

**STATE OF OHIO  
DEPARTMENT OF TRANSPORTATION**

**SPECIAL PROVISION  
HIGH-STRAIN DYNAMIC TESTING OF DRILLED SHAFTS**

**September 20, 2021**

**Item 524 - Drilled Shafts, Misc.: High-Strain Dynamic Testing Of Drilled Shafts**

**1.0 Description.** High-strain dynamic testing is performed by obtaining and analyzing records of shaft force and velocity under drop weight impacts for evaluations of shaft axial load resistance, structural integrity, and load-movement and shaft-soil load transfer relationships. Conform testing procedures to ASTM D4945, "Standard Test Method for High-Strain Dynamic Testing of Deep Foundations," unless otherwise noted herein. High-strain dynamic tests on drilled shafts (referred to below as dynamic tests) are non-destructive proof load tests. Proof load tests are performed to a maximum test load equal to the design factored axial load, defined as the proof test load (PTL). It is intended that the test shaft be left in a condition suitable for use in production.

This work consists of furnishing all materials, equipment and labor necessary for conducting high-strain dynamic tests on drilled shafts (referred to below as test shafts). Have the test shaft instrumented and tested by a Dynamic Testing Firm and Testing Engineer, acceptable to the Engineer, meeting requirements outlined in ASTM D4945 as well as those outlined below. Supply material and labor as hereinafter specified and including prior to, during, and after the load test.

**2.0 Equipment.** Supply all materials and equipment required to prepare the test shaft, dynamically test it, and return the test shaft to a condition acceptable for use in the finished structure. Equipment and procedures required to perform the test include but are not limited to:

1. If a permanent casing is not used as a feature to construct the test shaft, then use a shaft top extension, consisting of a thin walled casing or equivalent, to extend the test shaft by a length equal to two diameters. Expose this top length, defined as the "test area," and make it readily accessible to the Testing Engineer at the time of the test. If the top of the test shaft is below grade, then remove the surrounding soil to completely expose a test area as described above. Windows on four equidistant sides of the test shaft may have to be cut in the steel casing to expose the concrete. If the steel casing is relatively thick, then holes can be drilled and tapped in the steel for sensor attachment.
2. Means to ensure flat, level (perpendicular to the test shaft axis), and solid concrete shaft top. Concrete should be level with or slightly above the casing.
3. A drop weight of approximately 2 percent of the PTL, or as determined by the Testing Engineer (1 percent may be adequate for shafts with rock sockets); higher percentages are helpful when practical and when available. Provide a drop weight with an impacting surface area between

70 and 130 percent of the test shaft top area. Provide a ram weight with a shape that is as regular as possible (square, round, hexagonal, etc.).

4. A guide allowing variable drop heights typically up to between 3 and 7 ft, or as determined by the Testing Engineer.
5. A crane, rigging, and operator capable of lifting, unloading, assembling, disassembling, and packing all high-strain dynamic test equipment. Provide a crane and rigging of adequate size and strength to handle the required high-strain dynamic test equipment.
6. A top cushion consisting of new sheets of plywood with total thickness between 2 and 6 inches, or as determined by the Testing Engineer. Additionally provide a thin (1/8-inch to 1/4-inch) plywood sheet to cushion the top of the shaft if a load cell is used.
7. If protruding reinforcing bars are present, the Contractor has the option to incorporate the reinforcing steel in the test area. Upon successful completion of the dynamic test, remove the surrounding concrete to make the foundation suitable for use in the structure. If electing not to incorporate the steel in such a manner as described above, then provide a steel beam, pipe, or plates (cross sectional area approximately 20 percent or more of the shaft cross sectional area) placed on top of the drilled shaft, with sufficient length such that the ram impact will not interfere with the reinforcing bars. Steel striker plates and plywood cushion must also be sized to cover as much of the impact area as possible.
8. Surveyors transit, laser light, or equivalent for measurements of drilled shaft set under each impact.
9. A power source adequate for electronic equipment.

