**SPECIAL NOTE FOR DYNAMIC PILE TESTING**

**County (Item No.)**

**Route over River/Creek (or other description as appropriate)**

**1.0 GENERAL**

**1.1 Scope of Work** The scope of work includes furnishing all labor, equipment and analyses associated with dynamic testing of driven piles as specified in this Special Note and in general accordance with ASTM D 4945, ***High-Strain Dynamic Testing of Piles***. Dynamic testing involves attaching at least two strain transducers and two accelerometers to the pile near the pile head during initial driving or at a convenient location during restrike testing. A cable or wireless transmission connects the sensors near the pile head with the Pile Driving Monitoring Hardware located a safe distance from the pile, but not more than 330 ft from the pile. The piles that are to be tested must be of sufficient extra length to ensure that sensors are not driven into the ground.

**1.2 Personnel Qualifications** Perform dynamic pile testing utilizing the services of an independent Dynamic Pile Testing Consultant with qualified personnel as described below.

* Pile Driving Monitoring - An engineer with a minimum of 3 years dynamic pile testing and analysis experience or who has achieved Basic or better certification under the High-Strain Dynamic Pile Testing Examination and Certification process of the Pile Driving Contractors Association or Foundation QA.
* Wave Equation and Pile Driving Analyses - A licensed professional engineer with a minimum of 5 years dynamic pile testing and analysis experience or who has achieved Advanced or better certification under the High-Strain Dynamic Pile Testing Examination and Certification process of the Pile Driving Contractors Association or Foundation QA.

**1.3 Equipment** Supply equipment such as sensors, cables or wireless transmitters, etc. conforming to ASTM D 4945, ***High-Strain Dynamic Testing of Piles*** and furnished by the dynamic testing consultant. Prior to beginning work, submit the product name and manufacturer of the hardware and software components below for acceptance by the Engineer. If requested by the Engineer submit additional information including technical specifications, etc.

* Pile Driving Modeling - Wave Equation Software
* Pile Driving Monitoring - Hardware & Software
* Pile Driving Analysis - Signal Matching Software

To prepare the pile for sensor attachment, provide a drill (and bit) of sufficient power, operated by either a DC battery (preferred) or a generator. A hammer drill is required for preparation of concrete piles.

**1.4 Submittals and General Testing & Analysis Requirements** See Tables 1 and 2 on the following page. The Engineer will respond to the Contractor regarding acceptability of submittals as soon as practical.

| **Table 1 - Schedule of Dynamic Pile Testing Submittals** | | | |
| --- | --- | --- | --- |
| **Submittal**  **Number** | **Submittal**  **Item** | **Calendar Days** | **Event** |
| 1 | Proposed independent dynamic pile testing consultant, and a listing of assigned personnel and their experience and qualifications. | 45 Before | Start of  Pile Driving Monitoring |
| 2 | Details of the hardware and software components, method of testing, and materials to be used. | 45 Before | Start of  Pile Driving Monitoring |
| 3 | Completed *Pile and Driving Equipment Data Form* (Figure 1 of this Special Note) and the results of wave equations analyses. | 21 Before | Start of  Pile Driving Monitoring |
| 4 | Preliminary Reports as defined in Section 3.1 of this Special Note. | 1 After | Completion of Each Field Test |
| 5 | Summary Report(s) as defined in Section 3.2 of this Special Note. | 10 After | Completion of All Field Tests |
| **Provide all submittals and reports in .pdf format.** | | | |

| **Table 2 - General Testing and Analysis Requirements** | | |
| --- | --- | --- |
| **Item** | **Requirement** | |
| Wave Equation Analysis | Minimum of 1 and sufficient additional analyses as needed to define performance for all combinations of piles, driving systems and subsurface conditions anticipated. | |
| Dynamic Testing Pile  Resistance (i.e. Capacity) | Required Nominal Pile Resistance (i.e. Ultimate Pile Capacity) as shown in the plans and/or as directed by the Engineer. | |
| End of Initial Driving Test Frequency | Minimum of 1 production pile for each substructure or as directed by the Engineer during the final 25 feet of initial driving | |
| Beginning of Restrike Test Frequency | Minimum of 1 production pile for each substructure or as directed by the Engineer. | |
| Time Interval between End of Initial Driving and Restrike | Minimum of 72 hours unless stated otherwise elsewhere in the contract documents and/or directed otherwise by the Engineer based on the criteria below. | |
| **Soil Type** | **Time Delay Until Restrike** |
| Clean Sands | 24 hours |
| Silty Sands | 48 hours |
| Sandy Silts | 72 – 120 hours |
| Silts and Clays | 7 - 14 Days |
| Shales | 7 Days |
| Pile Driving Analyses using Signal Matching Techniques | For each End of Initial Driving Test and each Beginning of Restrike Test | |
| **Perform testing and analyses in accordance with this table and ASTM D 4945, *High-Strain Dynamic Testing of Piles*.** | | |

