16 State House Station
Augusta, Maine 04333

MaineDOT

Transportation Research Division

Material properties of FRP pile shells tested by Lawrence (Reference 2) are:

	Ultimate Stress (ksi)	Ultimate Strain (%)	Elastic Modulus (ksi)
Longitudinal Tension	76.9	2.56	3260
Hoop Tension	25.3	2.27	1980
Longitudinal Compression	72.0	2.17	3670
Hoop Compression	34.7	1.65	2140
In-Plane Shear	22.3	2.88	850

Technical Report 17-2

Experimental Evaluation and Design of Unfilled and Concrete-Filled FRP Composite Piles

Task 4B – Material & Construction Specifications

Final Report – Task 4B, January 2017

Technical Report Documentation Page

1. Report No. ME 17-2	2.	3. Recipient's Accession No.
4. Title and Subtitle Experimental Evaluation and Design of Unfilled and Concrete-Filled FRP Composite Piles Task 4B – Material & Construction Specifications		5. Report Date July 2015 6.
7. Author(s) Dale Lawrence Roberto Lopez-Anido Thomas Sandford		8. Performing Organization Report No. AEWC Report Number 1199.4
9. Performing Organization Name and Address University of Maine – Advanced Structures and Composites Center		10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. Contract # 20130731*535
12. Sponsoring Organization Name and Address Maine Department of Transportation		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract (Limit 200 words)

The overall goal of this project is the experimental evaluation and design of unfilled and concrete-filled FRP composite piles for load-bearing in bridges. This report covers Task 4B, Materials and Construction Specifications.

This technical report is organized in two sets of specifications for Fiber Reinforced Polymer (FRP) Concrete Piles, as follows:

1) Draft Material Specification (4 pages) titled: "FRP Pile Shell Material Specification", and
2) Draft Construction Specifications (18 pages) titled: "Section 501 – FRP Piles for Load-Bearing Applications"

Each specification is presented as a self-standing document with its own table of contents, summary, references, provisions and commentary. The corresponding structural and geotechnical design specifications are presented in a separate technical report.

17. Document Analysis/Descriptors Bridge piles, fiber reinforced polymer composites, material and construction specifications		18. Availability Statement	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages 29	22. Price

Technical Report

Draft Material Specifications and Draft Construction Specifications for Fiber Reinforced Polymer (FRP) Concrete Piles

Submitted by:

Dale Lawrence, Roberto Lopez-Anido[1], and Thomas Sandford

Advanced Structures and Composites Center, University of Maine

Project Task 1199.4

Project: Experimental Evaluation and Design of Unfilled and Concrete-Filled FRP Composite Piles

Prepared for:
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Technical Report Organization

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1) Draft Material Specification (4 pages) titled: “FRP Pile Shell Material Specification”, and

2) Draft Construction Specifications (18 pages) titled: “Section 501 – FRP Piles for Load-Bearing Applications”

Each specification is presented as a self-standing document with its own table of contents, summary, references, provisions and commentary. The corresponding structural and geotechnical design specifications are presented in a separate technical report.

Draft Material Specifications for Fiber Reinforced Polymer (FRP) Concrete Piles

Table of Contents

Summary

Material specifications are based on the AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements (Reference 1). These specifications have been adapted to reflect the results of field installation and laboratory testing (Reference 2).

This specification was modeled after AASHTO's Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, which was adopted for developing the testing program presented by Lawrence (Reference 2). At the time of this testing program, the AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members had not yet been approved. The durability section of the AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements includes more environmental exposure conditions and longer exposure durations than the AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members. However, the AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members provides more detailed guidelines for material selection, manufacturing processes, mechanical properties, quality control, and documentation than the AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements.

References

1. AASHTO. Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 2012.

2. Lawrence, D. "Experimental Evaluation of Fiber Reinforced Polymer Piles in Load Bearing Applications, M.S. Thesis, University of Maine, 2015.

3. ASTM International. ASTM D3039-08: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. West Conshohocken, PA, 2009.

4. ASTM International. ASTM D6641-09: Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture. West Conshohocken, PA, 2009.

5. ASTM International. ASTM D7078-12: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method. West Conshohocken, PA, 2012.

6. ASTM International. ASTM E1640-09: Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis. West Conshohocken, PA, 2009.

7. ASTM International. ASTM D5229-14: Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials. West Conshohocken, PA, 2014.

8. ASTM International. ASTM G154-12a: Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials. West Conshohocken, PA, 2012

9. ASTM International. ASTM C666-03(08): Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing. West Conshohocken, PA, 2008.

10. ASTM International. ASTM D7136-15: Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to Drop-Weight Impact Event. West Conshohocken, PA, 2015.

FRP Pile Shell Material Specification

1. Scope

This section defines the requirements for FRP material used in the manufacturing of FRP piles.

2. Material Requirements

2.1. Material Acceptability

The contractor shall submit for approval evidence of acceptable quality control procedures followed in the manufacture of the composite reinforcement system. The quality control procedure shall include, but not be limited to, specifications for raw material procurement, the quality standards for the final product, in-process inspection and control procedures, test methods, sampling plans, criteria for acceptance or rejection, and record keeping standards

2.2. Material Content

The contractor shall furnish information describing the fiber, matrix, and adhesive systems intended for use as reinforcing materials that is sufficient to define their engineering properties. Descriptions of the fiber system shall include the fiber type, percent of fiber orientation in each direction, and fiber surface treatments. Where required by the Engineer of Record, the matrix and the adhesive shall be identified by their commercial names and the commercial names of each of their components, along with their weight fractions with respect to the resin system.

