Reviewers: Accept all revision marks when there is no pay item on the plans for Dynamic Pile Restrike Testing. Reject all revision marks when there is a pay item for Dynamic Pile Restrike Testing.

Note: The MoDOT LRFD Bridge Design Manual indicates that the frequency of dynamic pile testing should be 1 to 10% of the number of piles. Additionally, the frequency of initial driving tests and restrike tests should also consider the variability of subsurface conditions and the criticality of the structure. See *AASHTO LRFD Bridge Design Specifications* Table 10.5.5.2.3-3 for additional guidance.



**In section 4.0 of this special provision, the time interval between end of initial driving and restrike is set to a default value of 7 days. This value needs to be adjusted as appropriate in accordance with *AASHTO LRFD Bridge Construction Specifications* commentary Section 4.4.4.3 based on the subsurface materials at the site. Also, we typically do one test per substructure unit unless subsurface conditions are very consistent, then we may not perform a test at every bent.**



 DYNAMIC PILE TESTING 4/8/21

**1.0 General.**

**1.1 Scope of Work.** Scope of work shall include furnishing all labor, equipment and analysis associated with dynamic testing of driven piles as specified in this special provision. Dynamic pile restrike testing is not required on this project, and references to restrike testing in this special provision will not apply.

**1.2 Performance and Design Requirements.** Performance and design conditions for dynamic testing of driven piles shall be in accordance with section 4.0 of this special provision.

**1.3 Approved Manufacturers.** For the following hardware and software components, only the listed manufacturer is recognized as providing the level of quality required. If the contractor wants to propose a non-listed manufacturer that is considered to provide an equivalent level of quality, this manufacturer shall be identified and supporting documentation provided. Acceptance of the manufacturer as a substitute will be at the discretion of the engineer.

| **Component** | **Product** | **Manufacturer** |
| --- | --- | --- |
| Pile Driving Modeling - Wave Equation Software | GRLWEAP | Pile Dynamics, Inc. |
| Pile Driving Monitoring - Hardware & Software | Pile Driving Analyzer - Model PAK | Pile Dynamics, Inc. |
| Pile Driving Analysis – Signal Matching Software | CAPWAP | Pile Dynamics, Inc. |

**1.4 Test Requirements.** Dynamic pile testing shall be conducted in accordance with the standard test method indicated below.

| **Standard Test Method** | **Designation** | **Conducted By** |
| --- | --- | --- |
| High-Strain Dynamic Testing of Piles  | ASTM D 4945 | Contractor |

**1.5 Qualifications.** The contractor shall perform dynamic pile testing utilizing the services of an independent dynamic pile testing consultant and qualified personnel. An engineer with a minimum of three years of 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 and Foundation QA shall perform pile driving monitoring. An engineer with a minimum of five years of 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 and Foundation QA shall perform pile driving modeling and pile driving analyses.

**2.0 Execution.**

**2.1 Pile Driving Modeling.** The contractor shall perform preconstruction wave equation analyses and prepare a summary report of the results. The wave equation analyses shall be used to assess the ability of all proposed pile driving systems to install piles to the required capacity and the desired penetration depth within allowable driving stresses. The report shall include a drivability graph relating pile capacity, blow count and driving stresses to depth. The report shall include a bearing graph relating the pile capacity to the pile driving resistance. The bearing graph shall indicate blow count versus capacity and stroke. The report shall also contain a constant capacity analysis or inspectors chart to assist the engineer in determining the required driving resistance at other field observed strokes. The contractor shall perform wave equation analyses in accordance with section 4.0 of this special provision. Acceptability of the wave equation report and the adequacy of analyses will be determined by the engineer.

**2.1.1** Approval 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 capacity at a pile driving rate of 2 to 10 blows per inch at the end of driving, and within allowable driving stresses per *AASHTO LRFD Bridge Construction Specifications*, Section 4.4.1. The contractor shall provide preliminary pile driving criteria based on wave equation analyses and any anticipated 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 approved pile driving system, additional wave equation analyses in accordance with section 2.1 of this special provision shall be required.

**2.2 High-Strain Dynamic Pile Testing.**

**2.2.1** The contractor shall perform dynamic pile testing at the locations and frequency required in accordance with section 4.0 of this special provision.

**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 shall provide information on the driving stresses, pile capacity, structural integrity and hammer efficiency.

**2.2.3** The contractor shall engage an independent dynamic pile testing consultant and qualified personnel in accordance with section 1.5 of this special provision. Prior to testing, the engineer will review and approve 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. The contractor shall provide all available details of the subsurface conditions, pile dimensions and properties, and pile driving systems to the independent dynamic pile testing consultant.

**2.2.4** All field testing and measurements shall be made in the presence of the engineer.

2.3 Field Testing.

**2.3.1 Equipment**. Dynamic pile testing field measurements shall be carried out using approved equipment, software and recording equipment. The data collected at the end of initial driving and the beginning of restrike shall be analyzed using approved signal matching techniques and software.

**2.3.2 Monitoring During Driving**. During pile driving, piles shall be instrumented and monitored with testing equipment satisfying the requirements of section 1.3 of this special provision.

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

**2.3.2.2** The equipment required to be attached to the pile shall be appropriately positioned and fixed to the approval of the engineer.

**2.3.2.3** The hammer and all site equipment used shall be capable of delivering an impact force sufficient to mobilize the specified pile capacity indicated in section 4.0 of this special provision without damaging the pile.

**2.3.2.4** The testing equipment shall monitor pile stresses during driving to prevent pile damage and ensure pile integrity and capacity. If the testing equipment indicates overstressing or damage to the pile, the contractor shall immediately discontinue driving and notify the engineer.

