402.04—Measurement and Payment.

Sheet piles will be measured in square feet of piles remaining in place and will be paid for at the contract unit price per square foot. The horizontal dimensions will be measured continuously along the outer face of the piling. For steel sheet piles, the horizontal dimension used shall be not more than the sum of the laying widths or driving dimensions of the individual piles.

Payment for temporary sheet piling will be made at the contract unit price per square foot which price shall be full compensation for furnishing, driving and removing the piling.

Payment will be made under:

Pay Item	Pay Unit
Sheet piles (Type)	Square foot
Temporary sheet piling	Square Foot

SECTION 403—BEARING PILES

403.01—Description.

This work shall consist of furnishing, driving, cutting off, and, when required, load-testing piles of the type and dimensions specified on the plans.

403.02—Materials.

(a) **Timber piles** shall conform to the requirements of Section 236.

(b) **Steel piles** shall conform to the requirements of Section 228.

(c) **Steel shells for cast-in-place piles** shall conform to the requirements of Section 228.

(d) **Concrete** shall conform to the requirements of Section 217. Concrete exposed to tidal water shall contain slag or silica fume.

(e) **Reinforcing steel,** Grade 40 or 60, for use in precast or cast-in-place piles, shall conform to the requirements of Section 223.

403.03—Pile Types.

(a) **Timber Piles:**

1. **Storing and handling:** Care shall be taken to avoid breaking the surface of treated piles. Cant hooks, dogs, or pike poles shall not be

used. Cuts or breaks in the surface of treated piles shall be given three brush coats of the preservative used to treat the pile. Preservative shall be poured into bolt holes.

2. **Cutoffs:** The tops of piles shall be cut off at the elevation shown on the plans or as directed by the Engineer. Piles that support timber caps or grillage shall be cut off to conform to the plane of the bottom of the superimposed structure. In general, the length of pile above the elevation of the cutoff shall be sufficient to permit removing material damaged by driving. Piles driven to or near the cutoff elevation shall be trimmed or otherwise freed from splintered or damaged material.

(b) **Precast Concrete Piles:** Precast concrete piles with conventional reinforcement shall be furnished in accordance with the requirements of these specifications. Prestressed concrete piles shall be furnished in accordance with the requirements of Section 405. Piles shall be manufactured to conform to the requirements of Section 404. Class A3 concrete shall be used.

1. **Casting:** Forms shall conform to the requirements of Section 404 and shall be accessible for vibrating, tamping, and consolidating concrete. Care shall be taken to place concrete to produce a satisfactory bond with the reinforcement and avoid segregation of components, honeycomb, or other defects.

   Concrete shall be continuously placed in each pile form and consolidated by vibrating. Forms shall be overfilled, the surplus concrete screeded off, and the top surface finished to a uniform, even texture similar to that produced by forms.

2. **Curing:** As soon as piles have set sufficiently, side forms shall be removed and the piles moist cured for at least 7 days. Piles shall not be driven until the concrete has reached the minimum 28-day compressive strength specified in Section 217. Concrete piles for use in brackish or tidal water or alkali soils shall be moist cured for at least 30 days before use.

3. **Finishing:** As soon as forms are removed, piles shall be pointed with mortar that conforms to the requirements of Section 218. Trestle piles exposed to view shall be finished above the ground line with a Class I finish in accordance with the requirements of Section 404.07(a). Foundation piles, that portion of trestle piles that will be below the ground surface, and piles for use in tidal water or alkali soils shall not be finished except by pointing as specified herein. Piles to be used in tidal water shall be protected in accordance with the requirements of Section 404.03(i).

4. **Storing and handling:** Storing, transporting, and handling shall be performed in a manner to prevent bending stresses, cracking,

spalling, or other damage. The method of handling shall not induce stresses in the reinforcement of more than 12,000 pounds per square inch or a concrete stress of more than 0.4 f'_c, where f'_c is equal to the compressive strength of a control test cylinder at the time of handling. Concrete stress shall be not more than 1,200 pounds per square inch.

Piles shall be supported or picked up only at pickup points shown on the plans or at a greater number of properly spaced pickup points as may be necessary to comply with stress requirements.

5. **Splicing:** Splicing will not be permitted unless deemed necessary by the Engineer. When splicing is permitted, it shall be performed as specified herein. Splicing shall be performed only with the piles in their normal driving position. The final locations of splices shall be below the ground line.