The contractor shall ensure that the resin and reinforcing system is appropriate for use with the wall thickness of the pile.

If the polymer resin does not completely embed the fiber reinforcement through the thickness of the shell, then the shear strength between layers of reinforcement is not fully achieved.

2.3. Material Testing

The contractor shall submit for approval test results that demonstrate that constituent materials and the composite system are in conformance with the physical and mechanical property values stipulated by the Engineer of Record. These tests shall be conducted by a testing laboratory approved by the Engineer of Record. For each property value, the batches from which test specimens were drawn shall be identified with the number of tested specimens from each batch, the mean value, the minimum value, the maximum value, and the coefficient of variation shall be reported. The minimum number of tested samples shall be ten.

Testing shall include, but not be limited to, tensile properties determined by ASTM D3039 (Reference 3), compressive properties determined by ASTM D6641 (Reference 4), shear properties determined by ASTM D7078 (Reference 5), and glass transition temperature determined by ASTM E1640 (Reference 6). Material properties may be determined by other means, if approved by the Engineer of Record.

Material properties of FRP pile shells tested by Lawrence (Reference 2) are:

	Ultimate Stress (ksi)	**Ultimate Strain (%)**	**Elastic Modulus (ksi)**
Longitudinal Tension	76.9	2.56	3260
Hoop Tension	25.3	2.27	1980
Longitudinal Compression	72.0	2.17	3670
Hoop Compression	34.7	1.65	2140
In-Plane Shear	22.3	2.88	850

2.4. Other Material Requirements

When cured under conditions identical to those of the intended use, the composite material system as well as the adhesive system, if used, shall conform to the following requirements.

Glass Transition Temperature

The characteristic value of the glass transition temperature of the composite system, determined in accordance with ASTM E1640 (Reference 6), shall be at least 40°F higher than the maximum design temperature, $T_{MaxDesign}$, defined in Section 3.12.2.2 of AASHTO LRFD.

The glass transition temperature shall also be high enough to withstand any temperatures seen during driving. If the glass transition temperature cannot withstand temperatures during driving, provisions must be made to maintain temperatures at an acceptable level during pile driving.

Glass transition temperatures of FRP pile shells tested by Lawrence (Reference 2) are:

Type	**Temperature (°F)**
Onset Point of Change of Slope of Storage Modulus	188
Peak of Loss Modulus	200
Peak of Tan Delta	245

Tensile Failure Strain

The characteristic value of the tensile failure strain in the direction corresponding to the highest percentage of fibers shall not be less than one percent, when the tension test is conducted according to ASTM D3039 (Reference 3).

Moisture Equilibrium Content

The average value and coefficient of variation of the moisture equilibrium content determined in accordance with ASTM D5229/D5229M (Reference 7) shall not be greater than two percent and ten percent, respectively. A minimum sample size of ten shall be used in the calculation of these maximum values.

Additional Requirements

After conditioning in the following environments, the characteristic value of the glass transition temperature determined in accordance with ASTM E1640 (Reference 6) and the characteristic value of the tensile strain, determined in accordance with ASTM D3039 (Reference 3), the composite in the direction of interest shall retain a minimum of 85 percent of the values established in Section 2.4 and 2.3, respectively.

The edges of the FRP material used for conditioning shall be sealed with a resin which meets or exceeds the durability criteria of this section. Sealing the edges of the FRP material will limit excessive degradation where the FRP material was cut prior to conditioning.

- *Water* – Samples shall be immersed in distilled water having a temperature of 100 +/- 3°F (38+/-2°C) and tested after 1,000, 3,000, and 10,000 hours of exposure

- *Alternating Ultraviolet Light and Condensation Humidity* – Samples shall be conditioned in an apparatus under Cycle 1-UV exposure condition according to ASTM G154 Standard Practice (Reference 8). Cycle 1 from Table X2.1 in ASTM G154 shall be used to condition samples for a duration of 1,000 hours. Samples shall be tested within two hours after removal from the apparatus.

Specified UV cycle and duration to standardize exposure conditions.

- *Alkali* – The sample shall be immersed in a saturated solution of calcium hydroxide (pH~11) at ambient temperature of 73+/-3°F (23+/-2°C) for 1,000, 3,000, and 10,000 hours prior to testing. The pH level shall be monitored and the solution shall be maintained as needed.

- *Freeze-Thaw* – Composite samples shall be exposed to 100 repeated cycles of freezing and thawing in an apparatus meeting the requirements of ASTM C666 (Reference 9).

Submersion of the samples during freeze-thaw exposure may be replaced by 100% relative humidity during the thawing phase to provide water to the sample.

2.5. Impact Tolerance

Where impact tolerance is stipulated by the Engineer of Record, the stipulated impact tolerance shall be determined by ASTM D7136 (Reference 10).

Draft Construction Specifications for Fiber Reinforced Polymer (FRP) Concrete Piles

Table of Contents

Summary

This specification is an adaptation of the Maine Department of Transportation (MaineDOT) Standard Specifications Section 501-Foundation Piles (Reference 1). Results of field installation and laboratory testing (Reference 2) have been incorporated to create guidelines for construction of FRP pile foundations. For the use of this specification, delete Section 501 – Foundation Piles from the MaineDOT Standard Specifications (Reference 1) in its entirety and replace with Section 501 – FRP Piles for Load-Bearing Applications.

Any Section referenced in this specification shall refer to the MaineDOT Standard Specifications (Reference 1). Abbreviations and definitions may be found in Section 101.

References

1. Maine Department of Transportation. Standard Specifications, November, 2014.

2. Lawrence, D. Experimental Evaluation of Fiber Reinforced Polymer Piles in Load Bearing Applications. M.S. Thesis, University of Maine, 2015.

