

EXPECTED IMPLEMENTATION JANUARY 2016

455 STRUCTURES FOUNDATIONS. **(REV 8-5-15) (FA 8-18-15) (1-16)**

SUBARTICLE 455-5.2 is deleted and the following substituted:

455-5.2 Pile Hammers: All equipment is subject to satisfactory field performance. Use a variable energy hammer to drive concrete piles. Hammers will be rated based on the theoretical energy of the ram at impact. Supply driving equipment which provides the required resistance at a blow count ranging from 3 blows per inch (36 blows per foot) to 10 blows per inch (120 blows per foot) at the end of initial drive, unless approved otherwise by the Engineer after satisfactory field trial. Ensure the hammer is capable of driving to a resistance equal to at least 2.0 times the factored design load plus the scour and down drag resistance shown in the Contract Documents, without overstressing the piling in compression or tension and without reaching or exceeding 20 blows per inch. When the Engineer determines the stroke height or bounce chamber pressure readings do not adequately determine the energy of the hammer, provide and maintain a device to measure the velocity of the ram at impact. Determine the actual hammer energy in the field so that it is consistent with the hammer energy used for each bearing capacity determination. When requested, furnish to the Engineer all technical specifications and operating instructions related to hammer equipment.

455-5.2.1 Air/steam: Variable energy air/steam hammers shall be capable of providing at least two ram stroke lengths. The short ram stroke length shall be approximately half of the full stroke for hammers with strokes up to 4 feet and no more than 2 feet for hammers with maximum strokes lengths over 4 feet. Operate and maintain air/steam hammers within the manufacturer's specified ranges. Use a plant and equipment for steam and air hammers with sufficient capacity to maintain, under working conditions, the hammer, volume and pressure specified by the manufacturer. Equip the plant and equipment with accurate pressure gauges which are easily accessible to the Engineer. The Engineer will not accept final bearing on piles the Contractor drives with air/steam hammers unless the Contractor operates the hammers within 10% of the manufacturer's rated speed in blows per minute, unless otherwise authorized by the Engineer.

455-5.2.2 Diesel: Variable energy diesel hammers shall have at least three fuel settings that will produce reduced strokes. Operate and maintain diesel hammers within the manufacturer's specified ranges. Determine the rated energy of diesel hammers using measured ram stroke length multiplied by the weight of the ram for open end hammers and by methods recommended by the manufacturer for closed end hammers.

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. Also provide and maintain in working order for the Engineer's use an approved device to automatically determine and display ram stroke for open-end diesel hammers.

Equip closed-end (double acting) diesel hammers with a bounce chamber pressure gauge, in good working order, mounted near ground level so the Engineer can easily read. Also, provide the Engineer with a chart, calibrated to actual hammer performance within 30 days prior to initial use, equating bounce chamber pressure to either equivalent energy or stroke for the closed-end diesel hammer to be used.

455-5.2.3 Hydraulic: Variable energy hydraulic hammers shall have at least three hydraulic control settings that provide for predictable energy or equivalent ram stroke. The

EXPECTED IMPLEMENTATION JANUARY 2016

D shortest stroke shall be a maximum of 2 feet for the driving of concrete piles. The remaining strokes shall include full stroke and approximately halfway between minimum and maximum stroke.

Supply hammer instrumentation with electronic read out, and control unit that allows the operator to read and adjust the hammer energy or equivalent ram stroke. When pressure measuring equipment is required to determine hammer energy, calibrate the pressure measuring equipment before use.

455-5.2.4 Vibratory: Vibratory hammers of sufficient capacity (force and amplitude) may be used to drive steel sheet piles and, with approval of the Engineer, to drive steel bearing piles a sufficient distance to get the impact hammer on the pile (to stick the pile). The Engineer will determine the allowable depth of driving using the vibratory hammer based on site conditions. However, in all cases, use a power impact hammer for the last 15 feet or more of the final driving of steel bearing piles for bearing determinations after all piles in the bent/pier have been driven with a vibratory hammer. Do not use vibrating hammers to install concrete piles, or to install support or reaction piles for a load test.

R ARTICLE 455-5.8 is deleted and the following substituted:

455-5.8 Penetration Requirements: Measure the penetration of piles from the elevation of natural ground, scour elevation shown in the Plans, or the bottom of excavation, whichever is lower. When the Contract Documents show a minimum pile tip elevation or a minimum depth of penetration, drive the tip of the pile to this minimum elevation or this minimum penetration depth. In all such cases, the Engineer will accept the bearing of a pile only if the Contractor achieves the required bearing when the tip of the pile is at or below the specified minimum tip elevation or depth of penetration and below the bottom of the preformed or predrilled pile hole.