Splices shall be made by providing dowels cast into the upper section of the pile. Dowels shall have a total area of at least 1 1/2 percent of the gross cross-sectional area of the pile and extend at least 30 bar diameters on each side of the splice. At least four dowels shall be used. Dowels shall be bonded into holes drilled or formed into the lower section of the pile. Holes shall be serrated to provide a mechanical bond. At least one dowel hole shall be provided with a bleeder vent near the bottom.

Ends of both sections shall be prepared to ensure that the concrete adjacent to the splice is sound material free from material that would interfere with the action of the bonding agent.

The bonding agent shall be a plasticized cement or other approved compound that can be placed or otherwise forced into the spaces around dowels and between ends of pile sections. The bonding agent shall have a compressive strength equal to that of the concrete and an adhesive strength equal to the shear and tensile strength of the concrete. The agent shall be able to withstand impact and driving stresses and shall have the same resistance as concrete to damaging water and soil conditions. These properties shall be obtained within a time limit consistent with the driving requirements. If compounds require heating, the manufacturer's recommendations shall be followed. The temperature of the concrete and the ambient temperature shall be not less than 50 degrees F at the time the splice is made.

Pile sections shall be held in such a manner that there will be a space of approximately 1/2 inch between the ends to permit free flow of the bonding agent. A splice form extending approximately 18 inches on each side of the splice shall be placed around the ends of the pile sections. The form shall have at least four ports for pouring of the bond-

ing agent and allowing the escape of air. The bonding agent shall be poured simultaneously through two opposing ports. Driving may be resumed after sufficient time has elapsed to permit the bonding agent to develop its required properties.

6. **Build-ups:** When necessary, build-ups shall be made as follows: After driving is completed, the concrete at the end of the pile shall be cut away, leaving the reinforcing steel or strand exposed for a length of 40 diameters. The final cut of the concrete shall be perpendicular to the axis of the pile. Reinforcement similar to that used in the pile shall be securely fastened to the projecting steel, and the necessary forms shall be placed, with care taken to prevent leakage along the pile. The concrete shall be of the same quality as that used in the pile. Just prior to concrete placement, the top of the pile shall be thoroughly wetted and covered with a thin coating of neat cement or other suitable bonding material. Forms shall remain in place at least 7 days and then carefully removed. The exposed surface of the pile shall be finished as specified for precast concrete piles.

(c) **Cast-in-Place Concrete Piles:**

1. **Construction:** Piles shall be cast in previously driven metal shells that shall remain permanently in place. The diameter shown on the plans shall be the nominal diameter of the uppermost section of shell. Shells shall be classified into the following types:

   a. **for driving without mandrels:** Type A, fluted, uniform taper; Type B, straight pipe

   b. **for driving with mandrels:** Type C, corrugated, step taper: when conditions require its use, the lower section may consist of pipe conforming to the requirements for Type B; Type D, corrugated, straight, or uniform taper

   The shell, including the tip, shall be of a design and thickness that are adequate to hold the original shape and prevent distortion of the shell resulting from driving it and any adjacent shell.

   The Contractor shall determine whether self-supporting or mandrel-driven shells will be used and the necessary shell thickness.

   If the steel shells collapse, the Contractor shall increase the shell thickness or furnish prestressed concrete piles as shown on the plans at his own expense.

   Concrete shall be Class A3.

2. **Reinforcement:** Reinforcement shall consist of a cage of No. 6 longitudinal bars tied with a 0.24-inch or greater spiral bar having a 6-

inch pitch. If the thickness of the shell wall is less than 0.12 inch, six longitudinal bars shall be used. If the thickness of the shell wall is 0.12 inch or greater, four longitudinal bars shall be used. The depth to which the reinforcement is extended below the top of the shell at the cutoff elevation shall be at least 1/3 the length of the shell, 10 feet below the elevation of material providing firm lateral support, or, in any case, 10 feet, except for shells less than 15 feet in length. The reinforcement shall not extend closer than 5 feet to the tip. If the thickness of the shell is 0.188 inch or more, the length of longitudinal reinforcement required herein may be reduced to 5 feet below the top of the shell provided any splices occurring within the length are made sufficient to develop the full strength of the pile shell. In all cases, the longitudinal reinforcement shall extend 15 inches above the top of the shell and shall be provided with standard hooks.

3. **Inspection of metal shells:** The Contractor shall have available a light suitable for the inspection of each shell throughout its entire length. Improperly driven, broken, or otherwise defective shells shall be removed and replaced. No shell will be accepted whose diameter at any section is altered by more than 25 percent.

4. **Placing concrete:** Concrete shall not be placed until all driving within a radius of 15 feet is completed unless this is not practicable, in which case driving shall be discontinued until the concrete in the last cast pile has been in place at least 7 days.

