INSTALLATION SPECIFICATION FOR DRIVEN PILES

PDCA Specification 103-07

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PDCA Technical Committee

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COMMENTARY

This document is similar to the AASHTO Driven Pile Installation Specification. The reference numbers in this specification, when preceded by a "4." would be similar to the AASHTO numbering system (e.g. Section 1. in this document is similar to AASHTO section 4.1.) This Specification may be modified by the Engineer, or adopted in part or in whole into contract documents, or adopted simply by reference as the governing document for the project. Non-applicable sections may be eliminated in specific use (e.g. pile materials or specific tests or procedures not in project use can be deleted).

1 INTRODUCTION

This work shall consist of furnishing and driving foundation piles of the type and dimensions designated in the contract documents, including cutting off or building up foundation piles when required. This specification also covers providing test piles and performing loading tests. Piling shall conform to and be installed in accordance with these specifications; at the location; and to the elevation, penetration, and the required ultimate pile capacity shown in the contract documents or as directed by the Engineer.

Except when test piles are required, the Contractor shall furnish the piles in accordance with the dimensions shown in the contract documents. When test piles are required, the production pile lengths shown in the contract documents are for estimating purposes only and the actual lengths to be furnished for production piles shall be determined by the Engineer after the test piles have been driven and tested. The lengths given in the order list provided by the Engineer shall include only the lengths anticipated for use in the completed structure. The Contractor shall increase the lengths shown or ordered to provide for fresh heading and for such additional length as may be necessary to suit the method of operation, without added

C1 INTRODUCTION

For the purposes of this document, "ultimate pile capacity" is considered synonymous with the "nominal resistance" as in the AASHTO code, or "nominal strength" as in the ACI code. The ultimate pile capacity is limited to the lesser of either the soil strength or the structural strength. The ultimate pile capacity is generally equivalent to the working or design load times the required safety factor. The ultimate pile capacity can also be used in LRFD.

Driven pile lengths are estimated for bidding purposes from soil investigation, static analysis, and perhaps local experience. However, rarely are these estimated lengths used to control production pile installations. Usually dynamic methods (e.g. dynamic testing, wave equation, or dynamic formula) are used to evaluate capacity of test piles or the early production piles and then develop a "driving criterion" with a specified number of blows per unit penetration ("blow count"). For larger projects, a static load test is sometimes used to confirm the pile capacity and establish a driving criterion. The same blow count criteria determined by the test piles is usually applied to production piles to assure they

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compensation.

The Specification is in this left column. A "Commentary" has been compiled and is contained in the adjoining right column.

Commentary

will achieve similar capacities as the test piles; The blow count is in effect an additional quality assurance test.

thus making the driven pile in effect a tested pile. In addition to their reliability, driven piles are also a very economic alternative when deep foundations are required, and prefabricated piles are superior for rapid construction needs.

The objective of this specification is to provide criterion by which the Owner can assure 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 based on 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 requirements specified. This work is usually accomplished within an established framework of restrictions necessary to insure 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.

2 MATERIALS

2 MATERIALS

2.1 Steel Piles

2.1 Steel Piles

2.1.1 Rolled Structural Steel Piles

C2.1.1 - Rolled Structural Steel Piles

2.1.1.1 Specifications for Steel Properties

Steel used in rolled structural steel piles shall conform to the following Standard Specifications of

C2.1.1.1 Specifications for Steel Properties

Although A36 is available from structural mills, better economy will be realized by specifying the

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the American Society for Testing and Materials: • ASTM A36/A36M – Standard Specification for Carbon Structural Steel • ASTM A572/A572M – Standard Specification for High-Strength Low-Alloy Columbium- Vanadium Structural Steel • ASTM A992/A992M – Standard Specification for Structural Steel Shapes The above listing does not exclude the use of steel ordered or produced to other than the listed specifications or other published ASTM specifications which establish its properties and suitability. Steel for cast steel shoes if used shall conform to A148 (90/60).	more readily available high-strength 50 ksi; (344 MPa) A572 or A992. Other 50 ksi steels, such as A588 (for exposure to the atmosphere) and A690 (for exposure to the splash/tidal zone in a marine environment) are available at higher cost, but suitable for limited applications (based on exposure conditions). Engineers sometimes think these two grades provide corrosion resistance in soil or water, but this is not true – all structural grades behave in a similar manner in soil or water. Grade 65 ksi steels such as A572 or A913 may be economical to save material costs where high end bearing or large soil set-up cause the soil strength to exceed a 50 ksi steel strength. Sheet piling can be used to support vertical loads. Pile shoes should be considered when structural steel shapes are driven through obstructions or to sloping hard rock. Pile shoes are discussed in Section 4.2.2.2. The increased usage of high strength steel in H-piles makes it good practice to use cast steel points meeting requirements of ASTM A148 (90/60) with a minimum yield point of 60 ksi.
2.1.1.2 Minimum Dimensions Sections of such piles shall be of "H" or "W" shape and shall comply with the following requirements: (a) – The flange projection shall not exceed 14 times the minimum thickness of metal in either the flange or the web, and flange widths shall not be less than 80 per cent of the depth of the section, (b) – The nominal depth in the direction of the web shall not be less than 8 inches (200 mm). (c) – Flanges and web shall have a minimum nominal thickness of not less than three-eighths inches (9.5 mm).	C2.1.1.2 Minimum Dimensions
2.1.2 Steel Pipe Piles	C2.1.2 - Steel Pipe Piles

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2.1.2.1 Specification for Steel	C2.1.2.1 Specifications for steel pipe piles
Steel pipe piles shall consist of steel pipe conforming to the following Standard Specification of the American Society for Testing and Materials: ASTM A252 Grade 2 or Grade 3 – Standard Specification for Welded and Seamless Steel Pipe Piles (a) Minimum Dimensions: Pipes shall have an outside diameter and a minimum nominal wall thickness as shown in the contract documents. (b) Ends of closed-ended pipe piles shall be closed with a flat plate or a forged or cast steel conical point, or other end closure of approved design. End plates shall have a minimum thickness of 0.75 inch (19 mm)	Open-end pipe piles sometimes are filled and closed-end steel pipe piles are usually filled with concrete as detailed in section 4.2.1.2.2 . While ASTM A252 Grade 2 is used, consideration should be given to using Grade 3 which provides additional strength with little increase in cost. Generally wall thicknesses should not be less than 0.188 inch (4.8 mm). Larger pile diameters generally require larger wall thickness. In some cases, a larger thickness may be desirable for both open end and closed end pipe piles. Very thin-wall pipe piles may be difficult to drive in some cases and a thicker wall may be required. Pipes installed open-ended may require a suitable cutting shoe. Larger diameter pipes may require thicker end plates, and/or reinforcement. The end plate can be cut flush with the outer pile wall, beveling the pile end before welding, or can be an oversized end plate up to ½ inch larger diameter, with a fillet weld attachment.
2.1.2.2. Concrete for Concrete-Filled Pipe Piles	C2.1.2.2 Concrete for Concrete-Filled Pipe Piles
Prior to the placing of concrete in a closed end pipe pile, the pile shall be inspected by an acceptable method to confirm the full pile length and dry bottom condition. If accumulations of water in pipes are present for either closed end or open end pipes, the water shall be removed before the concrete is placed. The concrete for concrete filled pipe piles shall have a minimum compressive strength of 2.5 ksi (17.3 MPa) and a slump of not less than 6 inches (150 mm) and not more than 10 inches (250 mm). Concrete shall be placed in each pile in a continuous operation.	A drop light or mirror system, or weighted tape with attached dry cloth are possible inspection methods. It is not necessary to use a tremie or centering cone when placing concrete in pipe piles. It is impossible to center the concrete in a batter pile. Continuous operation may include changing of concrete supply trucks or other brief interruptions.

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No concrete shall be placed until all driving within a radius of 15 feet (4600 mm) of the pile has been completed, or all driving within the above limits shall be discontinued until the concrete in the last pile cast has set for at least two days.

2.2 Timber Piles

C2.2. Timber Piles

2.2.1 General

The Contractor shall supply pressure treated Southern pine or Douglas fir piles conforming to ASTM D25, new and clean peeled one piece from butt to tip. Piles not meeting ASTM D25 requirements shall be rejected.