3. Material Specs

4. ASTM International. ASTM A27-13: Standard Specification for Steel Castings, Carbon, for General Application. West Conshohocken, PA, 2013.

5. ASTM International. ASTM A148-14: Standard Specification for Steel Castings, High Strength, for Structural Purposes. West Conshohocken, PA, 2014.

6. ASTM International. ASTM D6641-09: Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture. West Conshohocken, PA, 2009.

7. ASTM International. ASTM E1640-09: Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis. West Conshohocken, PA, 2009.

8. ASTM International. ASTM D4945-12: Standard Test Method for High-Strain Dynamic Testing of Deep Foundations. West Conshohocken, PA, 2012.

Section 501 – FRP Piles for Load-Bearing Applications

501.1 Description

This work shall consist of furnishing and driving piles, of the types and dimensions specified on the Contract Plans. Piles shall conform to and be installed as detailed in these specifications, to the lines, grades, locations, and required resistance(s) shown on the Plans or as authorized by the Resident. Work under this item shall also consist of any pile testing specified by the project Contract Plans and described in these specifications.

501.2 Materials

Materials shall meet the requirements of the following sections of Divisions 500, Structures, and 700, Materials:

Structural Concrete (Class A)	502.05
Reinforcing Steel	709.01

FRP pile shells shall meet the requirements established in the material specifications.

Material specifications were presented in the first part of this technical report.

Cast steel points, splices, and open end cutting shoes shall conform to the requirements of ASTM A27 Grade 65/35 (Reference 4) or ASTM A148 Grade 90/60 (Reference 5).

Taken from Section 711.01 Steel Pipe Piles, Splices, and Tips

501.3 Quality Control Plan

The Contractor shall control the quality of the foundation piles through testing, inspection, and practices which shall be described in the Quality Control Plan (QCP), sufficient to assure a product meeting the Contract requirements. The QCP shall meet the requirements of Section 106, Quality and this specification. The Department will use criteria established in the approved QCP to accept the work provided in this Section.

No work under this item shall proceed until the QCP, or amendments to the QCP, is submitted to and approved by the Resident.

The QCP shall address all elements that affect the quality of the foundation piles including but not limited to, the following:

A. Driving Equipment
B. Wave Equation Analysis
C. Static Load Testing Apparatus

D. Driving Procedures
E. Tolerances
F. Pile and Driving Equipment Data Form

Splicing of FRP piles is not allowed.

The Contractor's Schedule of Work shall allow time for the review of the QCP or amendments to the QCP, as noted in Section 106.4.1.B, Approval.

501.4 Construction Requirements

501.4.1 Ordering Piles

The Contractor shall order all pilings from an itemized list of order lengths provided by the Resident. When additional lengths of piles are necessary, the additional lengths will be ordered by the Contractor from a written list provided by the Resident.

An additional 1 to 2 feet of pile length may be needed to facilitate a cut-off at the pile head after driving. Additional pile length may also be required for piles which are instrumented for high-strain dynamic testing.

501.4.2 Equipment for Driving Piles

501.4.2.1 Hammers

Piles shall be driven with approved power-actuated impact hammers powered with steam/air, diesel fuel, or hydraulics (hereinafter referred to as power hammers).

Removed section on drop hammers for timber piles

Air/steam hammers shall be operated and maintained within the manufacturer's specified ranges. The plant and equipment furnished for air/steam hammers shall have sufficient capacity to maintain, at the hammer under working conditions, the volume and pressure specified by the manufacturer. The plant and equipment shall be equipped with accurate pressure gauges that are easily accessible to the Resident. The weight of the striking parts of air and steam power hammers shall not be less than 1/3 the weight of drive head and pile being driven, and in no case shall the striking parts weigh less than 2,750 pounds.

Open-end (single acting) diesel hammers shall be equipped with a device such as rings on the ram or a scale (jump stick) extending above the ram cylinder, to permit the Resident to visually determine hammer stroke at all times during pile driving operations. The Contractor shall provide the Resident with a chart from the hammer manufacturer equating stroke and blows per minute to energy imparted for the open-end diesel hammer to be used.

Closed-end (double acting) diesel hammers shall be equipped with a bounce chamber pressure gauge, in good working order, mounted near ground level to be easily read by the Resident. The Contractor shall provide the Resident with a chart, calibrated within 90 days of use, of actual hammer performance, equating bounce chamber pressure to either equivalent energy or stroke for the closed-end diesel hammer to be used.

Double-acting hydraulic hammers shall have a power plant with sufficient capacity to maintain the volume and pressure specified by the manufacturer, under working conditions. The power plant and equipment shall be equipped with digital readouts, easily accessible to the Resident, showing pertinent system criteria, including but not limited to energy imparted to the pile, to enable the Resident to visually determine whether or not the refusal criteria has been met. In addition, the Contractor shall provide the Resident with a chart, calibrated within 90 days of use, of actual hammer performance.

501.4.2.2 Approval of Pile Driving Equipment

All pile driving equipment shall be sized such that the specified piles can be driven to the required resistance, without damage, as indicated on the Plans. Approval of the pile driving equipment by the Department will be based on the wave equation analysis and a completed Pile and Driving Equipment Data Form, as shown on Figure 1.

Changed to reflect location of "Figure 1"

The wave equation analysis prepared by the Contractor shall include a proposed stopping criterion, where the number of blows per inch, for a number of 1 inch driving intervals, at a specified hammer-stroke and fuel setting, is clearly defined. The criteria that the Department will use to evaluate the driving equipment will be based on the approved wave equation analysis utilizing the information provided in the completed Pile and Driving Equipment Data Form.