**2.0 TESTING AND ANALYSES**

**2.1 Preconstruction Wave Equation Analyses** At least 21 calendar days before beginning pile driving monitoring submit to the Engineer the completed Pile and Driving Equipment Data Form (Figure 1 of this Special Note) and preconstruction wave equation analyses performed by the Dynamic Pile Testing Consultant in accordance with Table 2 in this Special Note and a summary report of the results. The required nominal resistance (i.e. ultimate capacity) is provided in the plans and/or elsewhere in the contract documents. Upon request, the Geotechnical Report for the structure can be provided.

The purpose of the wave equation analyses is to assess the ability of all proposed pile driving systems to install piles to the required nominal resistance (i.e. ultimate capacity) and the desired penetration depth within allowable driving stresses. Acceptability of the wave equation report and the adequacy of analyses will be determined by the Engineer. In the Wave Equation Summary Report, include:

1. drivability graph relating pile resistance (i.e. capacity), blow count and driving stresses to depth;
2. bearing graph relating the pile resistance (i.e. capacity) to the pile driving resistance which indicates blow count versus resistance (i.e. capacity) and stroke; and
3. constant resistance (i.e. capacity) analysis or inspectors chart to assist the Engineer in determining the required driving resistance at other field-observed strokes.

**2.1.1** Acceptance by the Engineer of the proposed pile driving system will be based upon the wave equation analyses indicating that the proposed system can develop the specified pile resistance (i.e. capacity) at a pile driving rate of 3 to 10 blows per inch (36 to 120 blows/ft.) at the end of driving and beginning of restrike, and within allowable driving compressive stress of 90% of the yield stress of the piles. Provide preliminary pile driving criteria based on wave equation analyses and any anticipated resistance (i.e. capacity) changes after driving, set-up or relaxation, subject to revision based upon dynamic pile testing field measurements.

**2.1.2** If any changes or modifications are made to the accepted pile driving system, additional wave equation analyses in accordance with Section 2.1 of this Special Note will be required.

**2.2 High-Strain Dynamic Pile Testing**

**2.2.1** Perform dynamic pile testing at the locations and frequency required in accordance with Table 2 in this Special Note.

**2.2.2** Dynamic pile testing involves monitoring the response of a pile subjected to heavy impact applied by the pile hammer at the pile head. The testing will provide information on the driving stresses, pile resistance (i.e. capacity), structural integrity, and hammer efficiency.

**2.2.3** Engage an independent dynamic pile testing consultant and qualified personnel in accordance with Section 1.2 of this Special Note. Prior to testing, the Engineer will review and accept the proposed independent dynamic pile testing consultant, the experience and qualifications of assigned personnel, details of the method of testing, a list of equipment, and the method of analysis of test results.

**2.2.4** Perform all field testing and measurements in the presence of the Engineer or authorized representative.

**2.2.5 Remote Dynamic Pile Testing** where data is collected in the field and sent to the office of the Dynamic Pile Testing Consultant **will not be allowed** on this project. The testing consultant is required to have at least one person meeting the requirements for “Pile Driving Monitoring” as defined in Section 1.2 of the Special Note for Dynamic Pile Testing in the field during all dynamic pile testing. However, “wireless” technology that eliminates cables from the test pile to the data acquisition equipment will be allowed.

**2.3 Field Testing**

**2.3.1 Equipment** Perform dynamic pile testing field measurements using equipment, software and recording equipment accepted in accordance with Section 1.4 of this Special Note. Analyze the data collected at the end of initial driving and the beginning of restrike using accepted signal matching techniques and software.

**2.3.2 Monitoring During Driving** During pile driving, instrument the piles and monitor them with testing equipment satisfying the requirements of Section 1.3 of this Special Note. Prior to lifting the pile to be dynamically tested, provide a minimum of 3 ft of clear access to 180 degree opposite faces of the pile for pile preparation then drill and prepare holes for sensor attachment. Sensors are usually attached near the pile top.

**2.3.2.1** Install two sets of strain transducers and accelerometers near the top of each pile to be tested, and use a compatible measuring and recording system to record the data during driving.

**2.3.2.2** Appropriately position and fix the equipment required to be attached to the pile to the satisfaction of the Engineer.