**2.3.2.5** If the testing equipment determines that pile stresses during driving exceed acceptable levels, a new pile driving system, modifications to existing system or new pile installation procedures shall be proposed by the contractor. Approval 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 provision.

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

**2.3.4 Dynamic Measurement and Analysis.** Monitoring of pile driving shall begin when pile driving begins. The data shall be recorded and processed immediately in the field by the pile driving monitoring equipment and software. Unless monitoring indicates that additional driving will damage the pile, pile driving and monitoring shall continue until both the specified pile tip elevation and the specified pile capacity are reached. For each pile tested, pile driving analysis using signal matching techniques shall be performed for a selected blow at the end of driving to determine the relative capacities from end bearing and skin friction along the pile.

**2.3.4.1** Restrike tests shall be performed at the frequency indicated in section 4.0 of this special provision. The time interval between end of initial driving and beginning of restrike shall be in accordance with section 4.0 of this special provision. During restrike, the pile shall be instrumented and monitored similar to during initial driving. For each restrike test, pile driving analysis using signal matching techniques shall be performed 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** The restrike test shall be performed with a warmed-up hammer and shall consist of striking the pile for 20 blows or until the pile penetrates an additional 3 inches whichever occurs first unless testing equipment indicates overstressing or damage to the pile. If such overstressing or damage to the pile is indicated, the contractor shall immediately discontinue driving and notify the engineer. In the event initial restrike testing indicates a pile capacity below the specified capacity additional driving 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** Pile bearing capacity and integrity shall be evaluated based on the standard procedure used in practice.

**2.3.4.5** Tabular records of the dynamic pile testing field measurements obtained at the end of initial driving and at the beginning of restrike shall be immediately provided to the engineer by the contractor.

**2.3.5 Results**.

**2.3.5.1 Preliminary Reports.** The contractor shall prepare a preliminary report for each pile tested for review by the engineer. Each report shall contain tabular as well as graphical presentation of the dynamic test results versus depth. Each report shall also indicate the pile driving criteria for the additional piles to be installed at the substructure unit of the pile tested. Each preliminary report shall include the following:

(a) The maximum force applied to the pile head.

(b) The maximum pile head velocity.

(c) The maximum energy imparted to the pile.

(d) The assumed soil damping factor and wave speed.

(e) Static capacity estimate.

(f) The maximum compressive and tensile forces in the pile.

(g) Pile integrity.

(h) Blows per inch.

(i) Stroke.

(j) Summary results of pile driving analysis from selected blow analyzed using signal matching techniques and software.

**2.3.5.2 Summary Report.** The contractor shall prepare a summary report of all piles tested for review by the engineer. The report shall include the results of hammer performance, pile driving stresses, and pile capacity during initial driving and restrike for all piles tested. The report shall also include the following:

(a) Date of testing and date of pile installation.

(b) Pile identification number and location.

(c) All information given in preliminary reports as follows:

(1) Length of pile below commencing surface.

(2) Total length of pile, including projection above commencing surface at time of test.

(3) Length of pile from instrumentation position to tip.

(d) Hammer type, drop and other relevant details.

(e) Blow selected for signal matching analysis.

(f) Maximum compressive and tensile stresses, stroke, and capacity versus penetration depth.

(g) Temporary compression.

(h) Pile integrity and location of damage, if any.

(i) Force/velocity versus time trace.

(j) Force/velocity match curve.

(k) Resistance distribution along the pile.

(l) Detailed graphical and tabular results from blow analyzed using signal matching techniques and software.

**3.0 Schedule of Contract Submittals.**

| **Item Number** | **Submittal Item** | **Type** | **Calendar Days** | **Event/Date** | **Liquidated Damages Apply** |
| --- | --- | --- | --- | --- | --- |
| 1 | Proposed independent dynamic pile testing consultant, and a listing of assigned personnel and their experience and qualifications. | DOCS | 45 Before | Start of pile driving monitoring | No |
| 2 | Details of the components, method of testing, pile driving equipment and materials to be used, and the results of wave equations analyses. | DOCS | 15 Before | Start of pile driving monitoring | No |
| 3 | Two copies of each Preliminary Report as defined in section 2.3.5.1 of this special provision | DOCS | 3 After | Completion of each field test | No |
| 4 | Four copies of the Summary Report as defined in section 2.3.5.2 of this special provision | DOCS | 7 After | Completion of all field tests | No |

**4.0 High-Strain Dynamic Pile Testing Specification.**

| **Item** | **Requirement** |
| --- | --- |
| Wave Equation Analysis | Minimum of one and sufficient additional analyses as needed to define performance for all combinations of piles, driving systems and subsurface conditions anticipated. |
| Dynamic Testing Pile Capacity | Nominal Axial Pile Compressive Resistance or 2.25 times the Design Bearing shown on the plans or as required by engineer |
| End of Initial Driving Test Frequency | As shown in the contract plans  |
| Restrike Test Frequency | As shown in the contract plans  |
| Time Interval between End of Initial Driving and Restrike | Minimum of 7 days or as required by the engineer |
| Pile Driving Analyses using Signal Matching Techniques | For each End of Initial Driving Test and each Restrike Test |

**5.0 Method of Measurement.** Dynamic pile testing will be measured per each.

**6.0 Basis of Payment.** Payment for the above described work, including all material, equipment, tools, labor and any other incidental work necessary to complete this item, will be considered completely covered by the contract unit price for Dynamic Pile Testing.