**3.0 Dynamic Testing Firm.** Employ a specialized dynamic testing firm acceptable to the Engineer. Dynamic testing is to be performed by an independent firm with a minimum of five years of experience in dynamic testing. The actual dynamic test is to be conducted and supervised by a Registered Engineer with at least two years of dynamic testing experience or who has achieved Advanced Level or better on the PDI / PDCA Dynamic Measurement and Analysis Proficiency Test, referred to as the Testing Engineer.

Submit a resume of the credentials of the proposed dynamic testing firm for acceptance by the Engineer at least 14 calendar days before the high-strain dynamic testing of the drilled shafts. Include a list of at least four similar projects in the resume.

The independent dynamic testing firm must supply the following testing instrumentation in addition to that outlined in ASTM Standard D 4945 Section 5:

1. Pile Driving Analyzer (PDA) system manufactured by Pile Dynamics, Inc. (30725 Aurora Road, Cleveland, OH 44139, USA; [www.pile.com](http://www.pile.com); email: [info@pile.com](mailto:info@pile.com); phone: +1.216.831.6131), or equivalent.

2. At least four calibrated strain transducers.
3. Four calibrated accelerometers.

Prior to performing the dynamic test, provide the Testing Engineer with soil borings, shaft installation records, concrete properties (strength, slump, etc.) and details regarding the anticipated dynamic loading equipment. The Testing Engineer will perform wave equation analyses to determine the suitability of the proposed dynamic load testing equipment and an acceptable range of ram drop heights so as not to cause damage in the test shaft during the test.

**4.0 Procedure.** Do not perform high-strain dynamic testing until the test shaft has a minimum concrete strength of 4 ksi (by cylinder test of deposited concrete).

Assist the Testing Engineer as necessary during all aspects of the high-strain dynamic test. Take the following steps in the performance of the high-strain dynamic test.

1. Construct the test shaft in accordance with the accepted installation plan.
2. If a permanent casing is not required, then case the upper length equal to two shaft diameters, noted as the "test area," in a thin wall tube or equivalent as noted above. Make this test area a continuation of the construction of the test shaft. Do not allow soil contamination or non-uniformities in the concrete located within or below the test area. Make test shaft top concrete level to the casing and smooth.
3. Prior to testing, make the shaft test area length completely accessible to the Testing Engineer. Prior to the test, for attachment of the sensors, cut windows (typically 8 x 8 inches square) out of the casing as directed by the Testing Engineer to expose smooth concrete surfaces, or if the casing wall thickness is adequate, drill and tap holes into the casing. Sensors are typically attached at least one diameter below the shaft top. If in the judgement of the Testing Engineer, the impedance percentage of the steel is relatively high and the permanent casing is relatively long (extending several diameters below the sensors), the sensors may be attached to the steel casing.
4. If a casing is not present, under the direction of the Testing Engineer, grind smooth four equidistant areas around the drilled shaft circumference such that proper sensor attachment can be accomplished.
5. Attach sensors at the direction of the Testing Engineer to the exposed concrete or steel casing in a secure manner to prevent slippage under impact. Alternatively, the Testing Engineer may provide a "top transducer" to perform the strain measurement (a thick wall steel pipe with stiffness calculated by the Testing Engineer to be approximately equal to the shaft impedance), with accelerometers attached to the shaft approximately 6 inches to 1 foot below the top of shaft.