For the driving system to be acceptable, the number of hammer blows at the required resistance indicated by the wave equation analysis shall be between 3 and 15 blows per inch, and the driving stresses shall not exceed 10% of the ultimate compressive strength of the material as determined by ASTM D6641 (Reference 6). The stopping criteria used for pile driving operations shall be approved by the Department.

Changed to reflect driving stresses seen in field testing. Stresses for other pile materials removed.

If the wave equation analyses show that the driving system is unacceptable, the Contractor shall modify or replace the proposed driving equipment in an amendment to the QCP, at its expense, until subsequent wave equation analyses indicate the piles can be driven to the required resistance, without damage or excessive blows. Department review times of a revised wave equation analysis and Pile and Driving Equipment Data Form will be per Section 106.4.1.B.

During pile driving operations, the Contractor shall use the approved system. No variations in the driving system will be permitted without an amendment to the

QCP and a revised wave equation analysis and Pile and Driving Equipment Data Form.

Acceptance of the pile driving equipment does not relieve the Contractor of the responsibility to properly install the piling. The hammer acceptance and driving criteria will be based on commonly accepted hammer efficiencies, component properties, and soil parameters. Local soil conditions and the actual driving system will affect the driving. If, in the opinion of the Resident, the accepted driving system fails to perform satisfactorily during actual driving, the Department reserves the right to revise the driving criteria.

501.4.2.3 Driving System Components and Accessories

<u>Leads</u>

Pile driver leads shall be constructed in such a manner as to afford freedom of movement of the hammer while maintaining alignment of the hammer and the pile to insure concentric impact for each blow

<u>Followers</u>

Followers, when used, must be included in the QCP. In cases where a follower is permitted, the first pile in each group and every tenth pile driven thereafter shall be driven full length without a follower, to verify that adequate pile length is being attained to develop the required pile resistance. The follower and pile shall be held and maintained in equal and proper alignment during driving. The follower shall be of such material and dimensions to permit the piles to be driven to the length determined necessary from the driving of the full-length piles. The final position and alignment of the first two piles installed with followers in each substructure unit shall be verified in accordance with location tolerances.

<u>Hammer Cushion</u>

All power pile driving equipment shall be equipped with a suitable thickness of hammer cushion material to prevent damage to the hammer and pile and to insure uniform driving behavior. Hammer cushions shall be made of durable, manufactured materials, provided in accordance with the hammer manufacturer's guidelines except that all wood, wire rope, and asbestos hammer cushions are specifically disallowed and shall not be used. A striker plate as recommended by the hammer manufacturer shall be placed on the hammer cushion to insure uniform compression of the cushion material. The hammer cushion shall be inspected in the presence of the Resident when beginning pile driving

Sufficient cushioning shall be used to reduce the effects of stress concentrations at the head of the pile during driving. Areas of high stress may cause FRP piles to delaminate under heavy driving.

Cushioning is required to prevent the FRP pile head from reaching elevated temperatures, which may exceed the glass transition temperature of the material.

at each pile group or after each 100 hours of pile driving, whichever is less. Any hammer cushion thickness measuring less than 75% of the original thickness shall be replaced by the Contractor before driving is permitted to continue.

Helmet

Piles driven with power hammers require an adequate drive head to distribute the hammer blow to the pile head. The helmet shall be axially aligned with the hammer and the pile. The helmet shall be guided by the leads and not be free-swinging. The helmet shall fit around the pile head in such a manner as to prevent transfer of torsional forces during driving while maintaining proper alignment of hammer and pile.

For special types of piles, appropriate driving heads, mandrels, or other devices shall be provided in accordance with the manufacturer's recommendations so that the piles may be driven without damage.

501.4.3 Driving Procedures and Tolerances

The sequence of driving piles in any substructure unit shall be included in the QCP. The ground surface shall be brought to the bottom of the footing elevation before driving the piles. The Contractor shall furnish all assistance required to make any observations and measurements. Prior to placing any pile section in the leads, the Contractor shall make the pile section available for foot and inch marking by the Resident. When pile sections are placed in the leads prior to marking by the Resident, the Contractor shall mark the pile in foot and inch increments, or provide reasonable means of access to the pile for foot and inch marking. The order of placing individual piles in pile groups shall be either starting from the center of the group and proceeding outwards in both directions or starting at the outside row and proceeding progressively across the group.

When driving is interrupted before final penetration is reached, data for the bearing resistance of the pile shall not be taken until at least 12 inches of pile penetration is attained after driving has been resumed, or pile refusal has been attained.

The heads of all piles shall be plane and perpendicular to the longitudinal axis of the pile before the helmet is attached. Approval of the hammer relative to driving stress damage shall not relieve the Contractor of responsibility for piles damaged because of misalignment of the leads, failure of cushion materials, failure of splices, malfunction of the pile hammer, or improper construction methods. Piles damaged for such reasons shall be rejected and replaced at the Contractor's expense when the Resident determines that the damage impairs the strength of the pile.

Jetting

Jetting shall be done only with the permission of the Resident and must be addressed in the Contractor's Soil Erosion and Water Pollution Control Plan (SEWPCP). When water jets are used, the number of jets and the volume and pressure of the water at the nozzles shall be sufficient to erode freely the material adjacent to the piles. The plant shall have sufficient capacity to deliver at all times at least 100 pounds per square inch pressure at two 3/4 inch jet nozzles. Before the desired penetration is reached, the jets shall be withdrawn and the piles shall be driven with the hammer to the required penetration or bearing capacity.

