

Modern Specification of Driven Pile Work

RICHARD S. CHENEY

In the past 20 years, extensive research and implementation efforts have been directed at improved construction control of driven piles. The feasibility of techniques such as wave equation analysis, quick load testing, and dynamic pile testing has been thoroughly evaluated and generally accepted by the engineering profession. The mechanics of the pile-driving operation have been studied with results confirming the importance of controlling the properties of pile driving appurtenances such as hammer cushion, drive head, pile cushion, followers, and so on. Finally, the elements of risk in bidding pile work have been learned through numerous court of claims cases on topics such as estimated lengths, fixed-cost items bid as variable costs, delays in furnishing proper equipment, or required pile lengths. Modernization of current specifications for construction control of driven piling requires philosophical as well as technical changes. Five areas of potential improvement that need to be addressed in detail are specifying ordered pile lengths, using ultimate pile capacity, approving driving equipment, field verifying pile capacity, and devising a pile payment method.

Nearly all pile specifications currently in use by U.S. highway agencies were developed many years ago and have been continually revised within the original format. The resulting specifications often contain a mixture of outdated and state-of-the-art requirements. What is needed is an entirely new modern specification that has state-of-the-art continuity yet allows state-of-the-practice introduction into current procedures. The specification should be restricted only to driven piles because control procedures for installation of drilled shaft foundations are radically different than for driven piles. Five key elements must be included in the modern pile specification to achieve successful implementation and equitable payment for work performed. Those elements are described in this paper with suggested wording (indicated by headings containing the word "Specifications:") for a modern construction specification.

PROVIDING ORDERED LENGTHS OF PILES

The objective of a pile specification is to provide criteria by which the owner can ensure that designated piles are properly installed and the contractor can expect equitable compensation for work performed. The owner's responsibility is to estimate the pile lengths required to safely support the design load. Pile lengths should be estimated on the basis of subsurface explorations, testing, and analysis, which are completed during the design phase. Pile contractors who enter contractual agreements to install piles for an owner should not be held accountable or indirectly penalized for inaccuracies in estimated

lengths. The contractor's responsibility is to provide and install designated piles, undamaged, to the lengths specified by the owner. This work is usually accomplished within an established framework of restrictions necessary to ensure a "good" pile foundation. The price bid for this item of work will reflect the contractor's estimate of both actual cost to perform the work and perceived risk. The following statement is an example of how to implement this concept in a pile specification.

I. SPECIFICATIONS: DESCRIPTION

This item shall consist of furnishing and driving foundation piles of the type and dimensions designated including cutting off or building up foundation piles when required. Piling shall conform to and be installed in accordance with these specifications, and at the location, and to be elevation, penetration, and/or bearing shown on the plans or as directed by the Engineer.

The Contractor shall furnish the piles in accordance with an itemized order list, which will be furnished by the Engineer, showing the number and length of all piles. When test piles are required, the pile lengths shown on the plans are for estimating purposes only and the actual lengths to be furnished for production piles will be determined by the Engineer after the test piles have been driven. The lengths given in the order list will be based on the lengths that are assumed after cutoff to remain in the completed structure. The Contractor shall, without compensation, increase the lengths to provide for fresh heading and for such additional length as may be necessary to suit the Contractor's method of operation.

DESIGN AND CONSTRUCTION CONTROL USING ULTIMATE PILE CAPACITY

The ultimate pile capacity during driving is the soil resistance that must be overcome to reach the pile tip elevation where the design load can be mobilized with an acceptable safety factor. The safety factor selected will depend both on design factors, such as quantity of subsurface information and type of geotechnical analysis, and construction factors, such as the use of load tests, wave equation, or dynamic formula to monitor pile capacity. Commonly, design load factors range from 2.0 (comprehensive foundation investigation and construction control) to 3.5 (minimal foundation investigation and construction control). However, the design load should not be used to monitor field installation of piles because only on the most routine pile

projects will the ultimate pile capacity be equal to the pile design load multiplied by the design safety factor.