6. Examine the shaft top to ensure concrete is flush with or above the casing.
7. Survey and record the shaft top elevation to a benchmark.
8. Apply plywood cushion and then striker plate to the shaft top. If reinforcing protrudes from the shaft top, then secure the steel beam or pipe (used to transfer the impact to the shaft top, and with a plate of sufficient area below to sufficiently distribute the impact force) in such a manner as not to move under impact.
9. Apply at least two hammer impacts to the top of the shaft. Make the first drop height minimal to allow the Testing Engineer to assess the testing equipment, the impact system, and the stresses on the foundation. Apply subsequent impacts by utilizing sequentially higher drop heights for successive loading events of increasing dynamic test energy and generate a load versus displacement curve from the calculated drilled shaft resistance, by superimposition from the multiple loading events with increasing energy. This will generate a simulated load versus settlement curve that can be evaluated similarly to a static load test. Increase the test energy until either:
  - a. The calculated drilled shaft resistance exceeds the PTL;
  - b. The measured drilled shaft stress reaches 80 percent of either the compressive or tensile strength of the drilled shaft concrete;
  - c. A single loading event produces a single drilled shaft set of 0.25 inches or greater;
  - d. The cumulative loading events produce a cumulative drilled shaft set greater than or equal to 5 percent of the drilled shaft nominal diameter.

Stop the dynamic test if any of these conditions are met. Please note that the Engineer will evaluate the simulated load versus settlement curve to provide information regarding the load displacement behavior of the shaft and to compare the cumulative set of the drilled shaft to the Davisson criterion, but it will not necessarily be used for acceptance of the drilled shaft.

A drilled shaft is defined as failing the proof load test in any of the following cases:

- a. If a cumulative drilled shaft set greater than 5 percent of the drilled shaft nominal diameter is reached prior to the PTL;
- b. If the load test fails to mobilize the full PTL;
- c. Structural failure of the drilled shaft occurs during testing.

If a drilled shaft fails the proof load test, the Engineer will determine the cause of the failure and the appropriate remedial actions. If remediation includes construction of an additional replacement or supplemental drilled shaft, perform an additional proof load test on the additional drilled shaft. If failure is not due to defective Work, the Department will pay for Extra Work necessary for the remediation as specified in 109.05. The Department will make no additional payment for remediation to correct defective Work.

10. Upon completion of the test, return the test shaft to a condition acceptable for use in the finished structure.

**5.0 Reporting of Results.** Submit a report of the testing results within 72 hours of test completion. In addition to the field results, submit results from at least one CAPWAP analysis (or equivalent), or as many analyses as needed to generate a load versus displacement curve from multiple impacts as required in Section 4.0. (CAPWAP software licenses are available from Pile Dynamics, Inc). CAPWAP analyses shall be performed by a Registered Engineer that has achieved Advanced Level or better on the PDI / PDCA Dynamic Measurement and Analysis Proficiency Test. The report must also provide the following:

1. Wave Equation analysis results obtained prior to testing.
2. CAPWAP (or equivalent) analysis results.
3. For each impact, the maximum measured force, maximum calculated tension force, transferred energy to the sensor location, corresponding stresses, and the Case Method bearing resistance.
4. Simulated load versus settlement curve, generated from the load versus displacement curve from the calculated drilled shaft resistance, by superimposition from the multiple loading events with increasing energy.
5. Assessment of the test results both with respect to shaft bearing resistance and integrity.

**6.0 Method of Measurement.** The Department will measure High-Strain Dynamic Testing of Drilled Shafts by the number of shafts on which high-strain dynamic testing is performed per the plans.

**7.0 Basis of Payment.** Payment for Drilled Shafts, Misc.: High-Strain Dynamic Testing of Drilled Shafts is full compensation for all costs incurred to perform the dynamic load testing, including, but not limited to, procurement, preparation, installation, and subsequent removal of test equipment and instrumentation, preparation and removal of the test area, conducting the tests, reporting of results, and return of the test shaft to a condition acceptable for use in the finished structure.

The Department will pay for construction of the test shaft in accordance with 524.17 under separate pay items.

The Department will pay for accepted quantities, after being provided the written test reports, at the contract unit price as follows:

<b>Item</b>	<b>Unit</b>	<b>Description</b>
524E95100	Each	Drilled Shafts, Misc.: High-Strain Dynamic Testing of Drilled Shafts.