   Concrete shall be placed continuously and consolidated by vibrating. Accumulations of water in shells shall be removed before concrete is placed.

(d) **Steel Piles or Steel Pile Shells:**

1. **Cutoffs:** The use of cutoffs will be permitted as extensions to driven or undriven piles, or as complete piles in themselves, provided the length of each cutoff is equal to or greater than the length of the extension or full-length pile required.

2. **Welding:** Splices, points, or point reinforcement shall be welded in accordance with the requirements of Section 407.04(a) except that welder certification will be required only for the particular welds performed as required for H-pile splices, built-up point reinforcement, and shell splices that require the full strength of the shell to be developed.

3. **Splicing:** For locations requiring pile lengths of 40 feet or less, one splice per pile will be permitted. For lengths over 40 feet, up to and including 80 feet, two splices will be permitted. For lengths exceeding 80 feet, one splice per 40 feet will be permitted. Sections less

than 10 feet in length shall not be spliced except as a final (top) section of the pile.

Splices on steel H-piles shall be made by means of butt joints with full penetration welds. Piles spliced in a vertical position shall receive a single-bevel groove weld. Piles spliced in a horizontal position shall receive a single vee or V-groove weld. Abutting ends of piles to be spliced shall be properly prepared for welding, including removing damaged material and squaring the two ends. The two sections of pile shall be securely clamped in proper position and alignment prior to welding.

Each splice between abutting pile shell sections shall be welded or adequately connected by mechanical means approved by the Engineer to give a complete seal and shall be of adequate strength to withstand handling, driving, and design stresses. If the diameters of abutting shell sections to be spliced are not the same, the shells shall be telescoped at least 6 inches at splices. When splices are required to develop the full strength of the shell, the top of the outside shell at the splice shall be scalloped to provide sufficient fillet welds. Sections of shell less than 5 feet in length shall not be spliced to another shell except as a build-up after driving is completed. More than one splice shall not be used within any 15-foot length of completed pile.

4. **Protection by painting:** When steel piles or steel pile shells extend above the ground or water surface, they shall be protected by System A as specified in Section 411. Protection shall extend from an elevation 2 feet below the lowest ground or water surface up to a level 2 inches into the concrete in which their tops are to be embedded.

5. **Variations in length:** Where steel H-piles are driven in limestone areas or where extreme variations in length are likely to be encountered, the following procedure shall be used: Wherever a pile has been driven to a depth requiring a length exceeding by 30 percent or 15 feet, whichever is greater, the length determined in accordance with the requirements of Section 403.04 or as indicated by the borings or piles already driven, the pile shall not be driven further until all other piles in the pier, abutment, or retaining wall have been driven or until a sufficient number has been driven to indicate clearly the trend of lengths. The Engineer will then determine the method to be used.

403.04—Determination of Pile Lengths.

For cast-in-place piles, the Contractor shall determine the type, thickness, and driving criteria of the steel pile shell. Lengths shall be determined by performing driving tests.

A driving test shall be performed by driving a pile of the same type and size as that required or proposed for the specific structure at each location shown on the plans or otherwise approved by the Engineer.

Driving test piles that are not to be load tested or dynamically analyzed shall be driven their full length or until practical or absolute refusal is reached.

403.05—Order List.

The Contractor shall submit to the Engineer for approval an itemized list for precast concrete and timber piles prior to placing the order with the supplier. The list shall include the lengths required for each pile location and the corresponding full or partial lengths of piles to be ordered.

Driving tests, dynamic pile tests, loading tests, and refined wave equation analyses shall be completed for a substructure element prior to submission of an order list for the substructure element.

403.06—Procedures.

(a) **Suitability of Foundation:** If there is any indication that piles cannot be driven in accordance with the requirements of these specifications or if the foundation material appears to be capable of supporting footings without piles, the foundation shall be explored in accordance with the requirements of Section 401.03(b) and the results of the exploration submitted to the Engineer for review to determine whether piles will be omitted and the substructure adjusted to give adequate bearing on a firm foundation.

(b) **Preparation for Driving:** Piles shall not be driven until excavation is complete. Material forced up between piles shall be removed to correct the foundation elevation before concrete for the foundation is placed.

Piles for supporting abutments on very soft or swampy original ground or on newly placed fill shall not be driven until the approach embankment, including any fill in front of the abutment, has been completed to the elevation of the top of the earthwork and compacted as specified in Section 303.

Piles shall not be driven in proximity to uncured concrete.