A When the Plans do not show a minimum depth of penetration, scour elevation, or minimum tip elevation, ensure that the required penetration is at least 10 feet into firm bearing material or at least 20 feet into soft material unless otherwise permitted by the Engineer. If a scour elevation is shown in the Plans, achieve these penetrations below the scour elevation. The Engineer may accept a penetration between 15 feet and 20 feet when there is an accumulation of five consecutive feet or more of firm bearing material. Firm bearing material is any material offering a driving resistance greater than or equal to 30 tons per square foot of gross pile area as determined by the Dynamic Load Testing (455-5.11.4). Soft material is any material offering less than these resistances. The gross pile area is the actual pile tip cross-sectional area for solid concrete piles, the product of the width and depth for H piles, and the area within the outside perimeter for pipe piles and voided concrete piles.

F Do not drive piles beyond practical refusal. To meet the requirements in this Subarticle, provide penetration aids, such as jetting or preformed pile holes, when piles cannot be driven to the required penetration without reaching practical refusal.

T If the Contractor encounters unforeseeable, isolated obstructions that the Contractor cannot practically penetrate by driving, jetting, or preformed pile holes, and the Contractor must remove the pile to obtain the required pile penetration, the Department will pay the costs for such removal as Unforeseeable Work.

EXPECTED IMPLEMENTATION JANUARY 2016

SUBARTICLE 455-5.10.1 is deleted and the following substituted:

455-5.10.1 General: Drive piles to provide the bearing required for carrying the loads shown in the Plans. For all types of bearing piles, consider the driving resistance as determined by the methods described herein sufficient for carrying the specified loads as the minimum bearing which is accepted for any type of piles. Determine pile bearing using the method described herein or as shown in the Plans.

For foundations requiring 100% dynamic testing of production piles, the Engineer may accept a driven pile when the pile has achieved minimum penetration and the minimum required bearing obtained for 6 inches of consecutive driving, or when the minimum penetration is achieved, driving has reached practical refusal in firm material and the bearing capacity is obtained in all the refusal blows.

For foundations not requiring 100% dynamic testing of production piles, the Engineer may accept a driven pile when the pile has achieved minimum penetration, the blow count is generally the same or increasing and the minimum required bearing capacity obtained for 24 inches of consecutive driving. At his discretion, the Engineer may also accept a driven pile when the minimum penetration is achieved and driving has reached practical refusal in firm material.

SUBARTICLE 455-5.10.2 is deleted and the following substituted:

455-5.10.2 Bearing Criteria: For foundations requiring 100% dynamic testing, the Engineer will determine the bearing of all piles using the data received from dynamic load testing equipment utilizing internally or externally mounted sensors according to the methods described in 455-5.11.1.

For foundations not requiring 100% dynamic testing, the Engineer will determine the number of blows required to provide the required bearing according to the methods described herein. Determine the pile bearing by computing the penetration per blow with less than 1/4 inches rebound averaged through 12 inches each of penetration. When it is considered necessary by the Engineer, determine the average penetration per blow by averaging the penetration per blow through the last 10 to 20 blows of the hammer.

SUBARTICLE 455-5.10.3 is deleted and the following substituted:

455-5.10.3 Practical Refusal: Practical refusal is defined as 20 blows per inch or less than one inch penetration, with the hammer operating at the highest setting determined by the Engineer and less than 1/4 inches rebound per blow. Stop driving as soon as the Engineer determines that the pile has reached practical refusal.

SUBARTICLE 455-5.11.1 is deleted and the following substituted:

455-5.11.1 General: Dynamic load tests using internal gauges or an externally mounted instrument system and signal matching analyses will be used to determine pile capacity for all structures or projects unless otherwise shown on the Plans. When necessary, the Engineer

EXPECTED IMPLEMENTATION JANUARY 2016

D may require static load tests to confirm pile capacities. When the Contract Documents do not include items for static load tests, the Engineer will consider all required static load testing Unforeseeable Work. Notify the Engineer two working days prior to placement of piles within the template and at least one working day prior to driving piles. Do not drive piles without the presence of the Engineer.

If the internally mounted system fails to communicate properly with the receiving system, allow the Engineer sufficient time to mobilize back-up equipment for performing dynamic load testing.