**2.3.2.3** Use a pile driving hammer and other equipment capable of delivering an impact force sufficient to mobilize the specified pile resistance (i.e. capacity) indicated in the structure plans without damaging the pile.

**2.3.2.4** Use the testing equipment to monitor pile stresses during driving to prevent pile damage and ensure pile integrity and resistance (i.e. capacity). If the testing equipment indicates overstressing or damage to the pile, immediately discontinue driving and notify the Engineer and propose a new pile driving system, modifications to existing system, or new pile installation procedures. Acceptance by the Engineer of any proposed changes to the pile driving system or pile installation procedures will be based upon the results of additional wave equation analyses in accordance with Section 2.1.2 of this Special Note.

**2.3.3 Preparation of the Pile Head** The preparation of the pile head for the application of dynamic test load may involve, where appropriate, trimming the head, cleaning, and building up the pile using materials that, at the time of testing, safely withstand the impact stresses. Provide an impact surface that is flat and at right angles to the pile axis.

**2.3.4 Dynamic Measurement and Analysis** Begin monitoring of pile driving when pile driving begins. Record and process the data immediately in the field by the pile driving monitoring equipment and software. Unless monitoring indicates that additional driving will damage the pile, continue pile driving and monitoring until both the specified pile tip elevation and the specified pile resistance (i.e. capacity) are reached. When the level of the sensors is within 1 foot of any obstruction endangering the survival of sensors or cables, halt driving to remove the sensors from the pile. If additional driving is required, remove the obstruction or splice the pile and reattach the sensors to the head of the next pile segment prior to resuming driving. For each pile tested, perform pile driving analysis using signal matching techniques for a selected blow at the end of driving (EOD) to determine the relative capacities from end bearing and skin friction along the pile. Unless stated elsewhere in the contract documents or directed otherwise by the Engineer use the table below to determine the pile resistance (i.e. capacity) required at EOD.

|  |  |  |
| --- | --- | --- |
| **Soil**  **Type** | **Setup Factor** | **EOD Resistance as a % of**  **Required Nominal Resistance** |
| Clay | 2.0 | **≈** 50% |
| Silt-Clay & Sand-Clay | 1.5 | **≈** 70% |
| Sand-Silt & Fine Sand | 1.2 | **≈** 85% |
| Sand & Sand-Gravel | 1.0 | **≈** 100% |

**Make any required adjustments to the fuel and/or power setting of the hammer** if necessary to verify the resistance at a pile driving rate of 3 to 10 blows per inch (36 to 120 blows/ft.) at the end of driving and beginning of restrike and within allowable driving compressive stress of 90% of the yield stress of the piles or to meet other applicable testing objectives.

**2.3.4.1** Perform beginning of restrike (BOR) tests at the frequency indicated in Table 2 of this Special Note with the time interval between end of initial driving and beginning of restrike in accordance with Table 2 of this Special Note. During restrike, instrument and monitor the pile in a manner similar to that used during initial driving. For each restrike test, perform pile driving analysis using signal matching techniques for a selected blow from the beginning of restrike to determine the relative capacities from end bearing and skin friction along the pile.

**2.3.4.2** Perform the restrike test with a warmed-up hammer by striking the pile a minimum of 10 blows unless testing equipment indicates overstressing or damage to the pile. If such overstressing or damage to the pile is indicated, immediately discontinue driving and notify the Engineer. Unless directed otherwise by the Engineer perform a redrive with dynamic testing for the remaining length of the test pile unless excessive driving stresses are encountered. In the event initial restrike testing indicates a pile resistance below the specified resistance, an additional restrike test after the redrive may be required as directed by the Engineer.

**2.3.4.3** The Engineer may request use of pile driving monitoring equipment and software on additional piles if inconclusive results are obtained or unusual driving conditions are encountered.

**2.3.4.4** Evaluate pile resistance and integrity based on the standard procedure used in practice.

**2.3.4.5** Immediately provide tabular records of the dynamic pile testing field measurements obtained at the end of initial driving and at the beginning of restrike to the Engineer.

**3.0 DYNAMIC PILE TEST REPORTS**

**3.1 Preliminary Dynamic Pile Test Reports** Submit a preliminary test report for each pile tested for review by the Engineer. In the reports, include tabular as well as graphical presentation of the dynamic test results versus depth and proposed pile driving criteria for the additional piles to be installed at the substructure unit of the pile tested. Also include the following:

1. The maximum force applied to the pile head.
2. The maximum pile head velocity.
3. The maximum energy imparted to the pile.
4. The assumed soil damping factor and wave speed.
5. Static resistance (i.e. capacity) estimate.
6. The maximum compressive and tensile forces in the pile .
7. Pile integrity.
8. Blows per inch.
9. Stroke.
10. Summary results of pile driving analysis from up to three selected blows analyzed using signal matching techniques and software.
11. Results of refined wave equation analyses based upon dynamic testing signal matching analysis, including tabular and graphical inspector’s charts at EOD and BOR for the required pile resistance values specified for each specific substructure.