C2.2.1 General

Timber piles are normally ordered only in 5 ft (1.5 m) incremental lengths. Usually, Douglas fir piles are available on the west coast, and southern pine in eastern locations. Southern pine is available up to 80 ft (24 m) in length. Douglas fir piles are available up to 120 ft (36 m). Most timber piles are 7 or 8 inch (180 or 200 mm) diameter at the tip. Due to the natural taper of the pile of one inch (25 mm) diameter reduction for each 10 ft (3 m) of pile length, the butt diameter depends on tip diameter and the pile length. Most commonly available pile sizes are shown within the boxed areas of Tables 3-3 and 3-4 for Southern Pine or Tables 3-5 and 3-6 for Douglas fir in the Timber Piling Council's "Timber Pile Design and Construction Manual" which can be downloaded without charge from www.timberpilingcouncil.org.

2.2.2 Submittals

Pile Data: Submit certification by treating plant stating type, pressure process used, net amount of preservative retained, and compliance with applicable standards. Show any structural connections such as for uplift loads.

2.2.3 Field Fabrication

When specified, fit timber piles with metal shoes as per section 4.2.2.3 of this specification. If the pile top is trimmed to the final cutoff elevation, treat cut surfaces at the pile head in accordance with Section 4.7.2.

2.2.4 Pressure Treatment

C2.2.4 Pressure Treatment

Pressure treatment shall be in accordance with the following American Wood Protection Association (AWPA) Use Category Standards:

AWPA Use Category for Foundation piles.
(a) Foundation, Land and Fresh Water Piles:

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UC4C (formerly C3)
(b) Standard for Highway Construction:
UC4A and UC4B (formerly C14)
(c) Standard for Marine Construction (saltwater):
UC5A, UC5B, and UC5C (formerly C18).

2.2.5 Required Retentions

Use Category AWPA Required Retentions
(Freshwater, Southern Pine) UC4C
0.80pcf CCA, 0.80 pcf ACQ, or 12.0 pcf creosote

(Freshwater, Douglas Fir) UC4C
1.0 pcf ACZA, 0.80 pcf ACQ, or 17.0 pcf creosote

(For guard rail and fence posts) UC4A
0.50 pcf CCA and ACZA, or 8.0 pcf creosote.

(For building poles) UC4B
Southern pine. 0.60 pcf CCA, or 10.0 pcf creosote
Douglas fir. 1.0 pcf ACZA, or 17.0 pcf creosote.

(Saltwater, Southern Pine)

UC5A	1.5 pcf CCA, or 16 pcf creosote
UC5B	2.5 pcf CCA, or 20 pcf creosote
UC5C	1.0 pcf CCA and 20 pcf creosote

(Saltwater, Douglas Fir)

UC5A	1.5 pcf ACZA, or 16 pcf creosote
UC5B	2.5 pcf ACZA, or 20 pcf creosote
UC5C	1.0 pcf ACZA and 20 pcf creosote

2.3 Prestressed Concrete Piles

Production of piles shall be in accordance with Prestressed Concrete Institute PCI MNL-116 “Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products.”

2.3.1. Forms

Forms for prestressed concrete piles shall

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Category UC4A covers guard rail posts and fence posts. Category UC4B covers building poles/piling used for structures in coastal areas with high wind.

C2.2.5 Required Retention

A single treatment of any one of the alternatives is acceptable for all freshwater applications and for saltwater use in UC5A and UC5B. UC5A governs north of San Francisco and north of NJ/DE line.

Dual treatment of both materials is required in UC5C for tropical saltwater environments.

Building poles include piles which extend from in the ground to the second floor, a construction common in coastal areas with high wind loads.

C2.3 Prestressed Concrete Piles

For additional information see reprint of PCI “Precast Prestressed Concrete Piles” Chapter 20 Bridge Design Manual (September 2004), Publication Number BM-20-04.

C2.3.1. FORMS

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conform to the general requirements for concrete form work as provided in the Prestressed Concrete Institute, PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."

2.3.2 Casting

Perform continuous concrete casting within 3 days after pretensioning steel; however, do not deposit concrete in forms until placement of reinforcement and anchorages has been inspected and approved by pile manufacturer's quality control representative. Each pile shall have dense concrete, straight smooth surfaces, and reinforcement retained in its proper position during fabrication. Unless self-consolidating concrete is used, the concrete shall be compacted by vibrating with a vibrator head smaller than the minimum distance between pretensioning steel. Ensure pile end surfaces are perpendicular to the longitudinal axis of the pile.

C2.3.2. CASTING

Continuous casting operation may include changing of concrete supply trucks or other brief interruptions.

2.3.3 Finish

Finish of piles shall be in accordance with PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products." Standard finish shall be that the formed sides are reasonably smooth from casting against approved forms. Standard finish of the top shall be a float finish with edges tooled.

C2.3.3. FINISH

Special finishes, if required by the Engineer, can be listed here.

2.3.4 Curing and Protection

Curing of piles shall be in accordance with PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."

Cure piles using moist curing or accelerated steam curing.

No pile shall be driven until it is sufficiently cured so as to resist handling and driving stresses without damage. In no case shall piles be driven before 7

C2.3.4 CURING AND PROTECTION

Local experience and driving conditions may require longer than 7 days curing time before driving. Piles driven early may show a higher risk of breakage. If ordered by the Engineer to drive early, then the Contractor should not bear the risk of damaged piles. Air entrainment, water/cement ratio and type of cement are all important factors in the design of concrete piles for harsh environments. ACI 318-02 Chapter 4 Article 4.3

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days' curing time and concrete compressive strength reaches at least 0.8 f'c. In cold weather, an extended curing period may be required as specified in the contract documents. Concrete shall be protected from freezing until the compressive strength reaches at least 0.8 f'_c.	discusses these issues that contribute to durability in harsh environment such as seawater and sulfate soils. If exposed to freezing conditions, dowel holes should be protected from water intrusion. For more information on cold weather requirements refer to PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."
2.3.5 Prestressing Prestressing of piles shall be in accordance with PCI MNL-116 "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."	C2.3.5 PRESTRESSING
2.3.6 Shop Drawings The Contractor shall submit the required number of shop drawings for prestressed concrete piles to the Engineer which indicate pile dimensions, materials, tendon arrangement and prestressing forces proposed for use, and any addition or rearrangement of reinforcing steel from that shown in the contract documents. Construction of the piles shall not begin until the Engineer has approved the drawings.	C2.3.6 SHOP DRAWINGS
2.3.7 Storage and Handling Handling, storing, and transporting prestressed concrete piles shall be done in such a manner as to avoid excessive bending stresses, cracking, spalling, or other injurious result.	C2.3.7 STORAGE AND HANDLING Cracks can be repaired, if necessary, by injecting epoxy under pressure into the cracks. Generally recognized guidelines suggest that cracks wider than 0.007 in. (0.18 mm) can be successfully injected. Smaller cracks often need no repair.
3 PROTECTIVE COATINGS If there is a required protection, the Contractor shall be responsible to restore or repair any damage to the coating.	C3. Protective Coatings

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4 DRIVING PILES

4.1 Pile Driving Equipment

All pile driving equipment, including the pile driving hammer, hammer cushion, helmet, pile cushion, and other appurtenances to be furnished by the Contractor shall be approved in advance by the Engineer before any driving can take place. Pursuant to obtaining this approval, the Contractor shall submit a description of pile driving equipment to the Engineer at least two weeks before pile driving is to begin. The description must contain sufficient detail so that the proposed driving system can be evaluated by the Engineer in a wave equation analysis.

If the ultimate pile capacity is to be determined by static load test, dynamic test, rapid load test or wave equation analysis, the Engineer shall use the equipment submittal to determine by wave equation analysis that the piles are drivable.

If the ultimate pile capacity is to be determined by dynamic formula, a wave equation analysis is not required. The blow count required by the dynamic formula shall not exceed 10 blows per inch (25 mm).