R SUBARTICLE 455-5.11.2 is deleted and the following substituted:

455-5.11.2 Wave Equation:

(a) General: Use Wave Equation Analysis for Piles (WEAP) programs to evaluate the suitability of the proposed driving system (including the hammer, follower, capblock and pile cushions) as well as to estimate the driving resistance, in blows per 12 inches or blows per inch, to achieve the pile bearing requirements and to evaluate pile driving stresses.

The Engineer may modify the scour resistance shown in the Plans if the dynamic load test is used to determine the actual soil resistance through the scour zone. Also, the Engineer may make modifications in scour resistance when the Contractor proposes drilling and/or jetting to reduce the soil resistance in the scour zone.

A Use Wave Equation Analyses to show the hammer meets the requirements described in 455-5.2.

(b) Required Equipment For Driving: Hammer approval is solely based on satisfactory field trial including dynamic load test results and Wave Equation Analysis. Supply a hammer system that meets the requirements described in the specifications based on the above analysis. Obtain approval from the Engineer for the pile driving system based on satisfactory field performance.

In the event piles require different hammer sizes, the Contractor may elect to drive with more than one size hammer or with a variable energy hammer, provided the hammer is properly sized and cushioned, will not damage the pile, and will develop the required resistance.

F (c) Maximum Allowed Pile Stresses:

(1) General: The maximum allowed driving stresses for concrete, steel, and timber piles are given below. In the event Wave Equation analyses show that the hammer will overstress the pile, modify the driving system or method of operation as required to prevent overstressing the pile. In such cases provide additional cushioning or make other appropriate agreed upon changes. For penetration of weak soils by concrete piles, use thick cushions and/or reduced stroke to control tension stresses during driving.

T (2) Concrete Piles: Use the wave equation to evaluate the proposed pile cushioning. Use the following equations to determine the maximum allowed pile stresses as predicted by the wave equation, and measured during driving when driving prestressed concrete piling:

EXPECTED IMPLEMENTATION JANUARY 2016

$$s_{apc} = 0.7 f'_c - 0.75 f_{pe} \quad (1)$$

$$s_{apt} = 6.5 (f'_c)^{0.5} + 1.05 f_{pe} \quad (2a) \text{ for piles less than 50 feet long}$$

$$s_{apt} = 3.25 (f'_c)^{0.5} + 1.05 f_{pe} \quad (2b) \text{ for piles 50 feet long and greater}$$

$$s_{apt} = 500 \quad (2c) \text{ within 20 feet of a mechanical splice}$$

where:

s_{apc} = maximum allowed pile compressive stress, psi

s_{apt} = maximum allowed pile tensile stress, psi

f'_c = specified minimum compressive strength of concrete, psi

f_{pe} = effective prestress (after all losses) at the time of driving, psi, taken as 0.8 times the initial prestress force ($f_{pe} = 0$ for dowel spliced piles).

(3) Steel Piles: Ensure the maximum pile compression and tensile stresses as predicted by the Wave Equation, and/or measured during driving are no greater than 0.9 times the yield strength ($0.9 f_y$) of the steel.

(4) Timber Piles: Ensure the maximum pile compression and tensile stresses as predicted by the wave equation, and/or measured during driving are no greater than 3.6 ksi for Southern Pine and Pacific Coast Douglas Fir and 0.9 of the ultimate parallel to the grain strength for piles of other wood.

SUBARTICLE 455-5.11.7 is deleted and the following substituted:

455-5.11.7 Structures Without Test Piles: For structures without test piles or 100% dynamic testing, the Engineer will dynamically test the first pile(s) in each bent or pier at locations shown in the Plans to determine the blow count criteria for the remaining piles. When locations are not shown in the Plans, allow for dynamic load tests at 5% of the piles at each bent or pier (rounded up to the next whole number). If the Engineer requires additional dynamic load tests for comparison purposes, the Contractor will be paid for an additional dynamic load test as authorized by the Engineer in accordance with 455-11.5.

Allow the Engineer one working day after driving the dynamic load tested piles for the Engineer to complete the signal matching analyses and determine the driving criteria for the subsequent piles in the bent or pier.

SUBARTICLE 455-5.13 is deleted and the following substituted:

455-5.13 Dynamic Load Tests: The Engineer will take dynamic measurements during the driving of piles designated in the Plans or authorized by the Engineer. Install instruments prior to driving and assist the Engineer in monitoring all blows delivered to the pile. All test piles will have dynamic load tests. The Engineer will perform dynamic load tests to evaluate any or all of the following:

EXPECTED IMPLEMENTATION JANUARY 2016

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1. Evaluate suitability of Contractor's driving equipment, including hammer, capblock, pile cushion, and any proposed follower.