(c) **Protection During Driving:** Heads of concrete piles shall be protected by caps of an approved design, with a suitable cushion equivalent to at least 4 inches of plywood or a sufficient amount as site-specific conditions dictate, next to the pile head and fitting into a casing that supports a shock block. During driving, the cap block and cushion shall be changed if compressed more than 50 percent or as required to prevent damage to the pile. When the area of the head of any timber pile is greater than that of the

face of the hammer, a suitable cap shall be provided to distribute the blow of the hammer throughout the cross section of the pile.

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

For steel piles, heads shall be cut squarely and a driving cap provided to hold the axis of the pile in line with the axis of the hammer.

Timber piles that are not enclosed in concrete shall be protected as specified in Section 418.03(d). Collars, bands, or other devices to protect timber piles against splitting and brooming shall be provided when specified by the Engineer.

Tips for timber piles shall be sharpened. When specified, timber piles shall be provided with steel or cast iron points conforming to the requirements of Section 236.02(b). When points are used, the tips of the piles shall be carefully shaped to secure an even and uniform bearing on the points.

When specified, steel H-piles shall be provided with cast steel points. Points shall be welded as recommended by the manufacturer, but the length of the weld shall be not less than twice the width of the flange.

If during the driving of a precast concrete pile a reduction in blow count indicates that the point of the pile has passed from a harder material into a softer material that offers little or no resistance to penetration, the energy per blow shall be reduced to an amount specified by the Engineer. When firm-bearing material is reached, the energy per blow shall be returned to normal.

Steel piles and steel pile shells shall be painted as specified in Section 403.03(d)4.

(d) **Driving:** The capability of the hammer to drive piles properly will be verified from records of the test piles. If the required penetration is not obtained in the driving test by the use of a hammer complying with the requirements, the Contractor shall provide a heavier hammer or use other approved means at his own expense. The method of driving shall not produce deformed piles. Where it is determined necessary by the Engineer in order to obtain the required tip elevation, design bearing capacity, or minimum penetration, driving shall be supplemented by jetting or preboring. After driving is completed, voids existing as a result of preboring, soil consolidation, or movement shall be filled with dry sand and consolidated to provide adequate lateral pile support. Damaged piles shall be removed and replaced.

1. **Hammers for timber and steel H-piles:** Hammers may be either gravity or power hammers. Striking parts of gravity hammers for driving timber piles shall weigh at least 2,000 pounds and for driving steel piles at least 3,000 pounds. In no case shall the weight of the striking parts of gravity hammers be less than the combined weight of the pile and any device used on the pile head for protection during driving. The hammer fall shall be regulated to avoid damage to piles. The fall shall be not more than 15 feet.

   Power hammers shall be capable of developing at least 7,000 foot-pounds of energy per blow when driving timber piles and at least 15,000 foot-pounds of energy per blow when driving steel piles.

2. **Hammers for concrete piles:** Precast concrete piles or shells for cast-in-place piles shall be driven with a power hammer that shall develop an energy per blow of at least 0.2 foot-pound per pound of the design bearing capacity of the pile being driven. Power hammers shall develop an energy (E) in foot-pounds per blow of at least 1 foot-pound per pound of pile weight (W) for piles weighing up to 25,000 pounds. For piles weighting more than 25,000 pounds, E shall be at least 25,000 + 0.6 (W-25,000). The value of E shall be at least 15,000 foot-pounds per blow.

3. **Leads:** Pile driver leads shall be constructed in a manner that will afford freedom of movement of the hammer and shall be held in position by guys or stiff braces to ensure support of the pile during driving. Except where piles are driven through water, leads shall be of sufficient length so that a follower will not be necessary.

   Inclined leads shall be used in driving battered piles.

4. **Followers:** Followers shall be used only with the written permission of the Engineer. When followers are used, 1 pile from every group of 10 shall be a long pile driven without a follower and shall be used as a test pile to determine the average bearing capacity of the group.

5. **Water jets:** The volume and pressure of water at the jet nozzles shall be sufficient to erode freely the material adjacent to the pile. A pressure of at least 100 pounds per square inch shall be delivered at the nozzles. At least two jet nozzles, having a diameter of at least 3/4 inch, shall be used and placed symmetrically about the circumference of the pile. Before the desired penetration is reached, the jets shall be withdrawn and the piles driven at least 5 feet or to the depth determined by the Engineer to be necessary to secure the final penetration.

6. **Preboring:** The area of each prebored hole shall be approximately 10 percent more than the area of the pile but not more than 20 percent of the area.