The following hammer efficiencies shall be used in a wave equation analysis of vertical piles unless better information is available

Hammer Type	Efficiency (in Percent)
Drop	25 to 40
Single acting air/steam	67
Double acting air/steam	50
Diesel	80
Hydraulic or diesel with built-in energy measurement	95

Hammer efficiencies shall be adjusted for batter driving.

In addition to the other requirements of these

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C4 DRIVING PILES

C4.1 Pile Driving Equipment

The actual hammer performance is a variable that can only be accurately assessed through dynamic measurements as in section 4.4.3.

Drop hammer efficiency can be highly variable depending on the drop mechanism. A lower efficiency for drop hammer will produce more conservative estimates of ultimate pile capacity, but a higher efficiency would be more conservative when assessing driving stresses.

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specifications, the criterion that the Engineer will use to evaluate the driving equipment shall consist of both the required number of hammer blows per inch (25mm) at the required ultimate pile capacity and the pile driving stresses over the entire driving process. The required number of hammer blows indicated by the wave equation analysis at the required ultimate pile capacity shall be between 2 and 10 blows per inch (25mm) for the driving equipment to be deemed acceptable.	Diesel hammers operate at variable ram strokes. Hydraulic hammers are often operated at less than full stroke to prevent overstressing piles.
In addition, for the driving equipment to be deemed acceptable, the pile stresses, which are determined by the wave equation analysis for the entire driving operation shall not exceed the values below:	
For steel piles, compressive driving stress shall not exceed 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, in pounds per square inch plus the effective prestress value, i.e., $[3(f'_c)^{0.5}$ + prestress] where f'_c is given in psi, $[7.9(f'_c)^{0.5}$ + prestress] where f'_c is given in kPa and compressive stresses shall not exceed 85 percent of the compressive strength minus the effective prestress value, i.e., ($0.85\ f'_c$ - prestress).	
For timber piles, the compressive driving stress shall not exceed 3.6 ksi (25 MPa).	
During pile driving operations, the Contractor shall use the approved system. Any change in the driving system will only be considered after the Contractor has submitted revised pile driving equipment data to the Engineer. The Contractor will be notified of the acceptance or rejection of the driving system changes within 2 working 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.	

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Approval of pile driving equipment shall not relieve the Contractor of responsibility to drive piles, free of damage, to the required ultimate pile capacity and, if specified, the minimum penetration, shown in the contract documents.	
4.1.1 Hammers	4.1.1. HAMMERS
4.1.1.1 General	C4.1.1.1 General
Piles shall be be driven with a drop, an air, a diesel a hydraulic hammer conforming to these specifications. Pile driving hammers shall be of the size needed to develop the energy required to drive the piles at a blow count that does not exceed 10 blows per inch (25 mm) at the required ultimate pile capacity.	The intent is to select the size of hammer at normal operating condition to be sufficient. Contractor may be asked to drive to a higher blow count by the Engineer to penetrate an unforeseen thin dense layer or minor obstruction. Jetting or drilling may be preferred means to penetrate a dense layer as discussed in Articles 4.1.2.6., 4.2.1.2 and 4.2.1.3. Overdriving will often damage the pile and/or hammer.
4.1.1.2 Drop Hammers	C4.1.1.2 Drop Hammers
Drop hammers shall not be used for concrete piles or for piles whose required ultimate pile capacity exceeds 60 tons (55 tonnes).	
When drop hammers are permitted, the ram shall have a weight not less than 1.0 ton (0.9 tonnes) and the height of drop shall not exceed 12 feet (3.7 meters). In no case shall the ram weight of drop hammers be less than the combined weight of helmet and pile. All drop hammers shall be equipped with hammer guides and a helmet to ensure concentric impact.	Lighter drop weights might be insufficient to spool the crane winch.
4.1.1.3 Air Hammers	C4.1.1.3 Air Hammers
If a dynamic formula is used to establish the required blow count, the weight of the striking parts of air hammers used shall not be less than one-third the weight of pile and drive cap, and in no case shall the striking part have a weight less than 1.4 tons (1.25 tonnes). If a wave equation analysis is used to establish the required blow count and driving	Smaller ram weight hammers can be used for special applications.

Specification	Commentary
stresses, this limitation on ram weight does not apply. The plant and equipment furnished for air hammers shall have sufficient capacity to maintain, under working conditions, the pressure at the hammer specified by the Manufacturer. The hose connecting the compressor with the hammer shall be at least the minimum size recommended by the Manufacturer. Hammer performance shall be evaluated at the end of driving by measuring blows per minute and comparing with the Manufacturer's recommendations.	
4.1.1.4 Diesel Hammers	C4.1.1.4 Diesel Hammers
Some open-end (single acting) diesel hammers are equipped with a device to measure impact velocity at all times during pile driving operations. If this device is not available the stroke shall be obtained by measuring the speed of operation either manually or with a device that makes the measurement automatically.	Either impact velocity or stroke measurement is required and should be recorded. Jump Sticks to visually measure stroke should not be used for safety reasons.
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. The Contractor shall provide a correlation chart of bounce chamber pressure and potential energy.	It is important to record stroke or bounce chamber pressure with the blow count.
4.1.1.5 Hydraulic Hammers	C4.1.1.5 Hydraulic Hammers
Hydraulic hammers shall be equipped with a system for measurement of ram energy. The system shall be in good working order and the results shall be easily and immediately available to the engineer.	The measurement of impact velocity makes it possible to calculate the kinetic energy of the ram at impact. The measurement device may display either impact velocity or energy. Record this information with the blow count.
4.1.1.6 Vibratory Hammers	C4.1.1.6 Vibratory Hammers
Vibratory or other pile driving methods may be used only when specified in the contract documents	

Specification	Commentary
or in writing by the Engineer. Except when pile lengths have been evaluated from load test piles, the ultimate pile capacity of piles driven with vibratory hammers shall be verified by redriving the first pile driven in each group of 10 piles with an impact hammer of suitable energy to measure the ultimate pile capacity before driving the remaining piles in the group. All piles which rely on point bearing capacity shall be redriven with an impact hammer.	
4.1.1.7 Additional Equipment or Methods	C4.1.1.7 Additional Equipment or Methods
In case the required penetration is not obtained by the use of a hammer complying with the minimum requirements above, the Contractor may be required to provide a hammer of greater energy or, when permitted, resort to supplemental methods such as jetting or predrilling.	
4.1.2 Driving Appurtenances	C4.1.2. DRIVING APPURTENANCES
4.1.2.1 Hammer Cushion	C4.1.2.1 Hammer Cushion
All impact pile driving equipment except drop hammers shall be equipped with a suitable thickness of hammer cushion material to prevent damage to the hammer or pile. Some hammers are designed such that a hammer cushion is not required. These hammers are excluded from this requirement. Hammer cushions, where applicable, shall be made of durable manufactured materials that will retain uniform properties during driving. Wood, wire rope, or asbestos hammer cushions shall not be used. A striker plate shall be placed on the hammer cushion to ensure uniform compression of the cushion material. The hammer cushion shall be replaced by the Contractor before driving is permitted to continue whenever there is a reduction of hammer cushion thickness exceeding 25 percent of the original thickness or, for air hammers, when the reduction in thickness exceeds the Manufacturer's recommendations.	For hammers requiring cushion material, mandatory use of a durable hammer cushion material which will retain uniform properties during driving is necessary to accurately relate blow count to ultimate pile capacity. Non-durable materials which deteriorate during driving cause erratic estimates of ultimate pile capacity and, if allowed to dissolve, result in damage to the pile or driving system.

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4.1.2.2 Helmet

Piles driven with impact hammers shall be fitted with a helmet to distribute the hammer blow uniformly and concentrically to the pile head. The surface of the helmet in contact with the pile shall be plane and smooth and shall be aligned parallel with the hammer base and the pile top. It shall be guided by the leads and not be free-swinging. The helmet shall fit the pile head in such a manner as to maintain concentric alignment of hammer and pile.

For special types of piles, appropriate driving heads, mandrels, or other devices shall be provided so that the piles may be driven without damage.

For timber piles, the least inside helmet or hammer base horizontal dimension shall not exceed the pile head diameter by more than two inches (50 mm). If the timber pile diameter slightly exceeds the least helmet or hammer base dimension, the pile head shall be trimmed to fit the helmet.