2. Determine pile capacity.

3. Determine pile stresses.

4. Determine energy transfer to pile.

5. Determine distribution of soil resistance.

6. Evaluate soil variables including quake and damping.

7. Evaluate hammer-pile-soil system for Wave Equation analyses.

8. Evaluate pile installation problems.

9. Other.

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Either install internal gauges in the piles in accordance with Design Standards, Index No. 20602 or attach instruments (strain transducers to measure force and accelerometers to measure acceleration) with bolts to the pile for dynamic load testing.

Make each pile to be dynamically tested with externally attached instruments available to drill holes for attaching instrumentation and for wave speed measurements. Support the pile with timber blocks placed at appropriate intervals. Ensure that the pile is in a horizontal position and does not contact adjacent piles. Provide a sufficient clear distance at the sides of the pile for drilling the holes. The Engineer will furnish the equipment, materials, and labor necessary for drilling holes and taking the wave speed measurements. If the Engineer directs dynamic load testing, instrumented set-checks or instrumented redrives, provide the Engineer safe access to the top of the piles for drilling the attachment holes. After placing the leads provide the Engineer reasonable means of access to the piles to attach the instruments and for removal of the instruments after completing the pile driving.

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The Engineer will monitor the stresses in the piles with the dynamic test equipment during driving to ensure the Contractor does not exceed the maximum allowed stresses. If necessary, add additional cushioning, replace the cushions, or reduce the hammer stroke to maintain stresses below the maximum allowable. If dynamic test equipment measurements indicate non-axial driving, immediately realign the driving system. If the cushion is compressed to the point that a change in alignment of the hammer will not correct the problem, add cushioning or change the cushion as directed by the Engineer.

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Drive the pile to the required penetration and resistance or as directed by the Engineer. Dynamic load testing of a pile may average up to two hours longer than for driving an uninstrumented pile.

When directed by the Engineer, perform instrumented set-checks or redrives. Do not use a cold diesel hammer for a set-check or redrive unless in the opinion of the Engineer it is impractical to do otherwise. Generally, warm up the hammer by driving another pile or applying at least 20 blows to a previously driven pile or to timber mats placed on the ground.

For steel production piles, the Engineer may accept instrumented set-checks or redrives for the purpose of meeting the requirements for 100% dynamic testing.

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SUBARTICLE 455-7.2 is deleted and the following substituted:

455-7.2 Manufacture: Fabricate piles in accordance with Section 450. When internal gauges will be used for dynamic load testing, supply and install in square prestressed concrete piles in accordance with Design Standards, Index No 20602. Ensure the internal gauges are installed by personnel approved by the manufacturer.

EXPECTED IMPLEMENTATION JANUARY 2016

D

SUBARTICLE 455-11.5 is deleted and the following substituted:

455-11.5 Dynamic Load Tests: Payment will be based on the number of dynamic load tests shown in the Plans, authorized by the Engineer, or required in 455-5.11.7, completed and accepted in accordance with the Contract Documents. No separate payment will be made for dynamic load tests used to evaluate the Contractor's driving equipment. This will generally be done on the first test pile or production pile driven on a project with each combination of proposed hammer and pile size and/or a separate pile to evaluate any proposed followers, or piles driven to evaluate proposed changes in the driving system. No payment will be made for dynamic load tests used to evaluate the integrity of a pre-planned epoxy-bonded dowel splice. Include all costs associated with dynamically testing production piles with epoxy-bonded dowel splices under Pay Item No. 455-34. No payment will be made for dynamic load tests on test piles.

For structures with 100% dynamic testing, the cost of dynamic load tests on production piles is included in the cost of the pile, no separate payment will be made.

For structures without 100% dynamic testing, payment for internal gauges or attaching equipment to each production pile for dynamic load testing prior to initial driving, authorized by the Engineer, will be 20 feet of additional pile. No payment will be made for attaching dynamic testing equipment for set-checks or redrives.

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SUBARTICLE 455-12.5 is deleted and the following substituted:

455-12.5 Dynamic Load Tests:

455-12.5.1 Dynamic Load Tests/ Test Piles: All test piles will require dynamic load tests. Include all costs associated with dynamic load tests in the pay items for test piles.

455-12.5.2 Dynamic Load Tests/ Production Piles: Payment will be full compensation for all labor, equipment, materials, instrumentation and installation required to assist the Engineer in performing this work.

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