(e) **Penetration:** In general, the penetration for any pile shall be at least 10 feet. In soft material, the penetration shall be at least 20 feet. Where piles are driven through fills, they shall penetrate at least 5 feet into undisturbed original ground under the fill. Friction piles, other than steel H-piles, in fills shall be driven through prebored holes extending to the elevation of the original ground.

(f) **Accuracy of Driving:** Piles shall be driven to within the tolerances specified in Table IV-1 for positions at cutoff elevations.

Piles shall not be driven with a variation of more than 1/4 inch per foot from the vertical or batter specified.

Steel and concrete piles shall not be subjected to force in order to place them in correct alignment or a horizontal position. The position of a timber pile that lies within the tolerance allowed for the driven position as specified in Table IV-1 under pile type No. 4, Condition (a) or (b), shall be corrected to the tolerance given for pile type No. 5, Condition (a) or (b), respectively, by the application of horizontal force wherever conditions will permit such corrective work without damage to the pile.

If the distances between the actual and theoretical pile centers or centers of gravity are more than the specified tolerances, the piles will be considered unacceptable unless the Contractor submits a satisfactory working plan showing the corrective work proposed. Such work shall not proceed until the plan has been approved by the Engineer.

The clear distance between the heads of piles and edges of footings shall be at least 6 inches. Additional concrete and reinforcement required to maintain the required minimum clear distance shall be placed only with the prior approval of the Engineer and shall be furnished at the Contractor's expense.

Timber piles driven below the cutoff elevation specified on the plans or by the Engineer or otherwise driven outside the limits for the driven position specified herein shall be withdrawn, and a replacement pile driven in the correct position at the Contractor's expense. Other types of piles driven to below the required elevation may be spliced or built up as otherwise provided for in these specifications.

(g) **Bearing Capacities:** Piles shall be driven to the following capacity:

1. **Steel H-piles** shall be point bearing and shall be driven to practical or absolute refusal. Steel H-piles designated as friction piles shall be driven to a safe bearing capacity of at least 3 tons per inch of nominal size.

2. **Timber piles** shall be driven to a safe bearing capacity of at least 20 tons per pile.

TABLE IV-1
Pile Tolerance Criteria

Pile Type	Condition	Tolerance for Position of Single Group (in)	Center of Gravityfor Pile Group[1]	
			Direction	Tolerance
1. Steel and Concrete	Column supports for bent caps	±3	About long axis of footing	3% of distance between extremes[2] or 1 1/2 in, whichever is greater
2. Steel and Concrete	(a) Footing supports for box culverts	±6		
	(b) Footing supports for column piers	±6	About both major axes	3% of distance between extremes[2] or 1 1/2 in, whichever is greater
	(c) Footing supports for abutments, retaining walls, and piers other than column piers	±6	About long axis of footing	3% of distance between extremes[2] or 1 1/2 in, whichever is greater
3. Timber	Footing supports for box culverts	±9		
4. Timber	(a) Footing supports for column driven through material that will permit correction of position without damage to pile	±9	About both major axes	4 1/2% of distance between extremes[2] or 2 1/4 in, whichever is greater
	(b) Footing supports for abutments, retaining and piers other than column piers driven walls, through material that will permit correction of position without damage to pile	±9	About long axis of footing	4 1/2% of distance between extremes[2] or 2 1/4 in, whichever is greater
5. Timber	(a) Footing supports for column piers driven through material that will not permit correction of position	±6	About both major axes	4 1/2% of distance between extremes[2] or 2 1/4 in, whichever is greater
	(b) Footing supports for abutments, retaining walls, and piers other than column piers driven through material that will not permit correction of position	±6	About long axis of footing	4 1/2% of distance between extremes[2] or 2 1/4 in, whichever is greater
6. Timber	Fender systems and other uses requiring non-load bearing piles as required for proper attachment of wales, bracing, etc. or tying of groups for dolphins			

[1]Piles under a separate footing of individually constructed units shall be considered a separate group. The tolerances expressed as a percentage of "distance between extremes" will be allowed only about the axis for which it is computed.
[2]If the group consists of a single row of piles, the distance shall be measured from the center line of the row to the center line of the footing.

3. **Precast concrete piles and shells for cast-in-place concrete piles** shall be driven to a safe bearing capacity of at least 3 1/2 tons per inch of the nominal diameter or side dimension.

(h) **Disposing of Pile Cutoffs:** Upon completion of pile driving operations for structures on the project, pile cutoffs left in storage, including precast concrete and timber cutoffs, shall become the property of the Contractor and shall be disposed of off the project.