C4.1.2.2. Helmet

Pipe piles and Timber piles which are approximately round sections are frequently driven using square helmets. If the helmet dimension is much larger than the pipe diameter, then a centering fixture is required.

The timber top greatest diameter can be slabbed with a chain saw to a reduced effective width to fit the helmet dimension and to a length sufficient for the helmet depth, provided that the slabbed length is above the final cutoff elevation.

4.1.2.3 Pile Cushion

A pile cushion shall protect the heads of concrete piles. The cushion thickness placed on the pile head prior to driving shall be selected by wave equation analysis so that the limiting driving stresses are not exceeded. If the required driving blow count is determined by a dynamic formula the cushion shall have a thickness of at least 4 inches (100mm).

A new pile cushion shall be provided if, during driving, the cushion begins to smoke or excessive compression occurs. The pile cushion dimensions shall be such as to distribute the blow of the hammer uniformly over the entire cross-section of the pile.

Pile cushions shall be protected from the weather, and kept dry prior to use. Pile cushion shall not be soaked in any liquid unless approved by the Engineer. The use of manufactured pile cushion materials in lieu of a wood pile cushion shall be

C4.1.2.3 Pile Cushion

Wood pile cushions may become overly compressed and hard after about 1500 hammer blows. If the hammer energy is relatively low, the cushion can last even longer. In easy driving conditions it is possible to drive more than one pile with a cushion.

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evaluated on a case by case basis. A used pile cushion in good condition shall be used for restrike tests.	A cushion with less than 50 blows is generally not suitable for restrike tests.
4.1.2.4 Leads	C4.1.2.4 Leads
Pile driving leads that align the pile and the hammer in proper positions throughout the driving operation shall be used. Leads shall be constructed in a manner that affords freedom of movement of the hammer while maintaining alignment of the hammer and the pile to ensure concentric impact for each blow. The leads shall be so designed as to permit proper alignment of battered piles when applicable. Leads may be either fixed or swinging type. Swinging leads, when used, shall be fitted with a pile gate at the bottom of the leads. The leads shall be adequately embedded in the ground or the pile constrained in a structural frame such as a template to maintain alignment.	In the case of batter piles, a horizontal brace may be required between the crane and the leads.
4.1.2.5 Followers	C4.1.2.5 Followers
Followers shall be used only when approved in writing by the Engineer or when specified in the contract documents. For concrete piles, a pile cushion shall be used at the pile top and suitability of the follower shall be checked by wave equation analysis to verify the blow count, driving stresses and the ultimate pile capacity. For steel or timber piles, if a wave equation analysis is not performed the follower shall have an impedance between 50% and 200% of the pile impedance. The follower and pile shall be maintained in proper alignment during driving. The follower shall be of such material and dimensions to permit the piles to be driven to the blow count determined to be necessary.	The pile driven with a follower should be checked with a wave equation and selected piles with either a static test, or dynamic tests on the pile and / or on the follower. This eliminates the necessity of driving a longer full length test pile in each bent or footing. The longer pile will have higher than normal tension stresses, probably different blow counts, and adds significant cost to the project because longer leads and bigger equipment is required to drive that pile. Impedance is the product of elastic modulus times cross sectional area divided by material wavespeed (wavespeed is typically 16,800 ft/sec, 5120 m/sec for steel or 12,500 ft/sec, 3800 m/sec for concrete or timber). The final position of the pile can be verified by checking the position and inclination of the follower at the end of driving.

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4.1.2.6 Jetting

Jetting shall be permitted only if specified in the contract documents or approved in writing by the Engineer.

The Contractor shall determine the number of jets, and the volume and pressure of water at the jet nozzles necessary to freely erode the material adjacent to the pile.

The Contractor shall control and dispose of all jet water in a manner satisfactory to the Engineer, or as specified in the contract documents. If jetting is specified or approved by the Engineer and is performed according to the specifications or as approved by the Engineer, the Contractor will not be responsible for any damage to the site caused by jetting operations. If jetting is used for the Contractor's convenience, the Contractor shall be responsible for all damages to the site caused by jetting operations.

Unless otherwise indicated by the Engineer or the contract documents, jet pipes shall be removed prior to or when the pile tip is 5 feet (1500 mm) above the minimum or final tip elevation and the pile shall then be driven without jetting to the final tip elevation or to the required ultimate pile capacity with an impact hammer. If the required ultimate pile capacity is not reached at the final tip elevation, the pile may be allowed to setup and then the required ultimate pile capacity will be determined by restriking the pile.

4.2 Preparation for Driving

4.2.1 Site Work

4.2.1.1 Excavation

If practical, piles shall not be driven until after the excavation is complete. Any material forced up between the piles shall be removed to the correct

Commentary

C4.1.2.6 Jetting

Jetting is the use of water and air to facilitate pile penetration by displacing the soil.

Predrilling can also be used to facilitate the penetration of the pile. The specification of predrilling is given in Article 4.2.1.2

C4.2 Preparation for Driving

C4.2.1 SITE WORK

C4.2.1.1. Excavation

In some cases such as high water table, it may be necessary to drive the piles before excavating. Also, in the case where the footings are closely

Specification	Commentary
elevation before concrete for the foundation is placed. Unless otherwise approved by the Engineer, do not drive piles at bridge ends until roadway embankments are placed.	spaced it may not be possible to move the piling rig around in the site. In these cases, it is common to use a follower to drive the piles to final grade before excavating for the pile cap. Alternatively, a longer pile can also be driven
4.2.1.2 Predrilling to Facilitate Driving	C4.2.1.2. Predrilling to Facilitate Driving
When required by the contract documents, the Contractor shall predrill holes of a size specified, at pile locations, and to the depths shown in the contract documents or approved in writing by the Engineer. Any void space remaining around the pile after completion of driving shall be filled with sand or other approved material. The use of spuds shall not be permitted in lieu of predrilling, unless specified in the contract documents or approved in writing by the Engineer. Material resulting from drilling holes shall be disposed of as approved by the Engineer.	Predrilling is a process where a hole is drilled with a continuous flight auger or a wet rotary bit to remove some soil or loosen the strata. Predrilling is usually used in the case where driving the pile will displace the upper soil enough to push adjoining piles out of the proper position or limit vibration in the upper layers. Predrilled holes shall be smaller than the diameter or diagonal of the pile cross-section and sufficient to allow penetration of the pile to the specified elevation. If subsurface obstructions are encountered, the hole diameter may be increased to the least dimension that is adequate for pile installation or to avoid obstructions. Jetting can also be used to facilitate driving. Jetting is specified in Article 4.1.2.6
4.2.1.3 Predrilled Holes in Compacted Fill	C4.2.1.3 Predrilled Holes in Compacted Fill
If required by the contract documents, piles to be driven through compacted fill of a depth greater than 5 feet (1500 mm) shall be driven in holes predrilled to natural ground. After driving the pile, the space around the pile shall be filled to the ground surface with sand or other approved material. Material resulting from predrilling the holes shall be disposed of as approved by the Engineer.	The predrilled hole should have a diameter not more than the greatest dimension of the pile cross-section plus 6 inches (150 mm).
4.2.2 Preparation of Piling	C4.2.2. PREPARATION OF PILING
4.2.2.1 Pile Heads	C4.2.2.1 Pile Heads
For steel and timber piling, the pile heads shall be	The goal of a well prepared pile head is to