More typically, piles are used to penetrate upper soil layers that are unsuitable for load bearing because of either poor soil characteristics or future loss of support by scour or erosion. In such cases the resistance in the unsuitable layers is not considered in determining the pile embedment necessary to support the design load at the appropriate safety factor. However, the estimated ultimate pile capacity to be encountered during driving must include the resistance to be encountered in penetrating those unsuitable layers in addition to the design load multiplied by the safety factor. This ultimate pile capacity must be shown on the contract documents to permit the contractor to properly size the driving equipment and the engineer to judge the acceptability of the contractor's driving equipment.

Hammer blow count measured in the field has no direct relation to design load, only ultimate capacity. The hammer blow count at any pile penetration reflects the total capacity mobilized by the pile. This total capacity may include capacity mobilized temporarily in soil deposits unsuited for bearing, as well as suitable bearing layers. Therefore, hammer blow count should be established for the ultimate pile capacity that must be overcome to reach the ordered length at which the design load can be supported at the chosen safety factor. Also the maximum pile stress is directly proportional to the ultimate resistance the pile section must overcome to reach final tip. This driving stress is far more critical than the stress caused after installation by the design load.

Note that the following two sections on approval of driving equipment and driven pile capacity contain example specification sections based on ultimate pile capacity.

APPROVING DRIVING EQUIPMENT

The current procedures in most public agency specifications for approval of driving equipment are inadequate because little or no information concerning the equipment is required previous to the actual production pile driving. The lack of proper criteria has frequently resulted in equipment being provided that either cannot drive the pile to the desired elevation or inflicts damage on the pile. Improvements are needed in equipment approval to reduce the problems associated with the "wrong" hammer being furnished. Contractors should applaud such restrictions as both driving time and the chance of pile damage will be reduced. The following model specification section is suggested to provide proper control for impact hammers:

II. SPECIFICATIONS: EQUIPMENT FOR DRIVING PILES

A. Pile Hammers

Piles may be driven with steam, air, or diesel hammers. Drop hammers, if specifically permitted in the contract, shall be used only to drive timber piles. When drop hammers are permitted, the ram shall weigh between 2,000 and 3,500 lb and the height of drop shall not exceed 15 ft. In no case shall the weight of drop hammers be less than the combined weight of drive head and pile. All drop hammers shall be equipped with hammer guides to insure concentric impact on the drive head.

The plant and equipment furnished for steam and air 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 Engineer. The weight of the striking parts of air and steam hammers shall not be less than $\frac{1}{3}$ the weight of drive head and pile being driven, and in no case shall the striking parts weigh less than 2,750 lb.

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 Engineer to visually determine hammer stroke at all times during pile-driving operations. Also, the Contractor shall provide the Engineer with a chart from the hammer manufacturer equating stroke and blows per minute 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 so as to be easily read by the Engineer. Also, the Contractor shall provide the Engineer a chart, calibrated to actual hammer performance within 90 days of use, equating bounce chamber pressure to either equivalent energy or stroke for the closed-end diesel hammer to be used.

B. Approval of Pile-Driving Equipment

All pile-driving equipment furnished by the Contractor shall be subject to the approval of the Engineer. It is the intent of this specification that all pile-driving equipment be sized such that the project piles can be driven with reasonable effort to the ordered lengths without damage. Approval of pile-driving equipment by the Engineer will be based on wave equation analysis and/or other judgments.

In no case shall the driving equipment be transported to the project site until approval of the Engineer is received in writing. Prerequisite to such approval, the Contractor shall submit to the Engineer the necessary pile-driving equipment information at least 30 days before driving piles. The form that the Contractor shall complete with the previous information accompanies this text [Figure 1]. A full-size form will be included in the contract documents or supplied by the Engineer.

[Commentary.] Use of wave equation analysis for approval of driving equipment can substantially reduce pile-driving costs and pile-driving claims by insuring that the equipment brought to the job can drive the pile to the required length without damage. Public agencies should encourage contractors to use wave equation analysis to select the optimum hammer for each project. In cases where disputes arise over rejection of pile-driving equipment, the engineer should ask the contractor to submit proof of the adequacy of the pile-driving equipment. Such proof should consist of, but not be limited to, a wave equation analysis of the proposed driving equipment performed by a registered professional engineer. All costs of such submissions, if required, shall be the responsibility of the contractor.

