SECTION 514
DRIVEN FOUNDATION PILES

514.01. DESCRIPTION.

This work consists of furnishing and driving piles of the type and dimensions designated in the contract documents, including cutting off or building up foundation piles when required. This work also includes providing test piles and performing loading tests, and furnishing and placing reinforcing steel and concrete in concrete filled steel shell and concrete filled pipe piles. Piling shall conform to and be installed according to these specifications, at the location, and to the elevation, penetration, and bearing capacity shown in the contract documents or as directed by the Engineer.

Piles are designated as steel H-piles, concrete filled steel shell piles, concrete filled pipe piles, precast concrete piles, prestressed concrete piles, or timber piles. Pile load tests are designated as static or dynamic.

Unless test piles are required, furnish the piles according to the dimensions shown in the contract documents. When test piles are required, the piling lengths shown on the plans are for estimating purposes only and actual length to be furnished for production piles shall be determined by the Engineer after the test piles have been driven. The lengths given in the order list provided by the Engineer shall include only the lengths anticipated for use in the completed structure. Increase the lengths shown or ordered to provide for heading and such additional length as may be necessary to suit the method of operation without added compensation.

514.02. MATERIALS.

(a) **General.** Material shall conform to the following Sections and Subsections:

Structural Concrete	509
Reinforcing Steel for Structures	511
Structural Steel	724
Steel Castings	725.03
Timber Piles	728
Paint	730
Timber Preservative and Treatment	731

(b) **Steel Piles.** Provide structural steel conforming to AASHTO M 270, Grade 36 (250) for steel piling.

When steel piles or steel pile shells extend above the ground surface or water surface and are left exposed in the finished structure (i.e., pile bents), prime each pile as shown on the Plans before driving. If the required remaining coat surface is accessible, remaining coats may be applied after driving. Recoat splices; recoat damaged areas above the water or ground surface. Comply with paint curing requirements before driving.

(c) **Cast-in-Place Concrete Piles.** Provide Class AA concrete for cast-in-place concrete piles cast in steel shells.

Provide steel shells for cast-in-place concrete piles of the thickness shown in the contract documents or thicker. Furnish shells of greater thickness if necessary to provide sufficient strength and rigidity to permit driving with the equipment selected for use without damage, and to prevent distortion caused by soil pressures or the driving of adjacent piles. Use watertight shells to exclude water during the placing of concrete. Alternate designs for shells must be approved before any driving is done. The shells may be cylindrical or tapered, step-tapered, or a combination of either, with cylindrical sections.

(d) **Precast Concrete Piles.** Provide Class AA concrete for precast concrete piles and Class P concrete for precast prestressed concrete piles.

514.03. EQUIPMENT.

(a) **Approval of Pile Driving Equipment.** Furnish pile driving equipment of such size that the permanent piles can be driven with reasonable effort to the required depths without damage.

The Engineer will evaluate the suitability of the equipment and will accept or reject the driving system within 14 calendar days of receipt of the pile and driving equipment information. Approval of pile driving equipment will be based on a wave equation analysis when:

- dynamic load testing is required, or
- ultimate pile capacities exceeding 270 tons (2400kN) , or
- precast or prestressed concrete piles are used, or
- specified in the contract documents.

When the wave equation analysis is not used, approval of the pile driving equipment will be based on minimum hammer energy in Table 514-2. Approval of a pile hammer relative to driving stress damage does not relieve the Contractor of responsibility to drive piles, free of damage, to the bearing and tip elevation shown in the contract documents.

Approval of the pile driving system is specific to the equipment submitted. If the proposed equipment is modified or replaced, resubmit the revised data for approval before using. The revised driving system will be accepted or rejected within 14 calendar days of receipt of the revised pile, equipment, and wave equation analysis (if required) information. The time required for submission, review, and approval of a revised pile driving system shall not constitute the basis for a contract time extension. Use the approved equipment during pile driving operations.

1. *Equipment submittal.* Submit the following pile driving equipment information at least 30 calendar days before driving piles. When either dynamic load testing or wave equation analysis are required by the contract documents, submit a wave equation analysis performed by a pile specialty consultant meeting the requirements of this section. If both dynamic load testing and wave equation analysis are not specified by the contract documents, the Engineer will perform the wave equation analysis, when needed.

   1.1 *General.* Project and structure identification, pile driving contractor or subcontractor, and auxiliary methods of installation such as jetting or preboring and the type and use of the equipment.

1.2 *Hammer.* Manufacturer, model, type, serial number, rated energy (_____ at _____ length of stroke), and modifications. Include charts required in Subsection 514.03(b)1 for diesel hammers.

1.3 *Capblock (hammer cushion).* Material, thickness, area, modulus of elasticity (E), and coefficient of restitution (e).