Specification	Commentary
cut and maintained square with the longitudinal axis of the pile. Precast concrete pile heads shall be flat, smooth and perpendicular to the longitudinal axis of the pile to prevent eccentric impacts from the helmet. Prestressing strands shall be cut off below the surface of the end of the pile. The pile head shall be chamfered on all sides.	provide uniform contact and thereby reduce the potential of pile top damage. Pile top distortions should be removed prior to assessing blow count acceptance for the driving criterion. Prestressed concrete piles may also be chamfered along their length.
4.2.2.1 Collars	C4.2.2.1 Collars
When timber piles are required to be driven to more than 100 tons (90 tonnes) ultimate pile capacity or when driving conditions otherwise require it, collars, bands, or other devices shall be provided to protect piles against splitting and brooming.	
4.2.2.2 Pile Shoes and End Plates	C4.2.2.2 Pile Shoes and End Plates
Pile shoes shall be used when specified by the Engineer or in the contract documents to protect all types of piles when hard driving or obstructions are expected. Steel pile shoes shall be fabricated from cast steel conforming to ASTM A148 (90/60) End plates are used on closed end pipe piles. They shall be made of A36 steel or better. The diameter and thickness shall be specified by the Engineer. When shoes are required by soil conditions, the tips of timber piles shall conform to the approved steel shoes to ensure a firm uniform contact and prevent local stress concentrations in the timber.	Pile shoes are sometimes called pile tips or points. Shoes are sometimes specified when not needed; to save cost, do not use shoes unless necessary. A pile driving acceptance criterion should be developed that will prevent damage to the pile toe. Steel piles driven into soft rock may not require toe protection. When hard rock, sloping rock, or obstructions are expected, the pile toe should be protected with cast steel shoes. Pile shoes used at the option of the Contractor shall be of a type approved by the Engineer.
4.3 Driving	C4.3 Driving
Unless approved by the Engineer, piles shall be driven to the required ultimate pile capacity, or the required ultimate pile capacity and minimum tip elevation, if specified, or the specified tip elevation The ultimate pile capacity is usually confirmed by	A minimum pile penetration should only be specified if needed to insure that uplift, lateral stability, depth to resist downdrag, depth to resist scour, and depth for structural lateral resistance are met for the strength or extreme event limit state. Where blow count or dynamic methods are used to evaluate if the required ultimate pile

Specification	Commentary
achieving the specified blow count which is the number of hammer blows required to cause one foot (300 mm) or one inch (25 mm) of penetration. The blow count shall always be measured, either during initial driving or by re-driving with a warm hammer after a wait period, as determined by the Engineer. For diesel hammers the stroke shall be recorded. Either energy or impact velocity shall be recorded for hydraulic hammers. If water jets are used in connection with the driving, the ultimate pile capacity shall be determined from the results of driving after the jets have been withdrawn. The procedure used in driving the piles shall not subject them to excessive and undue abuse producing crushing and spalling of the concrete, injurious splitting, splintering and brooming of the wood, or excessive deformation of the steel.	capacity has been achieved, a minimum pile penetration should not be used. Minimum pile tip elevations may also be required for the extreme event and service limit states. (For example, a normally consolidated layer of cohesive soil below the pile tips might settle under the pile loads causing an undesirable vertical deflection.) There are cases where piles are driven to a specified depth. Usually this is the case in soils that show a large amount of slowly developing setup and sufficient time is not available to verify the setup by re-striking a pile. The required blow count is determined either by a static load test, dynamic testing or wave equation analysis. Observation and recording of the penetration per blow or blow count is usually required for quality control. The blow count is the number of hammer blows required to cause one foot (300 mm) or one inch (25 mm) of penetration. Sometimes in easy driving, usually at the beginning of driving a pile, the penetration may be so large that it is recorded as feet (meters) per blow. There may be a few cases of very easy driving in soft soils with large setup where measuring blow count may not be necessary. However, in almost all cases the driving record (record of blow count per unit penetration for the entire driving of a pile) is important if questions arise at some time after completion of driving. The hammer can be warmed up by striking a previously driven pile at least 20 hammer blows. Jetting is discussed in more detail in Article 4.1.2.6.
4.3.1 Heaved Piles	C4.3.1 Heaved Piles
If pile heave is observed, level readings referenced to a fixed datum shall be taken by the Engineer on all piles immediately after installation and periodically thereafter as adjacent piles are driven to determine the pile heave range. If during the driving process for adjacent piles, piles shall be re-driven: • If they heave more than ½ inch (13 mm) and end	

Specification	Commentary
bearing is dominant. • If they heave more than 1-½ inches (38 mm) and shaft friction is dominant. If pile heave is detected for pipe or shell piles which have been filled with concrete, the piles shall be redriven to original position after the concrete has obtained sufficient strength and a proper hammer-pile cushion system, satisfactory to the Engineer, is used. The Contractor shall be paid for all work performed in conjunction with redriving piles due to pile heave, provided the initial driving was done in accordance with the specified installation sequence.	
4.3.2 Obstructions	C4.3.2 Obstructions
If piles encounter unforeseeable, isolated obstructions, The Contractor shall be paid for the cost of obstruction removal and for all remedial design or construction measures caused by the obstruction.	Removal would apply only if obstruction is near ground surface.
4.3.3 Installation Sequence	C4.3.3 Installation Sequence
The order of installing 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.	
4.3.4 Practical Refusal	C4.3.4 Practical Refusal
The selection of a practical refusal blow count limit is difficult because it can depend on the site soil profile, the pile type, and possibly hammer manufacturer limitations to prevent hammer damage. In no case shall driving continue for more than 3 inches (75 mm) at practical refusal driving conditions.	In cases where the driving is easy until near the end of driving, a higher blow count may sometimes be satisfactory, but if a high blow count is required over a large percentage of the depth, even 10 blows per inch may be too large. Blow counts greater than 10 blows per inch should be used with care, particularly with concrete or timber piles. In the case of hard rock, the driving criterion should be based on a blows per inch (25 mm) criterion and address limiting the blows following

Specification	Commentary
	an abrupt refusal to prevent damage. Typically, an example limiting driving criterion is 5 blows per 0.5 inch (12 mm). Refer to section 4.2.2.2 for Pile Shoes.
4.3.5 Limiting Driving Stresses	C4.3.5 LIMITING DRIVING STRESSES
Unless specified otherwise in the contract documents or by the Engineer the stresses induced during driving shall not exceed the limits set forth in section 4.1.	
4.3.6 Driving of Probe Piles	C4.3.6 DRIVING OF PROBE PILES
When required in the contract documents, probe piles shall be furnished to the lengths specified and driven at the locations and to the elevations, ultimate pile capacities or blow counts directed by the Engineer before other piles are ordered. All piles shall be driven with approved impact hammers unless specifically stated otherwise in the contract documents. The same type and size hammer shall be used on the production piles. The approval of driving equipment shall conform to the requirements of these Specifications. Unless otherwise approved by the Engineer, the Contractor shall excavate the ground at each probe pile to the elevation of the bottom of the footing before the pile is driven. (See Article 4.2.1.1 and Commentary) Probe piles shall be driven at locations selected by the Engineer or as shown in the contract documents to explore possible subsurface variations.	In the context used here probe piles are those driven to determine the required pile length at various locations on the site. In some parts of the country they are known as indicator piles or test piles. The use of probe piles is particularly common when concrete piles are used. In general, the specified length of probe piles will be greater than the estimated length of production piles in order to explore the variation of soil conditions. Probe piles that do not attain the hammer blow count or required dynamic test predicted ultimate pile capacity at the specified depth may be allowed to "set up" for a waiting period as determined by the Engineer before being redriven. Suggested waiting periods can be found in Commentary Section 4.4.3. When possible, the hammer shall be warmed up before redriving begins by applying at least 20 blows to another pile. If the specified ultimate pile capacity is not attained on redriving, the Engineer may direct the Contractor to drive a portion or all of the remaining probe pile length and repeat the setup-redrive procedure. When ordered by the Engineer, probe piles driven to plan grade and not having the required ultimate pile capacity shall be spliced and driven until the required bearing is obtained.
4.3.7 Accuracy of Driving	C4.3.7. ACCURACY OF DRIVING