Vibratory Hammers

When approved, non-displacement piles may be initially driven with a power-actuated vibratory hammer powered with electricity or hydraulics (hereinafter referred to as vibratory hammers). Vibratory hammers shall not be used for precast concrete piles due to pile damage and bending stress considerations. Vibratory hammers shall not be used to set piles which develop resistance primarily from friction with the surrounding soils through the pile length.

Piles permitted to be initially driven using a vibratory hammer shall be subsequently driven to the required capacity in accordance with the approved stopping criteria and the QCP using a power hammer. Vibratory hammers, when permitted, may only be used to initially set a pile up to a distance of 20 feet above the expected tip elevation, at which point a power hammer shall be employed. Vibratory hammers will only be permitted to initially set production piles after the pile tip elevation is established by load testing and/or piles driven with an impact hammer and the ultimate pile resistance is verified. If the pile penetration rate is 12 inches or less per minute, the use of a vibratory hammer shall be discontinued and a power hammer employed. When a battered pile is initially set using a vibratory hammer, the hammer shall be mounted in a set of leads and/or kept in alignment using a driving frame/template.

Preaugering

When necessary to clear obstructions or to obtain the specified pile penetration, as approved by the Resident, the Contractor may preauger. When specified in the Contract documents, the Contractor shall preauger holes at pile locations and to the depths shown on the Plans. Preaugered holes shall be of a size smaller than the diameter of the diagonal of the pile cross section. If subsurface obstructions, such as boulders or rock layers are encountered, the hole diameter may be increased to the least dimension needed for pile installation. Any void space remaining around any type pile after driving shall be completely filled with sand or other approved material. The use of spuds, which are driven and removed to make a hole for inserting a pile, shall not be permitted in lieu of preaugering.

Pre-excavation

When necessary to clear subsurface obstructions, such as boulders or rock layers, or to obtain the specified pile penetration, the Contractor may pre-excavate, with the approval of the Resident.

Heaved Piles

Piles that have heaved more than 1/4 inch during the driving of other piles in a group shall be reseated to the required penetration or bearing capacity at the Contractor's expense.

Location and Alignment Tolerance

The Contractor will be responsible to hold the piles in place to allowable tolerances. Piles shall be driven with a variation of not more than 1/4 inch per foot from the vertical or from the batter shown on the Plans. For piles that cannot be inspected for axial alignment internally after installation, an alignment check shall be made before installing the last 5 feet of pile, or after installation is completed, provided the exposed portion of the piles is not less than 5 feet in length. The Resident may require that driving be stopped in order to check the pile alignment. Pulling laterally on piles to correct misalignment, or splicing a properly aligned section of a misaligned section shall not be permitted.

The cutoff elevation of piles for trestle bents and pile bent piers shall not be out of position by more than 2 inches from the dimensions shown on the Plans. The cutoff elevation of piles for integral abutments shall not be out of position from the dimensions shown on the Plans by more than 2 inches in any direction. The cutoff elevation of piles, other than for trestle bents and integral abutments, shall not be out of position by more than 6 inches. Actual embedment of the piles in the concrete shall be within 6 inches of that shown on the Plans. The as-driven centroid of load of any group at cutoff elevation shall be within 5 percent of the Plan location of the designated centroid of load. No pile shall be nearer than 4 inches from any edge of the pile cap. Any increase in size of the pile cap to meet this edge distance requirement shall be at the Contractor's expense.

501.4.4 Special Requirements for FRP Piles

FRP piles shall be driven closed ended, unless otherwise specified. When open-ended FRP piles are specified or when the ends are not completely closed ended when driven, the inside of the pile shall be thoroughly cleaned out, and the inside walls cleaned by jetting or other means approved by the Resident. The sediment control required for cleaning operations shall be covered in the Contractor's SEWWPCP.

No changes in this paragraph except "pipe piles" changed to "FRP piles"

FRP piles shall be inspected and approved by the Resident immediately before concrete is placed in them. They shall be free from rupture and undue deformation and shall be free from water unless the Resident determines that the concrete can be placed without damage to the pile and such that the discharged water will be contained. The Contractor shall provide lights and other equipment necessary to enable the Resident to inspect each FRP pile.

No changes in this paragraph except "pipe piles" changed to "FRP piles"

Portland cement concrete for filling the FRP piles shall be placed in one continuous operation to fill the pile completely without causing water contamination. An internal type vibrator shall be used in the top 25 feet. Pile heads shall be protected and cured in accordance with Section 502, Structural Concrete.

No changes in this paragraph except "pipe piles" changed to "FRP piles"

The placing of concrete and the driving of piles shall be scheduled so that fresh and setting concrete will not be injured by the pile driving.

Concrete shall not be placed in FRP piles until pile driving has progressed beyond a radius of 15 feet from the pile to be concreted. If pile heave is detected for FRP piles that have been filled with concrete, the piles shall be redriven to the original position after the concrete has attained sufficient strength and a proper hammer-pile cushion system, is in place and is satisfactory to the Resident.

No changes in this paragraph except "pipe piles" changed to "FRP piles"

When a reinforcing steel cage is specified, it shall be placed inside the piles to allow for a minimum of 2 inches of concrete cover and the piles shall be filled with concrete to the elevation shown on the Plans.

Temperatures shall be monitored during pile driving to ensure that FRP piles do not exceed their glass transition temperature as determined by ASTM E1640 (Reference 7).

The compressive strength of the FRP material is reduced if the glass transition temperature is exceeded, which may lead to potential failure of the pile head.