The pile and driving equipment data form should be submitted for approval even if wave equation analysis will not be done for hammer approval. The approved form should be used by the pile inspector to insure that the proper hammer and

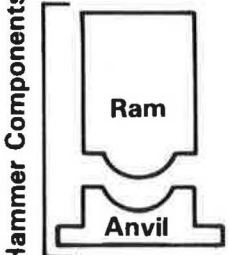
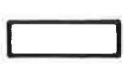
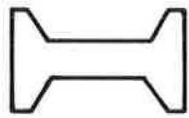
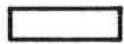

Contract No.: _____ Project: _____ County: _____	Structure Name and/or No.: _____ Pile Driving Contractor or Subcontractor: _____ (Piles driven by)
Hammer Components  <p style="text-align: center;">Ram Anvil</p>	Hammer Manufacturer: _____ Model: _____ Type: _____ Serial No.: _____ Rated Energy: _____ at _____ Length of Stroke _____ Modifications: _____ _____ _____
	Hammer Cushion Material: _____ Thickness: _____ Area: _____ Modulus of Elasticity - E _____ (P.S.I.) Coefficient of Restitution-e _____
	Drive Head <div style="border: 1px solid black; padding: 2px; display: inline-block;"> Helmet Bonnet Anvil Block Pile Cap </div> - Weight: _____
	Pile Cushion Cushion Material: _____ Thickness: _____ Area: _____ Modulus of Elasticity - E _____ (P.S.I.) Coefficient of Restitution _____
	Pile Pile Type: _____ Length (in Leads) - _____ Weight/ft. _____ Wall Thickness: _____ Taper: _____ Cross Sectional Area _____ in ² Design Pile Capacity: _____ (Tons) Description of Splice: _____ Tip Treatment Description: _____
<div style="border: 1px solid black; padding: 5px;"> Distribution One Copy Each To: <input type="checkbox"/> State Bridge Engineer <input type="checkbox"/> State Soils Engineer <input type="checkbox"/> District Engineer <input type="checkbox"/> Resident Engineer </div>	Note: If mandrel is used to drive the pile, attach separate manufacturer's detail sheet(s) including weight and dimensions. Submitted By: _____ Date: _____

FIGURE 1 Pile and driving equipment data form.

driving appurtenances are furnished and maintained during the driving operation. Few agencies currently supply the pile inspector with any such information on which rational inspection can be based.]

The criteria, which the Engineer will use to evaluate the driving equipment from the wave equation results, consist of both the required number of hammer blows per inch and the pile stresses at the required ultimate pile capacity. The required number of hammer blows indicated by the wave equation at the

ultimate pile resistance shall be between 3 and 15 per in. for the driving equipment to be acceptable.

In addition, for the driving equipment to be acceptable the pile stresses that are indicated by the wave equation to be generated by the driving equipment shall not exceed the values where pile damage impends. The point of impending damage in steel piles is defined herein as a compressive driving stress of 90 percent of the yield point of the pile material. For concrete piles, tensile stresses shall not exceed 3 multiplied by the square root of the concrete compressive strength, f'_c , plus the

effective prestress value ($3\sqrt{F'_c}$ + prestress), and compressive stresses shall not exceed 85 percent of the compressive strength minus the effective prestress value ($0.85 F'_c$ - prestress). For timber piles, the compressive driving stress shall not exceed three times the allowable static design strength listed on the plans. These criteria will be used in evaluating wave equation results to determine acceptability of the Contractor's proposed driving system.

The Contractor will be notified of the acceptance or rejection of the driving system within 14 calendar days of the Engineer's receipt of the Pile and Driving Equipment Data Form. If the wave equation analyses show that either pile damage or inability to drive the pile with a reasonable blow count to the desired ultimate capacity will result from the Contractor's proposed equipment or methods, the Contractor shall modify or replace the proposed methods or equipment at his expense until subsequent wave equation analyses indicate the piles can be reasonably driven to the desired ultimate capacity, without damage. The Engineer will notify the Contractor of the acceptance or rejection of the revised driving system within 7 calendar days of receipt of a revised Pile and Driving Equipment Data Form.