Specification	Commentary
Piles shall be driven with a variation of not more than ¼ inch per foot (1:50) from the vertical or not more than 1/2 inch per foot (1:25) from the batter shown in the contract documents. After driving, the pile head shall be within 6 inches (150 mm) of plan locations for all piles capped below final grade. No pile shall be nearer than 4 inches (100 mm) from any edge of the cap. Any increase in pile cap dimensions or reinforcing caused by out-of-position piles shall be at the Contractor's expense.	The amount that a pile can be out of position may be determined by the structural engineer. Tight tolerances of 3 inches or less are not practical. While the Contractor should make every effort to install piles at the planned location and at the planned batter, deviations in actual accuracy obtained may occur due to many reasons including obstructions. To avoid otherwise needless increases in costs, tight specifications in plan location should be specified only when absolutely necessary.
4.4 Determination of Ultimate Pile Capacity	C4.4 Determination of ultimate pile capacity
4.4.1 General	C4.4.1 GENERAL
The ultimate capacity of the piles will be determined by the Engineer using the method specified in the contract documents.	The required ultimate pile capacity is a function of the specified load evaluation method (when comparing various capacity determination methods, higher LRFD resistance factors or lower global safety factors for the more reliable methods like static testing result in more useable load per pile or fewer piles per project and thus cost savings). Consideration should be given to the potential for change in ultimate pile capacity after the end of driving. The effect of soil relaxation or setup should be considered in the determination of ultimate pile capacity for soils that are likely to be subject to these phenomena. For example, if setup is present, the pile can be driven to a lesser criterion and lesser capacity and then following a wait period to allow for gain due to setup, confirm the ultimate pile capacity by a retest (static or dynamic).
4.4.2 Static Load Tests	C4.4.2 STATIC LOAD TEST

Specification

Axial compression load tests shall be performed by procedures set forth in ASTM D 1143 using the quick load compression test method, except that the test shall be taken to plunging failure or one and one half times the required ultimate pile capacity or the structural resistance of the pile or the load specified in the contract documents whichever occurs first and that a load cell and spherical bearing plate shall be used. Testing equipment and measuring systems shall conform to ASTM D 1143. The equipment shall be supplied by the entity specified in the contract documents. The Engineer or the testing laboratory shall perform the test.

The Contractor shall submit detailed contract documents of the proposed loading apparatus, prepared by a licensed professional engineer, to the Engineer for approval. The submittal shall include calibrations for the hydraulic jack, load cell, and pressure gage conducted within 30 days prior to mobilization to the jobsite. When the approved method requires the use of tension (anchor) piles that will later be used as permanent piles in the work, such tension piles shall be of the same type and size as the production piles and shall be driven in the location of permanent piles when feasible.

While performing the load test, the Contractor shall provide safety equipment and employ adequate safety procedures. Adequate support for the load test plates, jack, and ancillary devices shall be provided to prevent them from falling in the event of a release of load due to hydraulic failure, test pile failure, or other cause.

The minimum waiting period, as specified in the contract documents, shall be observed between the driving of either the test pile or anchor piles and the beginning of the load test.

The method of defining failure of the static load test shall be as defined in the contract documents or by the Engineer.

Piles are sometimes tested in tension according to ASTM D 3689 or laterally according to D 3966.

Commentary

Piles tested to failure of the soil provide valuable additional information. A static test pile that has been load tested and fails due to soil failure can be used as a production pile. Actually, the pile will usually gain axial resistance as a result of a test to failure.

The practice varies widely across the country regarding who supplies the testing equipment, measuring systems and jack. The requirements should be stated in the contract documents.

If the method of failure is not defined, the following method is commonly used. Failure is defined to occur when the pile head displacement is

$$S_f = S + (0.15 + 0.008D) \qquad (4.4.2\text{-}1)$$

in Customary US Units

or

$$S_f = S + (4 + 0.008D) \qquad (4.4.2\text{-}2)$$

in SI Units

Where:

S_f = settlement at the defined ultimate pile capacity in inches (mm)

D = pile diameter or width in inches (mm)

S = elastic deformation in inches (mm) of total pile length at the defined nominal resistance assuming end bearing pile only

For piles greater than 24 inches (610 mm) in diameter or width b (inch or mm), and length L (inch or mm), the failure load can be defined as a gross settlement exceeding five percent of the pile diameter:

$$S_f = PL/AE + b/30$$

Reaction piles if used and if driven in production pile locations should be reseated by redrive if the test is a compression test.

The pile's ultimate pile capacity may increase (soil setup) or decrease (relaxation) after the end

Specification	Commentary
	of driving. Therefore, it is essential that static load testing be performed after equilibrium conditions in the soil are re-established. Static load tests performed before equilibrium conditions have re-established will underestimate the long term pile ultimate pile capacity in soil setup conditions and overestimate the long term ultimate pile capacity in relaxation cases. For piles driven in clays, into weathered shale, or in sandy silts and sands, specifications should require a delay period to elapse between driving and load testing of 2 weeks, 7 days, or 5 to 7 days respectively. Due to jack ram friction, loads indicated by a jack pressure gauge are commonly 10% to 20% higher than the actual load imposed on the pile. When static load tests are used to control production pile driving, the time required to analyze the load test results and establish driving criterion should be specified so that the delay time to the Contractor is clearly identified.
4.4.3 Dynamic Testing	C4.4.3 DYNAMIC TESTING
Dynamic testing shall be conducted in accordance with ASTM D4945. The Contractor shall prepare for the required instrument attachment as directed by the Engineer. The Contractor shall drive the pile as directed by the Engineer. If directed by the Engineer, the Contractor shall reduce the driving energy transmitted to the pile by using additional cushion or reducing the energy output of the hammer in order to maintain acceptable stresses in the piles. If non-axial driving is indicated by dynamic measurements, the Contractor shall immediately realign the driving system. If the required ultimate pile capacity is not achieved at the end of driving, the Contractor shall restrike the dynamic test pile following a waiting period specified in the contract documents or as directed by the Engineer. The dynamic testing instruments are then reattached, the pile is redriven and the dynamic test is repeated. The hammer shall be warmed up before restrike begins. The maximum penetration required during restrike shall be 3 inches	Dynamic Testing is often called "High Strain Dynamic Pile Testing" and requires impacting the pile with the pile driving hammer or a large drop weight and measuring force and velocity in the pile with pile analyzer instruments. The Contractor should attach the instruments to the pile after the pile is placed in the leads. Dynamic Testing estimates the ultimate pile capacity at the time of testing and as a minimum generally requires a signal matching analysis of the data However, dynamic testing can also evaluate the reliability of wave equation analyses for driveability by measuring pile stresses during driving and performance of the hammer in transferring energy to the pile. Because the ultimate pile capacity of a pile may change substantially during and after pile driving, waiting after driving for additional testing may be beneficial for a safe and economical pile foundation. If possible, the dynamic test should be performed as a restrike test if the Engineer anticipates significant time dependent increases in

Specification	Commentary
(75 mm) or the maximum total number of hammer blows required will be 20, whichever occurs first.	nominal strength called setup, or reductions called relaxation. When high blow counts are anticipated during restrike, it is important that the largest possible energy be applied for the very earliest blows. It is desirable to adjust the hammer energy so that the blow count be between 2 and 10 blows per inch (25 mm). Ultimate pile capacity may be overpredicted at blow counts below 2 blows per inch (25 mm). Ultimate pile capacity may be underpredicted at blow counts above 10 blows per inch (25 mm). About 20 blows are usually required to warm up the hammer. If a previously driven pile is not available to strike for warming up the hammer, the Contractor may choose to use something else such as timber pads on the ground. When dynamic tests are specified on production piles, the first pile driven in each foundation area is often tested. The restrike time and frequency should be based on the time dependent strength change characteristics of the soil. The following minimum restrike durations are often used: Soil Type — Time Delay Until Restrike Cleans Sands — 1 Day Silty Sands — 2 Days Sandy Silts — 3-5 Days Silts and Clays — 7-14 Days* Shales — 7 Days * - Longer times sometimes required. Specifying too short of a restrike time for friction piles in fine grained soils may result in pile length overruns. Testing personnel should have attained an appropriate level of expertise on the PDCA offered examination for providers of dynamic testing services. The time necessary to analyze the dynamic test results and provide the test results to the Contractor once testing is completed should be stated in the specifications. The time required for the Engineer to review the test results and provide driving criterion should be specified in the specifications, but should not exceed 3 working

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days.

4.4.4 Rapid Load Test

A specialty testing subcontractor shall be engaged that is experienced in rapid load test for instrumenting, conducting and preparing reports of the test. The specialty subcontractor shall provide a plan with testing procedures to the Engineer for approval. The Contractor shall assist the specialty testing subcontractor as necessary during all aspects of the rapid load test

The specialty subcontractor shall provide a rapid load test apparatus capable of applying a sufficiently large force pulse to produce a significant net residual displacement to assure achieving the required ultimate pile capacity.