501.4.5 Defective Piles and Corrective Measures

Pile driving activities shall not result in damage to, or deformation of, the piles. Any pile damaged due to internal defects, improper driving, or driven below cutoff elevation, shall be considered defective and shall be corrected by and at the expense of the Contractor, by a method approved by the Resident

501.4.6 Driven Pile Resistance, Pile Testing, and Acceptance

Pile testing will be required as shown on the Plans. Pile testing will be required to confirm that piles attain the required resistance and that the stresses in the piles do not exceed allowable limits during driving.

A dynamic load test consists of mounting instruments on the pile and accurately recording the output during driving using dynamic pile load test equipment meeting the requirements of ASTM D4945 (Reference 8). The stresses in FRP piles during driving shall not exceed 10% of the ultimate compressive strength of the material, as determined by wave equation analyses or dynamic pile load testing. Piles which have been overstressed, per wave equation or dynamic pile load testing, shall be replaced by the Contractor, at no additional cost to the Department.

Hollow FRP piles driven by Lawrence (Reference 2) showed a brooming type of delamination failure at a driving stress equal to 11% of the compressive strength of the FRP material. This driving stress was measured as an average pile stress during high strain dynamic pile monitoring.

A static load test consists of the application of a known load to the pile or group of piles and the accurate measurement of the resulting displacement. The Contractor shall furnish all labor and equipment for static load testing.

In the case of concrete filled FRP piles, no load shall be placed on the pile for at least 7 days after the concrete has been placed in the pile.

No change in this paragraph except changing “pipe piles” to ‘FRP piles”

On completion of either static or dynamic load testing, any test or anchor piling, not a part of the finished structure, shall be removed or cut off at least 1 foot below either the bottom of the footing or the finished ground elevation, whichever is lower.

501.4.6.1 Driven Pile Capacity – Wave Equation

The piles shall be driven to the required resistance using the approved stopping criteria. The pile acceptance will be based on obtaining the blow count and hammer stroke from the approved stopping criteria at the required resistance. When the wave equation is used in conjunction with dynamic or static pile load testing, the stopping criteria shall be amended based on correlation with the testing method results, as determined by the Resident. Adequate pile penetration shall be considered to be obtained when the specified wave equation resistance criteria (approved stopping criteria) is achieved within 5 feet of the pile toe elevation, based on Contract lengths. Piles not achieving the specified required resistance within these limits shall be driven to penetration established by the Resident.

The wave equation resistance criteria will not be considered valid under any of the following conditions:

a. The hammer or striking part does not have a free fall
b. The head of the pile becomes broomed or crushed
c. The penetration is not reasonably quick and uniform
d. There is an appreciable bounce after a blow
e. The hammer is operated outside the parameters recommended by the manufacturer

501.4.6.2 Static Load Test

When a static load test is specified in the Contract documents, load tests shall be performed by procedures set forth in ASTM D1143 using the quick load test method except that the test shall be taken to plunging failure or the capacity of the loading system. Testing equipment and measuring systems shall conform to ASTM D1143, except that the loading system shall be capable of applying 150% of the nominal pile resistance or 2,000 kips, whichever is less, and that a load cell and spherical bearing plate shall be used.

The Contractor shall submit in the QCP, detailed plans, prepared by a licensed Professional Engineer, of the proposed loading apparatus. The apparatus shall be constructed to allow the various increments of the load to be placed gradually without causing vibration to the test pile. When the approved method requires the use of tension (anchor) piles, such tension piles shall be of the same type and diameter as the production piles and shall be driven in the location of permanent piles when feasible, except that timber or tapered piles installed in permanent locations shall not be used as tension piles.

The design load shall be defined as 50% of the failure load. The failure load for a pile shall be defined as follows:

For piles 24 inches or less in diameter or width, the failure load of a pile tested under axial compressive load is that load which produces a settlement at failure of the pile head equal to:

$$s_f = \Delta + (0.15 + 0.008b)$$

where:

s_f = settlement at failure in inches

b = pile diameter or width in inches

Δ = elastic deformation of total unsupported pile length in inches

For piles greater than 24 inches in diameter or width:

$$s_f = \Delta + b/30$$

The top elevation of the test pile shall be determined immediately after driving and again just before load testing to check for heave. Any pile that heaves more than Y inch shall be redriven or jacked to the original elevation before testing. Unless otherwise specified in the Contract, a minimum 3-day waiting period shall be observed between the driving of any anchor piles or the load test pile and the commencement of the load test.

501.4.6.3 Dynamic Pile Tests

When dynamic load tests are specified in the Contract, dynamic measurements will be taken by the Contractor using procedures set forth in ASTM D4945 (Reference 8). Dynamic testing shall be completed during the driving of piles designated on the Plans, or as designated by the Resident. Dynamic load tests will be performed for the full length of the test pile during initial drive. The Contractor's representative performing the dynamic tests shall be an experienced pile testing engineer and have attained the dynamic pile load test Signatory Advanced level on the Foundation QA High Strain Dynamic Pile Testing Examination, or equivalent level of certification or training, or be a licensed Professional Engineer. The same Contractor's representative conducting the wave equation analysis shall perform the dynamic load tests. Each test shall also include a numerical evaluation of static axial pile resistance using field dynamic measurements obtained per ASTM D4945 (also known as signal matching) (Reference 8). The Contractor's representative shall be experienced in the use of dynamic pile load test equipment and its purpose related to pile capacity determinations. Dynamic measurements shall be reported to the Resident and include items specified in Section 7 of ASTM D4945 (Reference 8).