1.4 *Pile cap.* Helmet weight, bonnet weight, anvil block weight, and drivehead weight.

1.5 *Pile cushion.* Cushion material, thickness, area, modulus of elasticity (E), and coefficient of restitution (e).

1.6 *Pile.* Pile type, length (in leads), weight/foot (mass/meter) , wall thickness, taper, cross-sectional area, ultimate pile capacity, description of splice, and tip treatment description.

Capblock, pile cap, and pile cushion information are required for wave equation analysis only.

2. *Wave equation.* Use the hammer efficiencies shown in Table 514-1 for wave equation analyses.

Table 514-1
Hammer Efficiencies

Hammer Type	Efficiency (%)
Diesel Hammer	72
Air or Steam Hammer (Single Acting)	67
Air or Steam Hammer (Double Acting)	50
Gravity Hammer	95

The required number of hammer blows indicated by the wave equation at the ultimate pile capacity shall be between 3 and 10 per inch (25mm) . In addition, the pile stresses resulting from the wave equation analysis shall not exceed the values at which pile damage isimpending. The point of impending damage is defined for steel, concrete, and timber piles as follows.

- *Steel piles.* Limit the compressive driving stress to 90% of the yield stress of the pile material.

- *Concrete piles.* Limit both the tensile and compressive driving stresses as follows:

$$TS \leq EPV + a\,f'_c \quad (TS \leq EPV + a\,f'_c)$$
$$CS \leq 85f'_c - EPV \quad (CS \leq 0.85f'_c - EPV)$$

where: TS= Tensile Driving Stress, psi (MPa)

CS= Compressive Driving Stress, psi (MPa)

EPV= Effective prestress value, psi (MPa)

f'_c= Specified 28-day compressive strength of concrete, psi (MPa)

a = 3.0 (0.25)

- *Timber piles.* Limit the compressive driving stress to three times the allowable static design strength.

3. *Minimum hammer energy.* The energy of the driving equipment submitted for approval, as rated by the manufacturer, shall be sufficient to drive piles at a penetration rate of 120 blows per foot (300mm) at the required ultimate pile capacity. When the wave equation is not used, use Table 514-2 to determine the minimum hammer energy needed for the required ultimate pile capacity.

Table 514-2
Pile Hammer Minimums

Pile Hammer Type	Minimum Rated Hammer Energy, ft-lb (J)
Diesel Hammers	255 P (39P)
Air or Steam Hammers (Single or Double Acting)	195 P (30P)
Gravity Hammers	1080 P (165P)

1. "P" is the ultimate pile capacity (tons) (kN) required by the contract documents.
2. The table values are based upon the ENR formula for an average penetration rate of 120 blows per foot (300 mm).

(b) **Pile hammers.**

1. *Diesel Hammers.*

1.1 *Open-end diesel hammers.* Equip open-end (single acting) diesel hammers with a device, such as rings on the ram or a scale (jump stick) extending above the ram cylinder, to permit visual determination of hammer stroke. Submit a chart from the hammer manufacturer equating stroke and blows per minute for the hammer to be used. A speed versus stroke calibration may be used if approved.

1.2 *Closed-end diesel hammers.* Submit a chart, calibrated to actual hammer performance within 90 calendar days of use, equating bounce chamber pressure to either equivalent energy or stroke for the hammer to be used. Equip hammers with a dial gage for measuring pressure in the bounce chamber. Make the gage readable at ground level.

Calibrate the dial gage to allow for losses in the gage hose. Verify the accuracy of the calibrated dial gage during driving operations by ensuring that cylinder lift occurs when bounce chamber pressure is consistent with the maximum energy given in the hammer specifications. Do not use closed-end diesel hammers that do not attain cylinder lift at the maximum energy-bounce chamber pressure relationship given in the hammer specification.

2. *Air or steam hammers.* Furnish plant and equipment for steam and air hammers with sufficient capacity to maintain the volume and pressure specified by the hammer manufacturer. Equip the hammer with accurate pressure gages that are easily accessible. Use a hammer with the weight of the striking parts equal to or greater than 1/3 the combined weight of the driving head and pile. The combined weight shall be at least 2750 pounds (1250 kg).

3. *Gravity hammers.* Do not use a gravity hammer to drive concrete piles or piles having a required ultimate capacity greater than 30 tons (267kN) . Furnish a hammer with a ram weighing between 2000 pounds (900kg) and 3500 pounds (1600kg) and limit the drop height to 13 feet (4m) . The ram weight shall be greater than the combined weight of the drive head and pile. Provide hammer guides to ensure concentric impact on the drive head.