During pile-driving operations, the Contractor shall use the approved system. No variations in the driving system will be permitted without the Engineer's written approval. Any change in the driving system will only be considered after the Contractor has submitted the necessary information for a revised wave equation analysis. The Contractor will be notified of the acceptance or rejection of the driving system changes within 7 calendar days of the Engineer's receipt of the requested change. The time required for submission, review, and approval of a revised driving system shall not constitute the basis for a contract time extension to the Contractor.

C. Driving Appurtenances

1. Hammer Cushion

All impact pile-driving equipment except gravity hammers shall be equipped with a suitable thickness of hammer cushion material to prevent damage to the hammer or 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 Engineer when beginning pile driving at each structure or after each 100 hr of pile driving, whichever is less. Any reduction of hammer cushion thickness exceeding 10 percent of the original thickness shall be replaced by the Contractor before driving is permitted to continue.

[*Commentary.* Mandatory use of a durable hammer cushion material that will retain uniform properties during driving is necessary to accurately relate blow count to pile capacity. Nondurable materials that deteriorate during driving cause erratic estimates of pile capacity and, if allowed to disintegrate, result in damage to the pile or driving system.]

2. Pile Drive Head

Piles driven with impact hammers require an adequate drive head to distribute the hammer blow to the pile head. The drive head shall be axially aligned with the hammer and the pile. The drive head shall be guided by the leads and not be free swinging. The drive head 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 steel and timber piling, the pile heads shall be cut squarely and a drive head, as recommended by the hammer manufacturer, shall be provided to hold the axis of the pile in line with the axis of the hammer.

For precast concrete and prestressed concrete piles, the pile head shall be plane and perpendicular to the longitudinal axis of the pile to prevent eccentric impacts from the drive head.

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 can be driven without damage.

3. Pile Cushion

The heads of concrete piles shall be protected by a pile cushion made of plywood. The minimum plywood thickness placed on the pile head before driving shall not be less than 4 in. A new pile cushion shall be provided for each pile. In addition, the pile cushion shall be replaced if, during the driving of any pile, the cushion either is compressed more than one-half the original thickness or begins to burn. The pile cushion dimensions shall match the cross sectional area of the pile top.

[*Commentary.* A pile cushion is needed only for the protection of concrete piles. If the wave equation analysis of the Contractor's hammer indicates unacceptable tension stresses, the pile cushion may need to be substantially thicker than 4 in. Pile cushion thicknesses up to 18 in. have been used to mitigate tension stresses. Compressive stresses at the pile head can be controlled with a relatively thin pile cushion. However, cushions may become overly compressed and hard after about 1,000 hammer blows.]

4. Followers

Followers shall be used only when approved in writing by the Engineer, or when specifically stated in the contract documents. In cases where a follower is permitted, the first pile in each bent 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 desired pile capacity. 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 to be in accordance with the location tolerances in Section [XXX] before additional piles are installed.

[*Commentary.* The use of a follower causes substantial and erratic reductions in the hammer energy transmitted to the pile

because of the follower flexibility, poor connection to the pile head, frequent misalignment, and so on. Reliable correlations of blow count with pile capacity are impossible when followers are used. Severe problems with pile alignment and location frequently occur when driving batter piles with a follower in a cofferdam unless a multitier template is used. A follower should be a heavy structural section with a good connection at the pile head to reduce energy losses.]

VERIFYING DRIVEN PILE CAPACITY

Current good piling practices dictate use of the wave equation in place of dynamic formula to monitor driven pile capacity for all projects. The hammer blow count and maximum pile stress should be determined for the ultimate pile capacity. Use of the wave equation will permit the use of lower safety factors on the design load and the minimum permissible pile section to resist the driving force. This will result in significant cost reductions from savings in pile lengths and use of smaller pile sections. All highway agencies should begin phasing in wave equation analysis with an ultimate goal of specifying wave equation as the primary method for construction control of driven piles.