Before placement of the pile in the leads, the Contractor shall make the designated pile available for obtaining wave speed measurements and for predrilling the required instrument attachment holes. The Contractor shall mark the designated pile in foot and inch markings. The Contractor shall make provisions in ordered lengths of pile to account for an additional pile length, equal to three pile diameters or 5 feet, whichever is greater, for instrumentation attachment. Pre-driving wave speed measurements will not be required for steel piles. When wave speed measurements are made, the piling shall be in a horizontal position and not in contact with other piling. The Contractor will furnish the equipment, materials, and labor necessary for drilling holes in the piles for mounting the instruments. The instruments will be attached near the head of the pile with bolts placed through drilled holes on the steel piles or with wood screws for timber piles.

The Contractor shall provide the Contractor's dynamic testing technician with reasonable means of access to the pile for attaching instrumentation after the pile is placed in the leads. The Contractor shall furnish electric power for the dynamic test equipment. The power supply at the outlet shall be 10 amp, 115 volt, 55-60 cycle, A.C. only. Field generators used as the power source shall be equipped with functioning meters for monitoring voltage and frequency levels.

With the dynamic testing equipment attached, the Contractor shall drive the pile to the depth at which the dynamic test equipment indicates that the required nominal resistance has been achieved or to the minimum tip elevation, whichever results in the greatest depth, as called for on the Plans, or as directed otherwise by the Resident. The stresses in the piles will be monitored during driving with the dynamic test equipment to ensure that the values determined do not exceed the allowable values specified in this Section. If necessary, the Contractor shall reduce the driving energy transmitted to the pile by using additional cushions or reducing the energy output of the hammer in order to maintain stresses at or below the allowable values. If non-axial driving is indicated by dynamic test equipment measurements, the Contractor shall immediately realign the driving system.

When directed to restrike by the Resident, the Contractor shall wait a minimum of 24 hours, or as otherwise specified on the Contract Plans, and after the instruments are reattached, restrike the dynamic load test pile. A cold hammer shall not be used for the restrike. The hammer shall be warmed up before restrike begins by applying at least 20 blows to another pile. The maximum amount of penetration required during restrike shall be 6 inches, or the maximum total number of hammer blows required will be 50, whichever occurs first. After restriking, the Resident will either accept the re-driven pile or specify additional pile penetration and testing. The Contractor shall supply the Resident with a report of the test results of each dynamically tested pile, numerical evaluations of static axial pile resistance using dynamic field measurements (signal matching), and a driving criteria within 5 Working Days of the completion of testing. When directed by the Resident or required by the Contract Plans, numerical evaluations of static pile capacity using the field dynamic measurements and a driving criteria shall be supplied to the Resident within 24 hours of completing the testing.

501.4.6.4 Hammer Performance

If at any time during pile driving operations or dynamic testing the performance or efficiency of the power hammer is not in accordance with the Pile and Driving Equipment Data Form, the wave equation analyses, or the dynamic/static testing results, as determined by the Resident, the Contractor shall repair or replace the driving system. This may include, but not be limited to, rebuilding the hammer, or replacing the hammer with another hammer. All costs and time associated with replacing the driving system, including additional wave equation analyses and dynamic/static testing, as determined by the Department, shall be borne by the Contractor.

501.4.6.5 Required Pile Resistance

Piles shall be driven by the Contractor to the penetration depth shown on the Plans or to a greater depth if necessary to obtain the required pile resistance. The required pile resistance shall be determined by the approved wave equation analysis or by the results of dynamic testing and numerical evaluations of static pile resistance using dynamic field measurements (signal matching).

Piles shall not be driven to the required nominal pile resistance with a vibratory hammer.

501.4.7 Splicing Piles

There shall be no splicing of FRP piles, unless approved by the Resident

Further research into the splicing of FRP piles is required before it may be used for production piling.

501.4.8 Prefabricated Pile Tips

When hollow FRP piles are driven through soils with obstructions or to bedrock, a conical steel pile tip shall be used to reduce areas of high stress.

If hollow FRP piles are driven in loose soils without obstructions, an annular steel pile tip may be used in place of a conical tip.

Concrete-filled piles shall be driven with a conical tip or flat plate.

501.5 Method of Measurement

501.5.1 Equipment Mobilization

A lump sum price bid for mobilization shall include the cost of furnishing all labor, materials, and equipment necessary for the transporting, erecting, dismantling, and removing all pile driving equipment.

501.5.2 Piles Furnished

The unit of measurement for furnishing FRP piles shall be the linear foot. The quantity to be paid for will be the sum of the lengths in feet of the piles, of the types and lengths ordered in writing by the Resident. No allowance will be made for the length of piles, including test piles furnished by the Contractor, to replace piles that were previously accepted by the Resident, but are subsequently damaged prior to completion of the Contract. When additional lengths of piles are necessary, the additional length ordered in writing by the Resident will be included in the length of piling furnished. All piles must be cutoff at the cutoff elevation shown on the Plans.

Changed “H-piles, pipe piles and steel casings” to “FRP piles”

501.5.3 Piles in Place

Initiation of pile installation by use of a vibratory hammer, preaugering, jetting or other methods used for facilitating pile driving procedures will not be measured and payment shall be considered included in the unit price bid for the Piles, In Place, pay item.

The quantity of FRP pile to be paid for will be the actual number of linear feet of FRP pile driven and left in place in the completed and accepted work. Measurements will be made from the tip of the H-beam pile, steel pipe pile or casing to the cutoff elevation as shown on the Plans.

Changed “pile” to “FRP pile”.

Unused pile cutoffs 10 feet or more in length, except those required to accommodate the Contractor's construction method, as discussed herein, will remain the property of the Department and will be stored at a bridge maintenance yard nearest the project. Hauling and unloading of piles will be done by the Contractor or by the Department, depending upon availability of services.