403.07—Determination of Bearing Capacities.

(a) **Loading Tests:** When required, the safe bearing capacities of piles shall be determined in accordance with 72-hour or quick load tests as specified herein.

The loading test shall commence no sooner than 5 days after the pile to be tested has been driven. Telltales consisting of steel rods 1/2 inch in diameter shall be lubricated and inserted in plastic pipe 3/4 inch in inside diameter. Individual sections of telltales shall be joint coupled flush so that each rod is of uniform diameter throughout its length.

Where necessary, the unsupported length of the test pile shall be braced to prevent buckling without influencing the test results.

The clear distance from the reaction frame to the test pile shall be at least 5 times the maximum diameter of the test pile or as approved by the Engineer.

Loading shall be applied through a hydraulic jack with spherical bearings jacked against a platform load. The loading apparatus shall have a capacity of at least that required for the test. If more than one jack is used, the jacks shall have the same piston diameter, be connected to a common manifold and pressure gage, and be operated by a single hydraulic pump.

The method of determining test loads shall be by using a pressure gage or load cell. The pressure gage, hydraulic ram, and hydraulic pump shall be calibrated as a unit to an accuracy of at least 5 percent of the applied load. If a multiple jacking system is used, each jack shall be fitted with a pressure gage in addition to the master gage. Load-measuring devices shall have been calibrated not more than 3 months prior to the loading test and shall be recalibrated when directed by the Engineer.

Loads shall be applied uniformly with no impact. The load cell or pressure gage shall be continuously monitored, and the jacking pressure adjusted to maintain a constant load.

The load shall be applied to a steel test plate of appropriate thickness for the loads involved and of a size not less than the size of the pile butt and

not less than the area covered by the base(s) of the hydraulic jack rams. The plate shall be set in high-strength, quick-setting grout to ensure uniform bearing. Provision shall be made for the telltale rod to extend through the test plate.

Movement of the pile butt and telltale relative to the pile butt shall be measured with dial gages to an accuracy of 0.001 inch. Dial gages shall have a travel of at least 2 inches, and gage blocks shall be provided to record measurements as required. The pile butt shall be measured by dial gages attached to an independently supported frame. Movement shall be measured by a secondary system consisting of a scale, mirror, and piano wire. The scale and mirror shall be attached parallel to the longitudinal axis of the pile. The wire shall be properly tensioned and supported so that it passes within 1 inch of the face of the scale. The scale shall have gradations of 1/100 of an inch.

Supports for dial gage frames and wires shall be more than 7 feet clear of the pile and as far from anchor piles or reaction supports as is practicable. Supports and frames shall be checked by a surveyor's level.

Gages and measuring devices shall be protected from the weather, including direct sunlight. Adequate ventilation shall be provided to prevent fogging or frosting of the gages.

The Contractor shall provide the Engineer reasonable access to and from the site of the test pile. The Contractor shall assist the Engineer in recording load, settlement, and rebound measurements throughout the test and shall furnish complete information on the driving equipment used and the pile driving record.

Other piles of the same type and size that are not load tested shall be driven to the safe bearing capacity of at least that required for the satisfactory load-tested pile(s).

1. **The 72-hour loading test** shall be 200 percent of the design capacity applied in increments of 25 percent of the design capacity. Each load increment shall be maintained until the rate of settlement is not greater than 0.01 inch per hour or until 2 hours have elapsed, whichever occurs first. The test load shall be applied fully and continuously for at least 72 hours and shall produce no measurable settlement during the last 24 hours. After the required holding time, the test load shall be removed in decrements of 25 percent of the total test load with at least 1 hour between decrements.

   Permanent settlement of the pile after completion of the specified loading test shall be not more than 1/4 inch. If the permanent settlement is more than 1/4 inch, the Contractor shall redrive and test load the same pile or drive and test load additional piles until the loading test is satisfactory.

Proven safe bearing capacity for piling from the 72-hour loading test is defined as 1/2 the test load for a satisfactory loading test.

2. **The quick load test** shall be 300 percent of the design capacity applied in increments of 10 percent of the design capacity, with a constant time interval between increments of 5 minutes. Load increments shall be added until continuous jacking is required to maintain the test load or until the specified capacity of the loading apparatus is reached, whichever occurs first. After a 10-minute interval, the full test load shall be removed in four approximately equal decrements with 5 minutes between decrements.

