile contractor,

7.1.1.8 Test boring contractor,

7.1.1.9 Designation and location of nearest test boring with reference to location of the test pile and vertical control datum,

7.1.1.10 Log of nearest test boring,

7.1.1.11 Horizontal control datum, and

7.1.1.12 Vertical control (elevation) datum.

7.1.2 *Pile Installation Equipment:*

7.1.2.1 Make, model, type, size, and recent service history of hammer,

7.1.2.2 Weight of hammer and ram,

7.1.2.3 Rated and actual stroke of ram,

7.1.2.4 Rated energy of hammer,

7.1.2.5 Rated capacity of boiler or compressor,

7.1.2.6 Type, dimensions and stiffness values of capblock and pile cushion,

7.1.2.7 Weight and dimensions of drive cap,

7.1.2.8 Detailed description and drawings of follower,

7.1.2.9 Size of predrilling or jetting equipment,

7.1.2.10 Type, size, length, and weight, and stress transmitting area of mandrel, and

7.1.2.11 Detailed specifications of any special arrangement for applying impact force.

7.1.3 *Test Piles:*

7.1.3.1 Identification and location of test pile(s),

7.1.3.2 Working load of pile(s),

7.1.3.3 Type of pile(s),

7.1.3.4 Test pile material including basic specifications, including strength,

7.1.3.5 Tip and butt dimensions of pile(s),

7.1.3.6 General quality of timber test piles including type of timber, occurrence of knots, splits, checks and shakes, and straightness of pile(s),

7.1.3.7 Preservative treatment and conditioning process used for timber test piles including inspection certificates,

7.1.3.8 Wall thickness of pipe test pile,

7.1.3.9 Weight per unit length of H test pile,

7.1.3.10 Description of test pile tip reinforcement or protection,

7.1.3.11 Description of banding timber piles,

7.1.3.12 Description of special coating used,

7.1.3.13 Test pile (mandrel) weight as driven,

7.1.3.14 Date precast test piles made,

7.1.3.15 Concrete cylinder strengths when pile tested (approximate),

7.1.3.16 Description of internal reinforcement used in test pile (size, length, number longitudinal bars, arrangement, spiral, or tie steel),

7.1.3.17 Description, location, size, weight and, where applicable, catalogue data concerning splices,

7.1.3.18 Condition of precast piles including spalled areas, cracks, head surface, and straightness of piles,

7.1.3.19 Effective prestress,

7.1.3.20 Which piles vertical or batter,

7.1.3.21 Degree of batter, and

7.1.3.22 Final elevation of test pile butt(s) referenced to fixed datum.

7.1.4 *Pile Installation:*

7.1.4.1 Date driven (installed),

7.1.4.2 Date concreted (cast-in-place),

7.1.4.3 Volume of concrete or grout placed in pile,

7.1.4.4 Grout pressure used,

7.1.4.5 Description of pre-excavation or jetting (depth, size, pressure, duration),

7.1.4.6 Operating pressure for all hammers,

7.1.4.7 Throttle setting—diesel hammer during testing,

7.1.4.8 Fuel type diesel—hammer,

7.1.4.9 Description of special installation procedures used, such as piles cased off,

7.1.4.10 Type and location of pile splices,

7.1.4.11 Driving records,

7.1.4.12 Final penetration resistance,

7.1.4.13 Visual observations of stroke of ram during final driving and blows per minute of hammer,

7.1.4.14 Penetration for last two series of five blows with the hammer,

7.1.4.15 Penetration resistance during restrike,

7.1.4.16 When capblock replaced (indicate on log),

7.1.4.17 When pile cushion replaced (indicate on log),

7.1.4.18 Cause and duration of interruptions in pile installation, and

7.1.4.19 Notation of any unusual occurrences during installation.

7.1.5 *Dynamic Testing:*

7.1.5.1 Description, calibration data and date of calibration of all components of the apparatus for obtaining dynamic measurements and apparatus for recording, reducing and displaying data,

7.1.5.2 Date tested,

7.1.5.3 Test pile identification,

7.1.5.4 The modulus of elasticity, density, and wave speed of test pile, and how determined,

7.1.5.5 Sequence in pile driving test carried out, such as end of initial driving, beginning of restrike,

7.1.5.6 Length of pile, as being driven, embedded and below apparatus for obtaining dynamic measurements,

7.1.5.7 Penetration resistance during dynamic testing,

7.1.5.8 The range, average, and standard deviation of the measurements of maximum and minimum compression force,

7.1.5.9 The range, average, and standard deviation of the impact velocity data,

7.1.5.10 The range, average and standard deviation of the measurements of maximum acceleration,

7.1.5.11 The range, average, and standard deviation of the measurements of final penetration of the pile,

7.1.5.12 The range, average, and standard deviation of the maximum and final energy data,

7.1.5.13 Which one-dimensional wave theory was used for the analysis of the pile driving, give reference,

7.1.5.14 The variables entered into the wave theory, such as damping, quake, and resistance,

7.1.5.15 When applicable, the computed soil resistance acting on the pile at the time of testing and how computed, and

7.1.5.16 Comments on the integrity of the pile.

NOTE 10—Data on the forces, velocity, acceleration, penetration and energy can be recorded at any point of interest during the pile driving. The standard deviation of these values should be calculated for a minimum of 20 consecutive hammer blows.

8. Precision and Bias

8.1 *Precision*—The precision of the procedure in this test method for direct measurements of strain and acceleration is difficult to determine because of the variability of the pile driving hammer and the materials in which the pile is located. Information is being gathered on the precision of the procedure.

8.2 *Bias*—No justifiable statement of bias can be made on the procedure in this test method because there are no standard values to which the measured values can be referenced.