When hauling and unloading is done by the Contractor, payment will be made under the provisions of Section 109, Changes. There will be no separate payment to load piles at the project site; loading will be considered an incidental cost to the item.

No separate measurement will be made for reinforcing steel, excavation, pre-excavation, drilling, cleaning of drilled holes, cleaning out of pipe piles, drilling fluids, sealing materials, concrete, required casing, and other items required to complete the Work.

501.5.4 Pile Tips

Pile Tips will be measured by the number of tips authorized and satisfactorily installed.

501.5.5 Pile Splices

Pile splices will be measured by the number of splices authorized and satisfactorily completed to drive the piles in excess of the ordered length furnished and approved by the Resident.

Splicing of FRP piles is not allowed.

501.5.6 Static Load Tests

Static load tests will be measured by the number of unit tests authorized and satisfactorily made.

501.5.7 Dynamic Load Tests

Dynamic load tests will be measured by the number of dynamic pile tests authorized and satisfactorily made. One dynamic test includes all data collected on one pile during both the initial pile driving and a restrike done a minimum of 24 hours after the initial driving, and numerical evaluation of static axial pile resistance using dynamic field measurements (signal matching).

501.6 Basis of Payment

The accepted quantities of piles and casings will be paid for at the Contract Unit Price per linear foot, delivered, and complete, in place. Such payment will include full compensation for any necessary excavation or backfilling required after driving, to bring the foundation area to the correct elevation.

Pile cutoffs and concrete for pipe piles and casings will not be paid for separately but will be considered as incidental to related Pay Items. Damaged pile lengths removed for pile splicing will be considered incidental to related Pay Items.

Payment for all Work related to the following will not be made directly, but will be considered incidental to related Pay Items: Jetting; preaugering; pre-excavation; providing special driving, or other work necessary to obtain the specified penetration and bearing resistance of the piles; reseating of piles; excavating and cleaning within FRP piles; furnishing and placing reinforcing steel and steel templates in FRP piles; disposing of material resulting from cleaning out FRP piles; all excavation and backfilling involved in installing piles; installation and removal of temporary falsework and driving frames; and development of an approved QCP and amendments, as required.

Removed “providing heavier sections of steel piles”.

Changed “cleaning within steel pipe piles and steel casings” to “cleaning within FRP piles”.

Changed steel pipe piles to FRP piles.

Wave equation analyses and any subsequent wave equation analyses re-submittals, required to demonstrate the appropriateness of the driving system, will be considered incidental to the related Pay Items.

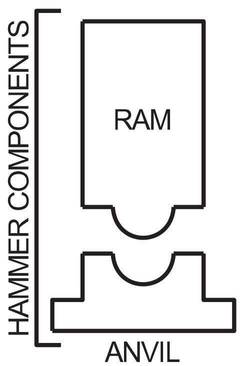
Payment for pile tips and pile splices will be paid for at the Contract Unit Price each.

Payment for dynamic and static pile tests will be paid at the Contract Unit Price per pile tested. The price shall be full compensation for satisfactory completion of all Work associated with performing and collecting measurements from initial dynamic tests, restrike tests, numerical evaluations of static pile resistance using dynamic measurements (signal matching), all sensors and wiring, monitoring equipment, setup time, reaction piles and frame, load cells, jacking equipment, survey tie-in, monitoring personnel, as applicable, and costs associated with the Contractor's down time during regular working hours while setting up equipment, performing tests and taking measurements.

Payment will be made under:

Pay Items		Pay Unit
501.230	Static Loading Test	Each
501.231	Dynamic Loading Test	Each
XXXXX	FRP Piles, delivered	Linear Foot
XXXXX	FRP Piles, in place	Linear Foot
501.90	Pile Tips	Each
501.91	Pile Splices	Each
501.92	Pile Driving Equipment Mobilization	Lump Sum

Project/Bridge:____ Town:______________________________
WIN:__________________ Fed. Proj. No:________________________ Bridge No:_________________
Contractor:____________________________ Pile Driving Sub:__________________________________



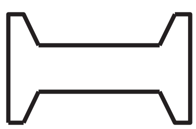
HAMMER

Manufacturer:______________________ Model:_______________
Hammer Type:_____________________ Serial No:______________
Max Energy:________________(ft-lbs) @Stroke Length:________(ft)
Ram Weight:_____________(lbs)

Modifications:____
____
____
____

HAMMER CUSHION

Material:____
Thickness:________________(in.) Area:__________________(in.^{2})
Modulus of Elasticity (E):________________________________(psi)
Coefficient of Restitution (e):________________________________



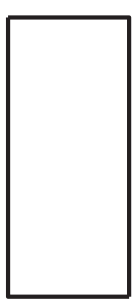
DRIVE HEAD

Helmet
Bonnet
Anvil Block
Pile Cap

Weight:____________________(lbs)

PILE CUSHION

Material:_______________________ Thickness:____________(in.)
Modulus of Elasticity (E):________________________________(psi)
Coefficient of Restitution (e):________________________________



PILE

Pile
Type:____
Length (in Leads):_____________________________________(ft)
Weight/Length:_____________(lbs/ft) Diameter:_____________(in.)
Wall Thickness:__________(in.) X-Section Area:____________(in.^{2})
Maximum Factored Load:______________________________(kips)
Required Resistance:_________________________________(kips)
Splice Description:____
Pile Tip Description:_______________________________________
Submitted by:________________________ Date:_______________
Telephone #:___________________ Fax #-____________________

Figure 1- Pile and Driving Equipment Data Form. Form can be found on MaineDOT Website