   The Contractor shall record readings of time, load, and settlement for the pile and telltale immediately before and after applying each load increment. When the maximum load has been applied, the Contractor shall record when jacking is stopped. Readings shall be repeated after 5 minutes and again at 10 minutes after jacking has stopped. Readings of time, load, and rebound shall also be recorded after each decrement during load removal and repeated 5 minutes and 10 minutes after the load has been removed.

   The ultimate bearing capacity of a pile tested under an axial compressive load is that load which produces a settlement of the pile head equal to the following:

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

   Where:
   S_f = settlement at failure in inches;
   D = pile diameter or width in inches;
   S = elastic deformation of pile length in inches = P_tL/AE;
   P_t = load on pile in pounds;
   L = length of pile in inches;
   A = area of pile in square inches; and
   E = the modulus of elasticity of the pile [57,000 f'_c for concrete; $29(10^6)$ for steel].

   Proven safe bearing capacity for piling is defined as 1/2 the ultimate bearing capacity obtained and shall be at least the required design capacity. If the proven safe bearing capacity is less than the required design capacity, the Contractor shall redrive and test load the same pile or drive and test load additional piles until the loading test is satisfactory.

(b) **Timber Piles:** If timber piles are not required to be driven to practical refusal or if their safe bearing capacity is not required to be determined by loading tests, their theoretical safe bearing capacity shall be determined by the following formulas:

$$P = \frac{2WH}{S + 0.1} \quad \text{for single-acting steam hammers}$$

$$P = \frac{2H\,(W + Ap)}{S + 0.1} \quad \text{for double-acting steam hammers}$$

$$P = \frac{2\,WH}{S + 1.0} \quad \text{for gravity hammers}$$

$$P = \frac{1.6E}{S + 0.1} \quad \text{for diesel hammers}$$

Where:

P = theoretical safe bearing capacity in pounds;
W = weight in pounds of striking part of hammer;
H = height of fall in feet;
S = average penetration in inches per blow for the last 5 to 10 blows for gravity hammers and the last 10 to 20 blows for power hammers;
A = area of piston in square inches;
p = steam pressure in pounds per square inch at the hammer; and
E = equivalent energy in foot-pounds as determined by a gage attached to the hammer for hammers with enclosed rams or the weight in pounds of the ram multiplied by the length of travel in feet for hammers without enclosed rams. The value of E shall be not more than the manufacturer's rating for developed energy.

These formulas are applicable only when (1) the hammer has a free fall, (2) the head of the pile is not broomed or crushed, (3) the penetration is reasonably quick and uniform, or (4) a follower is not used.

If there is an appreciable bounce, twice the height of the bounce shall be deducted from H to determine its value in the formula.

If the Engineer determines that energy losses attributable to pile rebound exceed the nominal values assumed in these formulas, safe bearing capacity shall be reevaluated by wave equation analysis or substantiated pile formulas that rationally consider energy losses in the cap, pile, and soil.

When water jets are used in connection with driving, the capacity shall be determined by the formulas from the results of driving after the jets have been withdrawn or by application of a test load.

Theoretical safe bearing capacity for piling from the timber pile formulas shall be no less than the required design capacity.

(c) **Bearing Value of Piles:** Bearing values for concrete and steel piles shall be determined by the loading tests specified in (a) herein. In the absence of loading tests, safe-bearing capacities may be determined using a dynamic pile analyzer during pile driving or results of wave equation analysis. In the absence of loading tests, wave equation analysis, or a dynamic pile analyzer, the safe bearing capacity may be approximated by using substantiated pile formulas or the timber pile formulas given in (b) herein. The character of the soil penetrated; conditions of driving; followers; size, length, and weight of the piles; and computed load per pile shall be given due consideration in determining the safe bearing capacity.

Bearing piles shall be driven until the blow count determined to produce the required design capacity has been continuously maintained for 3 feet or to practical or absolute refusal, whichever occurs first. *Practical refusal* is defined as twice the blow count required to produce a safe bearing capacity when maintained for 1 foot. *Absolute refusal* is defined as 4 times the blow count required to produce a safe bearing capacity when maintained for 1 inch.

A pile shall not be driven above the blow count if wave equation analysis indicates that maximum stress levels will be exceeded.

The following are the maximum allowable driving stresses (attributable to hammer impact only):

1. **prestressed concrete piles:**

   a. **compression:** $0.85\ f'_c$ – unit prestress (after losses)

   b. **tension :** $3/f'_c$ + unit prestress (after losses)

2. **steel piles:**

   a. **compression:** $0.9\ F_y$

   b. **tension:** $0.9\ F_y$

At the Contractor's option, piles reaching bearing value with heads above the cutoff grade may be driven to the cutoff grade provided driving is less than practical refusal and no damage to the pile occurs.