III. SPECIFICATIONS: CONSTRUCTION METHODS

A. Driven Pile Capacity

1. Wave Equation

The ultimate driven pile capacity shall be determined by the Engineer on the basis of a wave equation analysis. Piles shall be driven with the approved driving equipment to the ordered length or other lengths necessary to obtain the required ultimate pile capacity. Jetting or other methods to facilitate pile penetration shall not be used unless either specifically permitted in the contract documents or approved by the Engineer after a revised driving resistance is established from the wave equation analysis. Adequate pile penetration shall be considered to be obtained when the specified wave equation resistance criteria are achieved within 5 ft of the tip elevation based on ordered length. Piles not achieving the specified resistance within these limits shall be driven to penetrations established by the Engineer.

B. Load Tests

1. Static Load Test

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 percent of the ultimate pile capacity, or 1,000 tons, whichever is less. The Contractor shall submit to the Engineer for approval 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 safe pile load shall be defined as 50 percent of the failure load. The failure load for the pile shall be defined as follows: for piles 24 in. or less in diameter or width the failure load of a pile tested under axial compressive load is that load that produces a settlement at failure of the pile head equal to

$$S_f = S + (0.15 + 0.008 D)$$

where

$$\begin{aligned} S_f &= \text{settlement at failure in inches,} \\ D &= \text{pile diameter or width in inches, and} \\ S &= \text{elastic deformation of total pile length in inches.} \end{aligned}$$

For piles greater than 24 in. in diameter or width

$$S_f = S + D/30$$

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 $\frac{1}{4}$ in. 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.

[Commentary. The load transferred to both the top of the bearing layer and the pile tip should be determined from instrumentation for each static load test pile. Instrumentation commonly consists of strain gauges or telltale rods mounted at varying depths from the pile top. Also, a load cell should be mounted between the load frame and the pile head to verify the readings from the hydraulic jack pressure gauge. Because of jack ram friction, loads indicated by a jack pressure gauge are commonly 10 to 20 percent higher than the actual load imposed on the pile.

Lastly, after completion of a load test on a nonproduction pile, the static test pile should be pulled and checked for damage. The examination of the extracted pile will determine driving damage and its effect on capacity.]

2. Dynamic Load Tests

Dynamic measurements will be taken by the Engineer during the driving of piles designated as dynamic load test piles.

[Commentary. When static load tests are specified, dynamic load tests are recommended to be performed on at least half the reaction piles before driving the static load test pile. The dynamic test results are used both to verify that the desired ultimate resistance can be attained at the proposed estimated static load test pile length and to fine tune the dynamic test equipment for site soil conditions. When dynamic tests are specified on production piles, the first pile driven in each substructure foundation is recommended to be tested. Where uniform soil conditions exist across a site, the number of dynamic tests may be reduced based on recommendations from the agency's geotechnical engineer.]

Before placement in the leads, the Contractor shall make each designated concrete and/or timber pile available for taking wave speed measurements and for predrilling the required instrument attachment holes. Predriving 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 Engineer 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 in masonry anchors for the concrete piles or through drilled holes on the steel piles or with wood screws for timber piles. The Contractor shall provide the Engineer reasonable means of access to the pile for attaching instruments after the pile is placed in the leads. A platform with minimum size of 4 by 4 ft (16 ft²) designed to be raised to the top of the pile while the pile is located in the leads shall be provided by the Contractor. It is estimated that the Engineer will need approximately 1 hr per pile to install the dynamic test equipment.

The Contractor shall furnish electric power for the dynamic test equipment. The power supply at the outlet shall be 10 amp, 115 V, 55–60 cycle, AC only. Field generators used as the power source shall be equipped with functioning meters for monitoring voltage and frequency levels.

The Contractor shall furnish a shelter to protect the dynamic test equipment from the elements. The shelter shall have a minimum floor size of 8 by 8 ft (64 ft²) and minimum roof height of 7 ft. The inside temperature of the shelter shall be maintained above 45°F. The shelter shall be located within 50 ft of the test location.

The Contractor shall drive the pile to the depth at which the dynamic test equipment indicates that the ultimate pile capacity shown in the contract plans has been achieved, unless directed otherwise by the Engineer. 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 critical values. 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 below the critical values. If nonaxial driving is indicated by dynamic test equipment measurements, the Contractor shall immediately realign the driving system.