The top of the pile shall be a smooth and level surface perpendicular to the central longitudinal axis of the pile appropriate for the application of the force pulse.

The applied force pulse duration of typically 0.1 seconds shall exceed 6 times the pile's natural period; this limits concrete pile lengths to 105 ft (32 m) and steel pile lengths to 130 ft (40 m) for typical analysis methods. Above that pile length either the pulse duration shall be extended or extra instrumentation along the pile length shall be used with the segmental analysis method.

C4.4.4 RAPID LOAD TEST

"Rapid load test" should not be confused with a "quick static test". Rapid load test is a dynamic test typically lasting only 0.1 seconds, and the ultimate pile capacity is estimated from the test after elimination of all dynamic components.

A standard for rapid load test is under consideration by ASTM. A submittal of specific procedures and specialty testing subcontractor should be required.

The rapid load test can be applied in axial compression or laterally. The applied force pulse is measured by a load cell, and the resulting displacement is measured by a displacement transducer or multiple accelerometers.

Various analytical methods are available to estimate ultimate pile capacity from the rapid load test. Studies (NCHRP 21-08) suggest "rate factors" should be applied to further reduce the estimated ultimate pile capacity; reductions are larger for finer grained soils. Time dependent soil strength changes should be considered when selecting the date of testing.

Strain instrumentation may also be installed in the pile to determine side shear and base resistance during the test. If strain instrumentation is specified, a minimum of 30 days notice shall be given to the pile contractor and specialty contractor before test pile construction to allow for instrumentation procurement and installation at the casting yard.

4.4.5 Wave Equation Analysis

When specified in the contract documents the Engineer, using a wave equation analysis, shall determine the driving criterion necessary to reach the required ultimate pile capacity. Soil and pile properties to be used in this analysis shall be as shown in the contract documents or as determined by the Engineer. The Contractor shall supply the Engineer the necessary information on his proposed

C4.4.5 WAVE EQUATION ANALYSIS

A wave equation analysis is sometimes used to establish a driving criterion in preparation for performing a static or a dynamic test. The wave equation is also useful to evaluate if driving stresses are acceptable for the proposed hammer.

Specification	Commentary
driving equipment to perform the wave equation analysis.	
4.4.5 Dynamic Formula	C4.4.5 DYNAMIC FORMULA
When using a dynamic formula, the particular formula shall be specified in the contract documents. A dynamic formula shall not be used if the required ultimate pile capacity is more than 250 tons. Formulae are applicable only when: the head of the pile is not broomed, crushed, or otherwise damaged, a follower is not used	Several different dynamic formulae are available. Two of them are given below. The dynamic formula that is to be used should be specified by the designer. Dynamic formulae were empirically developed from data and procedures of 50 to 100 years ago when driving equipment and pile sizes were more modest than today's installations. Use of dynamic formulae has been in general decline for several decades as most engineers realize the database supporting this method is of questionable relevance and that superior methods are now available to assess ultimate pile capacity. For larger or more important projects, higher loads should be verified by more accurate methods. Modified Gates Empirical Formula. Customary US Units $P = 1.75 E^{0.5} \log (10N_b) - 100$ (4.4.5-1) SI Units $P = 7.0 E^{0.5} \log (10N_b) - 550$ (4.4.5-2) Where: P = ultimate pile capacity in kips (kN) E = hammer's potential energy per blow in foot-pounds (Joules). If the manufacturer's rating is used rather than the potential energy from ram weight times stroke, then the result may be unconservative. N_b = the blow count in blows per inch (25 mm) ENGINEERING NEWS FORMULA – ULTIMATE

Specification	Commentary
	PILE CAPACITY VERSION Customary US Units P = 4.8 E/(s + 0.1) (4.4.5-3) SI Units P = 0.4 E/(s + 2.5) (4.4.5-4) Where: P = ultimate pile capacity in kips (kN) E = hammer's potential energy per blow in kip-foot (kJ). If the manufacturer's rating is used rather than the potential energy from ram weight times stroke, then the result may be unconservative. s = set per blow in inches (mm) It should be noted that the traditional version of the Engineering News formula is written for determining design load with a factor of safety of 6.0. If the factor of safety is removed the formula predicts the ultimate pile capacity, although statistical analysis shows the result should be reduced by an additional factor of 0.4 to achieve best average correlation. Both Gates and ENR formula (which includes the 0.4 reduction factor) as referenced above have been "calibrated" to give the average ultimate pile capacity.
4.5 Splicing of Piles Where splices are unavoidable for steel or concrete piles, their number, locations and details shall be subject to approval of the Engineer.	C4.5 Splicing of Piles
4.5.1 Steel Piles	C4.5.1 Steel Piles

Specification	Commentary
Full-length piles shall be used where practicable. If splicing is permitted, the method of splicing shall be according to AWS D1.1 or as approved by the Engineer. The arc method of welding shall be preferred when splicing steel piles. Only certified welders shall perform welding. Mechanical splices may also be used.	The recommended detail for welded pipe splices during installation is AWS D1.1 : B-U4a. Mechanical splices that are not welded are for compression piles only.
4.5.2 Concrete Piles	C4.5.2 CONCRETE PILES
Full-length piles shall be used where practical. If splicing is permitted, concrete pile splice details shall conform to the contract documents, or as approved by the Engineer. Mechanical splices including drive-fit splices may also be used.	Drive-fit mechanical splices are for compression piles only. There are mechanical splices which are designed for tension.
4.5.3 Timber Piles	C4.5.3 TIMBER PILES
Timber piles shall not be spliced unless specified in the contract documents or in writing by the Engineer.	
4.6 Defective Piles	C4.6 Defective Piles
Manipulation of piles to force them into proper position, considered by the Engineer to be excessive, will not be permitted. Any pile damaged by reason of internal defects or by improper driving shall be corrected by one of the following methods approved by the Engineer for the pile in question: • The pile is withdrawn if practicable and replaced by a new and, if necessary, longer pile. • One or more replacement piles are ` driven adjacent to the defective pile. A pile driven below the specified butt elevation	The Engineer's determination may be influenced by the pile size and material and the soil conditions.

Specification	Commentary
shall be corrected by one of the following methods approved by the Engineer for the pile in question. • The pile is spliced or built up as otherwise provided herein • A sufficient portion of the footing is extended down to properly embed the pile. A pile driven out of its proper location, fixed by the contract documents or by the Engineer, shall be corrected by one of the following methods approved by the Engineer for the pile in question: • One or more replacement piles are driven next to the out of position piles. • The footing is extended laterally to incorporate the out of location pile Additional reinforcement is added. Cost for remediating defective piles should rest with the party at fault.	If piles are driven below cutoff elevation, build-ups are generally required. The concrete at the top of the pile should be cut away, leaving the reinforcing steel exposed for a length of 40 bar diameters. The final cut of the concrete should be perpendicular to the axis of the pile. Reinforcement similar to that used in the pile should be securely fastened to the projecting steel and the necessary formwork shall be placed, care being taken to prevent leakage along the pile. The concrete should be of not less than the quality used in the pile. Just prior to placing concrete, the top of the pile should be thoroughly flushed with water, allowed to dry, and then covered with a thin coating of neat cement, mortar, or other suitable bonding material. The forms should remain in place not less than seven days and should then be carefully removed and the entire exposed surface of the pile finished as previously specified.
4.7 Pile Cut-Off	C4.7 Pile Cut-Off
4.7.1 General All piles shall be cut off to a true plane at the elevations required and anchored to the structure as shown in the contract documents. All cut-off lengths of piling shall remain the property of the Contractor and shall be properly disposed of.	C4.7.1 GENERAL
4.7.2 Timber Piles Timber piles shall be cut to the elevations shown on the contract documents. The length of pile above the elevation of cut-off shall be sufficient to permit the complete removal of all material injured by driving.	C4.7.3 TIMBER PILES