4. *Non-impact hammers.* Do not use non-impact hammers, such as vibratory hammers, unless permitted in writing or specified in the contract. If permitted, use such equipment for installing production piles only after the pile tip elevation for safe support of the pile load is established by static or dynamic load testing. Control the installation of production piles when using vibratory hammers with power consumption, rate of penetration, specified tip elevation, or other acceptable methods that will ensure the pile load capacity equals or exceeds the load test pile capacity. On one out of every 10 piles driven, re-tap with an impact hammer of suitable energy to verify the required pile capacity is obtained.

5. *Additional Equipment or Methods.* If the required penetration is not obtained using 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 preboring.

(c) **Driving appurtenances.**

1. *Hammer cushion.* Equip all impact pile driving equipment, except gravity hammers, with a suitable thickness of hammer cushion material to prevent damage to the hammer or pile and to ensure uniform driving behavior. Fabricate hammer cushions from durable, manufactured material according to the hammer manufacturer's recommendations. Do not use wood, wire rope, or asbestos hammer cushions. Place a striker plate, as recommended by the hammer manufacturer, on the hammer cushion to ensure uniform compression of the cushion material. Inspect the hammer cushion in the presence of the Engineer when beginning pile driving at each structure or after each 100 hours of pile driving, whichever is less. Replace the cushion when its thickness is reduced by more than 25% of its original thickness.

2. *Pile drive head.* Provide adequate drive heads for impact hammers to distribute the hammer blow to the pile head. Align the drive head axially with the hammer and pile. The drive head shall be guided by the leads and not be free-swinging. Fit the drive head around the pile head so that it will prevent transfer of torsional forces during driving while maintaining proper alignment of hammer and pile.

For steel and timber piling, cut the pile heads squarely and provide a drive head to hold the longitudinal axis of the pile in line with the axis of the hammer.

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

For special types of piles, provide appropriate driving heads, mandrels or other devices according to the manufacturer's recommendations so that the piles may be driven without damage.

3. *Pile Cushion.* Protect the heads of concrete piles using a pile cushion when the nature of the driving is such as to unduly injure the piles. When plywood is used, place at least 4 inches (100m) of plywood before driving. Provide a new pile cushion if, during driving, the cushion is either compressed more than one-half the original thickness or begins to burn. Provide a new pile cushion for each concrete pile. The pile cushion dimensions shall be such as to distribute the blow of the hammer throughout the cross-section of the pile.

4. *Leads.* Support piles in line and position with leads while driving. Construct pile driver leads to allow freedom of movement of the hammer while maintaining axial alignment of the hammer and the pile to insure concentric impact for each blow. Provide leads of sufficient length that do not require a follower but will permit proper alignment of battered piles.

5. *Followers.* Followers are not permitted unless approved in writing. When followers are permitted, drive the first pile in each bent or substructure unit and every tenth pile driven thereafter, full length without a follower, to verify that adequate pile length is being attained to develop the required ultimate pile capacity. Provide a follower of such material and dimensions that will permit the piles to be driven to the required penetration. Hold and maintain the follower and pile in proper alignment during driving.

   The follower shall be of such material and dimensions to permit the piles to be driven to the length determined to be necessary from the driving of the full length piles. In each substructure unit, check the final position and alignment of the first two piles installed with followers. Verify that these piles are within location tolerances before additional piles are installed.

6. *Jetting.* Do not use jetting unless specified or approved in writing.

   When jetting is not specified, but approved by the Engineer, 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 without affecting the lateral stability of the final in-place pile. The Contractor shall be responsible for all damage to the site caused by jetting operations.

   When jetting is specified, provide jetting equipment with sufficient capacity to deliver a consistent pressure equivalent to at least 100 psi (0.7MPa) at two $^3/_4$ inch (20mm) jet nozzles. Jet so as not to affect the lateral stability of the final in-place pile.

   In either case, remove jet pipes when the pile tip is at least 5 feet (1.5m) above the prescribed tip elevation and drive the pile to the required ultimate pile capacity with an impact hammer. Control, treat, if necessary, and dispose of all jet water in an approved manner.

514.04 CONSTRUCTION METHODS.

(a) **Manufacture of Piles.**

1. *Precast Concrete Piles.*

1.1 *Forms.* Conform to the requirements for formwork in Section 502, "Temporary Works," and, where applicable, Section 503, "Prestressed Concrete Bridge Members." Provide access in the forms for vibration and consolidation of the concrete.

1.2 *Casting.* Conform to the requirements for handling and placing of concrete in Section 509, "Structural Concrete." Conform to Section 511, "Reinforcing Steel." Take special care placing the concrete to produce a satisfactory bond with the reinforcement and to avoid the formation of "stone pockets," honeycomb, or other defects.

To secure uniformity, place the concrete in each pile continuously and compact by vibrating or other means acceptable to the Engineer. Overfill the forms, screed off surplus concrete, and finish the top surfaces to a uniform, even texture similar to that produced by the forms.