When directed by the Engineer, the Contractor shall wait up to 24 hr and, after the instruments are reattached, retap the dynamic load test pile. It is estimated that the Engineer will require approximately 1/2 hr to reattach the instruments. A cold hammer shall not be used for the redrive. The hammer shall be warmed up before redrive begins by applying at least 20 blows to another pile. The maximum amount of penetration required during redrive shall be 6 in. or the maximum total number of hammer blows required will be 50, whichever occurs first. After retapping, the Engineer will either provide the cut-off elevation or specify additional pile penetration and testing.

[*Commentary.* For purposes of measurement and payment, one dynamic test includes all data collected on one pile during both the initial pile driving and a retap done up to 24 hr after the initial driving. Additional long-term retaps should be paid for as separate tests unless the retap schedule is specifically stated in the dynamic test specification. The retap data taken in a 12 to 24 hr period after initial testing will normally provide

the engineer sufficient information on which to determine the long-term pile capacity. Particularly for friction piles in silt or low plasticity clay soils, the capacity measured in the first few blows where full hammer energy was applied may reliably be taken as the long-term capacity.]

3. General

On completion of the load testing, any test or anchor piling not a part of the finished structure shall be removed or cut off at least 1 ft below either the bottom of footing or the finished ground elevation if not located within the footing area.

C. Test Piles (Indicator Piles)

Test piles shall be driven when shown on the plans at the locations and to the lengths specified by the Engineer. All test piles shall be driven with impact hammers unless specifically stated otherwise in the plans. In general, the specified length of test piles will be greater than the estimated length of production piles in order to provide for variation in soil conditions. The equipment used for driving test piles shall be identical to that which the Contractor proposes to use on the production piling. Approval of driving equipment shall conform with the requirements of these Specifications. The Contractor shall excavate the ground at each test pile to the elevation of the bottom of the footing before the pile is driven.

Test piles shall be driven to a hammer blow count established by the Engineer at the estimated tip elevation. Test piles that do not attain the hammer blow count specified above at a depth of 1 ft above the estimated tip elevation shown on the plans shall be allowed to "set up" for 12 to 24 hr, or less if directed by the Engineer, before being redriven. A cold hammer shall not be used for redrive. The hammer shall be warmed up before driving begins by applying at least 20 blows to another pile. If the specified hammer blow count is not attained on redriving, the Engineer may direct the Contractor to drive a portion or all of the remaining test pile length and repeat the "set up" redrive procedure. Test piles driven to plan grade and not having the hammer blow count required shall be spliced and driven until the required bearing is obtained.

A record of driving of test piles will be prepared by the Engineer that includes the number of hammer blows per foot for the entire driven length, the as-driven length of test pile, cut-off elevation, penetration in ground, and any other pertinent information requested by the Engineer. The Contractor shall provide the information listed in Figure [X] to the Engineer for inclusion in the record. If redrive is necessary the Engineer will record the number of hammer blows per inch of pile movement for the first foot of redrive. The Contractor shall not order piling to be used in the permanent structure until test pile data have been reviewed and pile order lengths are authorized by the Engineer. The Engineer will provide the pile order list within 7 calendar days after completion of all test pile driving specified in the contract documents.

[*Commentary.* Test piles are particularly recommended on projects in which (a) large quantities or long length of friction piling are estimated, even if load tests are to be used at adjacent footings; (b) large ultimate soil resistance is expected in relation to the design load, and (c) precast concrete piles are used.]

DEVISING A METHOD OF MEASUREMENT AND BASIS OF PAYMENT

Pile payment items should be chosen to separate the major fixed costs from the variable costs. Many highway agencies oversimplify pile payment by including all costs associated with the driving operation into the price per foot of pile installed. Contractors bidding such "simple" items are required to break down the total cost of the mobilization, splices, shoes, and so on, into a price per foot based on the total estimated pile footage. If that footage underruns, the Contractor does not recover the full cost of mobilization, splices, shoes, and so on; if the footage overruns, the owner pays an unfair price for the overrun footage. The use of separate items for piling operations of major fixed cost, such as mobilization, can substantially mitigate the inequitable impact of length variations. Similarly, separate payment for both furnishing piles and driving piles compensates the contractor for actual materials used and installation costs even when overruns or underruns occur. Also, separate items permit the Contractor to obtain payment for work completed in a timely, equitable manner instead of requiring him or her to carry large debts for materials purchased or equipment furnished. The following section on measurement and payment is suggested.