Specification	Commentary
Immediately after making final cut-off on treated timber foundation piles, the cut area shall be given a liberal application of copper napthenate until visible evidence of further penetration has ceased. The copper naphthenate solution must have minimum 2.0% copper metal. Treated marine piling exposed to the weather shall be capped with a permanently fixed coating such as epoxy or with conical or other caps attached to the piles. Piling supporting timber structures where the piles are cut off, but not concrete capped, shall be treated with a liberal application of copper naphthenate until visible evidence of further penetration has ceased. In addition a layer of saturated building felt or fiberglass cloth which overlaps the side of the pile at least two inches, shall be securely fastened and completely covered with 20 gauge thick galvanized metal or aluminum sheet. All cuts, injuries and holes as would occur from removal of nails or spikes that would penetrate the treating zone as well as bolt holes for connections shall be treated by applying coal-tar roof cement meeting ASTM D 5643. Cut-off pile ends shall be properly disposed of in compliance with local, state and federal regulations.	Disposal in land fills is the normal requirement. Cut-off pile ends may not be burned in open fires, in stoves or fireplaces. Treated wood may be burned in commercial or industrial incinerators or boilers. Burning should be in compliance with local, state and federal regulations.
4.8 Measurement and Payment	C4.8 MEASUREMENT AND PAYMENT
4.8.1 Method of Measurement	C4.8.1 Method of Measurement
4.8.1.1 Piles	C4.8.1.1. PILES
4.8.1.1.1 Piles Furnished	C4.8.1.1.1. Piles Furnished
The quantities of pile to be paid for shall be the sum of the lengths in feet (meters). The piles shall be of the types and lengths indicated in the contract documents or ordered in writing by the Engineer,	

Specification	Commentary
furnished in compliance with the material requirements of these specifications and stockpiled or~~,~~ installed in good condition at the site of the work by the Contractor, and accepted by the Engineer. When extensions of piles are necessary, the extension length ordered in writing by the Engineer shall be included in the total length of piling furnished.	
4.8.1.1.2 Piles Driven The quantities of driven piles of each type to be paid for shall be the quantities of acceptable piles of each type that were driven.	C4.8.1.1.2 Piles Driven
4.8.1.2 Pile Splices and Pile Shoes When pile splices or protective pile tip shoes are shown in the contract documents, the number of pile splices or shoes measured for payment shall be those shown in the contract documents, or ordered in writing by the Engineer, and actually installed on piles used in the work. No payment shall be made for splices or shoes used at the option of the Contractor. When not shown in the contract documents, pile splices or shoes ordered by the Engineer shall be paid for as extra work.	C4.8.1.2. PILE SPLICES and PILE SHOES
4.8.1.3 Load Tests The quantity of load tests to be paid for shall be the number of load tests completed. Test piles for load tests, whether incorporated into the permanent structure or not, shall be measured as provided for test piles furnished and test piles driven and shall be paid for under the appropriate pay item.	C4.8.1.3 LOAD TESTS Not all load tests yield the predicted results. A properly performed test that fails to yield the predicted results is still a successfully completed test and should be paid for as such.
4.8.2 Basis of Payment	C4.8.2 Basis of Payment Two methods of payment, unit pricing or lump sum pricing, are typically used.

Specification | Commentary

4.8.2.1 Unit Pricing

The quantities, determined as provided, shall be paid for at the contract documents price per unit of measurement, respectively, for each of the general pay items listed below, for each size and type of pile shown in the contract documents.

Pay Item	Pay Unit
Mobilization & Demobilization	Lump Sum
Piles Furnished	LF or Each
Piles Driven	LF or Each
Test Piles, Furnished	LF or Each
Test Piles, Driven	LF or Each
Static Pile Load Test	Each
Dynamic Pile Test during driving	Each
Dynamic Pile Test during restrike	Each
Rapid Load Test	Each
Splices	Each
Pile Shoes	Each
Predrilling or preaugering	LF or Each
Jetting	LF or Each
Cutoff (over 5 ft lengths only)	Each
Spudding (Punching)	Per Hr.
Delays, Downtime or out-of-sequence moves	Per Hr.

Payment for Piles Furnished includes full compensation for all costs involved in the furnishing and delivery of all piles to the project site.

Payment for Piles Driven includes full compensation for all costs involved in the actual driving and for all costs for which compensation is not provided for under other specified pay items involved with the furnishing of labor, equipment, and materials used to install the piles.

Payment for static or dynamic tests includes full compensation for providing labor, equipment, and materials needed to perform the load tests as specified. If the dynamic pile test requires substantial repositioning or idle time of the crane, additional compensation for out-of-sequence moves shall be paid at the bid rate for this item).

C4.8.2.1 Unit Pricing

Mobilization and Demobilization is generally considered to be for one each, and grouped as a single priced item (Lump Sum). For jobs which could have more than one mobilization & demobilization, such as sequenced jobs, it would be appropriate to use the term “Each”, rather than “Lump Sum”.

It also may be appropriate to separate mobilization and demobilization prices for major subcontractors.

Piles whose price per foot changes with length (such as timber piles) do not lend themselves well to unit price contracts. In the event that piles exceed the bid length by 5 ft (1.5 m) or more, an adjustment in unit prices is probably appropriate. Longer piles may cause transportation problems.

Dynamic pile tests to evaluate hammer performance and driving stresses during driving require a brief interruption to the driving of the Test Pile to attach the sensors to the pile.

Dynamic pile tests to evaluate capacity often are made during restrike to take advantage of the common setup or guard against relaxation. If the

Specification	Commentary
Payment for rapid load tests includes full compensation for all costs of materials, personnel and equipment to perform the test as specified.	restrike is for a pile nearby the current crane location, the interruption will be brief.
Payment for pile splices or shoes includes full compensation for all costs involved with furnishing all materials and performing the work involved with attaching or installing splices or shoes to the piles.	Some pay items (such as pile shoes) can be included in the "furnished pile" pay item, if established prior to bid.
Payment for predrilling, jetting or spudding includes full compensation for providing labor, equipment, and materials needed to perform these pile installation aid procedures.	Spudding is generally driving or dropping a steel member to create a pathway through obstructions.
Payment for cutoff includes full compensation for providing labor and equipment needed to adapt the pile top to the specified cutoff elevation and to properly dispose of the removed material.	If cutoff lengths become excessive, additional costs will be incurred.
Payment for delays or downtime includes full compensation for unproductive time caused by the owner, his agent, or his subcontractor.	Delays or downtime caused by the owner, his agent(s) or subcontractor(s), and out-of-sequence moves will be charged at the rate established in the pay item.
4.8.2.2 Lump Sum Pricing	C4.8.2.2 Lump Sum Pricing
Payment shall be a lump sum for the piles as specified in the contract documents. There shall be no change in contract price if the specified pile does not drive to the plan-tip elevation due to refusal caused by soil strata or obstructions. The bid form shall include the following items to accommodate changes in pile quantities. If the Engineer determines that pile lengths or number of piles are to be changed, the lump sum shall be adjusted as follows:	This method of bidding may be useful in design build or for rapid construction situations. Many private sector projects are bid on lump sum basis The specification may call for predrilling or jetting to facilitate penetration.
Increase (Add) — Pay Unit Longer piles, up to 5-ft (1.5 m): LF Longer piles, 6 to 10-ft (1.5 to 3 m): LF Decrease (Deduct) Shorter piles, up to 5-ft (1.5 m): LF Shorter piles, 6 to 10-ft (1.5 to 3 m): LF Increase (Add) Added piles: Each Decrease (Deduct)	The unit prices apply to piles before manufacture. Pile lengths are determined by the Engineer. No credit is due for any length of properly installed pile left above cutoff elevation. In the case of piles that are normally supplied in stock increments (normally 5 ft [1.5 m]), the unit price is to be applied to the entire length of pile ordered. (e.g. a 31' pile may be paid as 35' due to order lengths.)

Specification	Commentary
Deleted piles Each Added or deleted piles apply only up to 10 percent of the original quantity. Changes greater than this shall require a change in the unit prices. Pile length changes of more than 10 ft shall require renegotiation of the contract. If changes occur during driving, unanticipated work shall be paid as an extra.	