When required by the Engineer, a pile shall be restruck with the same hammer and cushion system used for the initial driving. Pile restrike shall be at least 24 hours after initial driving. A cold hammer shall not be used for the restrike. The hammer shall be warmed up prior to restrike by striking at least 20 blows on a pile that is at least 25 feet from the pile to be restruck. The maximum amount of penetration required during restrike shall be 6 inches or the maximum total number of hammer blows required will be 50, whichever occurs first.

403.08—Measurement and Payment.

Piles will be measured in linear feet from the tip (excluding any added pile point) to the head of the pile remaining in place in the completed structure and will be paid for at the contract unit price per linear foot. This price shall include furnishing piles; driving piles; splices; obtaining safe bearing capacity, tip elevation, or minimum penetration; jetting; performing wave equation analysis; disposing of piling cutoffs; concrete and reinforcing steel required for steel shell piles, including reinforcing steel that extends into the structure footing; painting; and waterproofing.

Precast concrete and timber cutoffs will be measured in linear feet of pile excluding that portion of the precast concrete pile the Contractor elects to furnish to facilitate driving. Only precast concrete and timber cutoffs will be paid for. Payment will be limited to the invoice price plus 15 percent, not to exceed the contract unit price per linear foot of pile.

Pile points for timber and steel H-piles will be measured in units of each, complete-in-place, and will be paid for at the contract unit price per each. This price shall include furnishing and attaching to the pile.

Driving tests shown on the plans or required by the Engineer will be measured in linear feet and will be paid for at the contract unit price per linear foot. Piles used in driving tests will be measured from the tip (excluding any added pile point) to the head of the pile. When a pile used in a driving test is incorporated in the completed structure at the required location, no separate measurement of the pile will be made for payment. This price shall include performing the test; furnishing, removing, and disposing of piles; and restoring the pile hole when the pile is not incorporated in the structure.

Driving tests not specified on the plans or required by the Engineer but performed to determine lengths or other required properties will not be measured as driving tests. However, when piles used for the tests are incorporated in the completed structure, they will be measured and paid for the same as other piles of the same type.

Loading tests will be measured in units of each and will be paid for at the contract unit price per each. This price shall include performing the loading test. If a loading test is terminated by the Engineer because of insufficient bearing capacity, the test will be measured for payment. If a loading test is terminated because of malfunction of the Contractor's equipment or other reasons that are the fault of the Contractor, the test will not be measured for payment.

The length of pile driven to the cutoff grade after obtaining required bearing will be measured in linear feet and will be paid for as cutoff.

Preboring fills in accordance with the requirements of Section 403.06(e) will not be measured for separate payment. The cost thereof shall be included in the price for pile.

Pile restrike will be measured in linear feet of pile from the tip, excluding any added pile point, to the head of the pile remaining in the structure. Payment will be made at the contract unit price for the driving test for the same size and type pile less the invoice price per foot for the pile. This price shall include the equipment and driving effort required for the restrike.

Jetting not shown on the plans and specified by the Engineer in accordance with the requirements of Section 403.06(d) will be measured in linear feet and will be paid for per linear foot at 30 percent of the contract unit price per linear foot for the particular size and type of pile for which the jetting was ordered. This price shall include disposing of surplus material and erosion, siltation, and water quality controls required as a result of the jetting operations.

Preboring not shown on the plans and specified by the Engineer in accordance with the requirements of Section 403.06(d) will be measured in linear feet for the particular size and type of pile for which the preboring was ordered in accordance with the requirements of Section 104.03 and Section 109.05. This price shall include disposing of surplus material, and for erosion and siltation controls when required as a result of the preboring operations.

Preboring shown on the plans will be measured in linear feet for the particular size and type of pile for which preboring was specified. This price shall include disposing of surplus material erosion and siltation controls when required as a result of the preboring operations.

Payment will be made under:

Pay Item	Pay Unit
Pile (Type and size)	Linear foot
Pile point for (Size and type) pile	Each
Driving test for (Size and type) pile	Linear foot
Loading test for (Size and type) pile	Each
Preboring (Size and Type) pile	Linear foot

SECTION 404—HYDRAULIC CEMENT CONCRETE OPERATIONS

404.01—Description.

This work shall consist of furnishing and placing hydraulic cement concrete in accordance with these specifications and in reasonably close conformity with the dimensions, lines, and grades shown on the plans or as established by the Engineer.