The Engineer will use the results of the preliminary reports to provide pile driving criteria for production piles to the Contractor.

**3.2 Dynamic Pile Test Summary Report** Submit a summary report of all piles tested on each structure for review by the Engineer. (Where phased construction is used it may be desirable to provide different reports for each phase. In such cases, the contractor should seek the approval of the Engineer.) In the report, include the results of hammer performance, pile driving stresses, and pile resistance during initial driving and restrike for all piles tested. Also include the following:

1. Identification of the structure, including: County, Route, Crossing, and Drawing Number.
2. Date of testing and date of pile installation.
3. Pile identification number and location.
4. All information given in preliminary reports as follows:
   1. Length of pile below the surface.
   2. Total length of pile, including projection above the surface at time of test.
   3. Length of pile from instrumentation position to tip.
5. Hammer type, drop, and other relevant details.
6. Blow selected for signal matching analysis.
7. Maximum compressive and tensile stresses, stroke, and resistance (i.e. capacity) versus penetration depth.
8. Temporary compression.
9. Pile integrity and location of damage, if any.
10. Force/velocity versus time trace.
11. Force/velocity match curve.
12. Resistance distribution along the pile.
13. Detailed graphical and tabular results from up to three selected blows analyzed using signal matching techniques and software.
14. Results of refined wave equation analyses based upon dynamic testing signal matching analysis, including tabular and graphical inspector’s charts at EOD and BOR for the required pile resistance values for each specific substructure.

**4.0 INCIDENTAL EQUIPMENT**

Prior to the beginning of dynamic testing, provide one electronic device to aid in recording pile hammer blows, stroke, and energy such as an "E-Saximeter" or accepted equivalent meeting the specifications in the Appendix to this Special Note. This device will immediately become property of the Department for use on the project.

**Provide field training by someone proficient in the use of the device** to ensure that approximately 3 to 5 employees of the Department are competent in the use of the device. This training may be performed by a representative of the independent Dynamic Pile Testing Consultant who is proficient in the use of the device or a manufacturer's representative. The required training time is anticipated to be no more than one day.

The cost of furnishing this device and providing the training is incidental to the contract price for "Dynamic Pile Testing" and no separate payment will be made.

**5.0 METHOD OF MEASUREMENT AND BASIS OF PAYMENT**

Dynamic pile testing will be measured per each. Payment for each restrike test performed will be in addition to payment for each test performed at the end of initial driving. Payment for redrive testing will be included in the price for the restrike test immediately prior to the redrive. Payment for each test will include pile driving monitoring and pile driving analysis performed. Payment for the above described work, including all material, equipment, tools, labor and any other incidental work necessary to complete this item.

Payment will be made under:

**Pay Item Pay Unit**

Dynamic Pile Testing Each

90

**Figure 1**

**Pile and Driving Equipment Data Form (From FHWA-HI-097-014)**



**(ft. - lb.)**

**(ft.)**

**(ft. - lb.)**

**(ft.)**

**(lb.)**

**(lb.)**

**(in.)**

**(in.)**

**(in.2)**

**(in.)**

**(in.2)**

**(in.2)**

**(in.)**

**(in.)**

**(lb.)**

**(in.)**

**(ft.)**

**(kips)**

**(kips)**

**(in.)**

**(in.2)**

**Weight/Foot**

**Appendix**

**Physical:**

Size: 100mm X 190mm X 50mm (4 inches X 7.5 inches X 2 inches)

Weight: 0.7 kg (1.5 lb.)

Temperature range: -10 to 50°C (14 to 104°F) operating

Power: built-in rechargeable battery w/ 8 hour min duration

Display: LCD, 4 Lines x 16 characters, viewing area 62 mm by 26 mm (2.5 inches by 1 inch)

Keypad: Large key (1.27 mm2 ), non tactile

**Electronic:**

32 bit microcontroller up to 20.97 MHz

12 bit digital to analog converter 8 bit 4 channel analog to digital converter

Internal microphone 70 to 115 dB

RS232 connector for data transfer

4 MB internal memory

**Functional and Other:**

Maximum blow detection rate: 68 bpm for open end diesel hammers; 300 bpm for all others

Furnished with SAXLINK program for data transfer in text format

Operates in English or SI units

Full one year warranty

Technical manual included