IV. SPECIFICATIONS: METHOD OF MEASUREMENT

A. Timber, Steel, and Precast Concrete Piles

1. Piles Furnished

The unit of measurement for payment for furnishing timber, steel, and precast concrete 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 Engineer, furnished in compliance with the material requirements of these specifications and stockpiled in good condition at the site of the work by the Contractor, and accepted by the Engineer. No allowance will be made for that footage of piles, including test piles, furnished by the Contractor to replace piles that were previously accepted by the Engineer, but are subsequently damaged prior to completion of the contract.

When extensions of piles are necessary during construction, the extension length ordered in writing by the Engineer will be included in the linear footage of piling furnished.

2. Piles Driven

The unit of measurement for driving timber, steel, and precast concrete piles shall be per linear foot of piling in place measured below the cut-off elevation. The measured length will be rounded to the nearest foot.

Preboring, 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 Driven pay item.

B. Cast-in-Place Pipe of Shell Concrete Piles

The quantity of cast-in-place pipe of shell concrete piles to be paid for will be the actual number of linear feet of steel pipe or shell piles driven, cast, and left in place in the completed and

accepted work. Measurements will be made from the tip of the steel pipe or shell pile to the cut-off elevation shown on the plans.

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

C. Pile Shoes

The number of pile shoes measured for payment shall be those shoes actually installed on piles accepted for payment by the Engineer.

D. Load Tests

The quantity of load tests to be paid for will be the number of load tests completed and accepted, except that load tests made at the option of the Contractor will not be included in the quantity measured for payment.

Anchor and test piling that are not a part of the permanent structure will be included in the unit price bid for each load test. Anchor and test piling or anchor and test shafts, which are a part of the permanent structure, will be paid for under the appropriate pay item.

E. Splices

The number of splices measured for payment shall be only those splices actually made and required to drive the piles in excess of the ordered length furnished by the Engineer.

F. Furnishing Equipment for Driving Piles

Payment will be made at the lump sum price bid for this item as follows: 75 percent of the amount bid will be paid when the equipment for driving piles is furnished and driving of satisfactory piles has commenced. The remaining 25 percent will be paid when the work of driving piles is completed. The lump sum price bid shall include the cost of furnishing all labor materials and equipment necessary for transporting, erecting, maintaining, making any ordered equipment replacement, dismantling, and removing the entire pile-driving equipment. The cost of all labor, including the manipulation of the pile-driving equipment and materials in connection with driving piles, shall be included in the unit price bid per linear foot for the piles to be driven. The furnishing of equipment for driving sheet piling is not included in this work. Payment for furnishing and using a follower, augers, or jetting will be considered as included in the unit price bid for piles.

V. SPECIFICATIONS: BASIS OF PAYMENT

The accepted quantities, determined as provided in the previous sections, will be paid for at the contract price per unit of measurement, respectively, for each of the particular pay items in the following list that is shown in the bid schedule, which prices and payment will be full compensation for the work prescribed in this Section. Payment will be made under:

<i>Pay Item</i>	<i>Pay Unit</i>
Piles, furnished	Linear foot
Piles, driven	Linear foot
Piles, cast-in-place	Linear foot
Test piles, furnished	Linear foot
Test piles, driven	Linear foot
Test piles, cast-in-place	Linear foot
Pile load test (static)	Each
Pile load test (dynamic)	Each
Splices	Each
Pile shoes	Each
Furnishing equipment for pile driving	Lump sum

wave equation analysis and dynamic and static pile load testing. Consideration also needs to be given to both improvement in the use of modern design analyses such as static analyses on which the construction control depends and the equitable distribution of responsibility and payment for work specified and accomplished. Use of these methods combined with local experience will improve pile foundation reliability, allowing the design and construction of cost-effective foundations with reduced frequency of claims and disputes.

CONCLUSION

In summary, current pile specifications need to be modernized to include state-of-the-art construction control methods such as

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