1.3 *Finish.* Finish portions of piling exposed to view according to the provisions governing the finishing of concrete columns. Do not finish other piling, except as set forth above.

1.4 *Curing and Protection.* Cure concrete piles as provided in Section 509, "Structural Concrete." When the piles have set sufficiently to avoid damage, remove the piles from the forms and stack in a curing pile separated from each other by wood spacing blocks. Note handling requirements below.

Before driving, allow each pile to age at least 21 days, and, in cold weather, for a longer period as determined by the Engineer. Cure concrete piles for use in high chloride or sulfate soils for at least 30 days before driving. Protect concrete from freezing until the compressive strength reaches at least 80 percent of the specified 28-day compressive strength.

1.5 *Prestressing.* Conform to the requirements of Section 503, "Prestressed Concrete Bridge Members," for prestressing of concrete piles. Use an approved corrosion-inhibiting admixture in precast prestressed concrete piles.

1.6 *Storage and Handling.* Perform the removal of forms, curing, storing, transporting, and handling of precast concrete piles in a manner to avoid excessive bending stresses, cracking, spalling, or other injurious results. Comply with the AASHTO *Standard Specifications for Highway Bridges* and Subsection 503.04(g) for transporting and handling concrete piles. Cracks or other damage will be cause for rejection.

2. *Cast-in-Place Concrete Piles.*

2.1 *Inspection of Metal Shells.* At all times before placing of concrete in the driven shells, provide a suitable light for the inspection of each shell throughout its length.

2.2 *Placing Concrete.* Do not place concrete until all driving within a radius of 16 feet (5m) has been completed, or discontinue all driving until the pile concrete within this radius has set for at least five days.

Provide concrete for cast-in-place piles that is dense and homogeneous. Place concrete for each pile in continuous operation with the flow of concrete directed down

the center of the pile to consolidate the concrete by impact. Vibrate all concrete from at least 5 feet (1.5 m) below the ground surface to the top of the cast-in-place pile. Remove accumulations of water before concrete is placed.

After the concrete has hardened, cut back the top surface to remove laitance and to expose aggregate as specified for construction joints in Subsection 509.04(d)2.

(b) **Preparation for Driving.**

1. *Site Work.*

1.1 *Excavation.* In general, drive piles only after excavation is complete. Remove any material forced up between the pile to the correct elevation before concrete for the foundation is placed.

1.2 *Preboring to Facilitate Driving.* When required by the contract documents, prebore holes at pile locations to the depths specified in the contract documents or by the Engineer. If the depth of preboring is not specified in the contract documents, stop preboring for skin friction piles at least 5 feet (1.5m) above the pile tip elevation and drive the pile with an impact hammer to a specified blow count. Preboring for end bearing piles may extend to the surface of the rock or hardpan where piles are to be end-bearing on rock or hardpan. Seat installed piles into the end-bearing strata.

Use auguring, wet rotary drilling, or other approved methods of preboring. Make prebored holes smaller than the diameter or diagonal of the pile cross-section and sufficient to allow penetration of the pile to the specified depth. If subsurface obstructions, such as boulders or rock layers are encountered, increase the hole diameter to the least dimension that is adequate for pile installation. Fill any void space remaining around the pile after the completion of driving with sand or other approved material. Do not use a spud or punch unless otherwise permitted or specified. (A spud is a short, strong driven member that is removed to make a hole for inserting a pile.) Dispose of material from drilling in a manner approved by the Engineer.

Do not impair the carrying capacity of existing piles or the safety of adjacent structures. If preboring disturbs the load carrying capacities of previously installed piles or structures, restore the required ultimate capacity of piles and structures by approved methods.

1.3 *Predrilled Holes in Embankments.* When the depth of a new embankment is more than 6 feet (2 m) , prebore or spud through the embankment where piles are to be driven. Make the hole diameter not less than the greatest dimension of the pile cross-section plus 6 inches (150 mm) . After driving the pile, fill the space around the pile with dry sand or pea gravel. Dispose of material from drilling in a manner approved by the Engineer.

2. *Preparation of Piling.* In addition to squaring up pile heads before driving, further prepare piles as described below.

2.1 *Collars.* When timber piles are required to be driven to more than 35 tons (310 kN) bearing or when driving condition required it, provide collars, bands, or other devices to protect piles against splitting and brooming.

2.2 *Pointing.* Point timber piles where required by soil conditions. When necessary, shod the piles with metal shoes of a design satisfactory to the Engineer. The points of the piles shall be carefully shaped to secure an even and uniform bearing on the shoes.

Point steel piles as specified in the contract documents. Perform welding according to Section 724. If approved by the Engineer, pile shoes may be either substituted for pointing steel piles or used at the option of the Contractor when hard driving is expected.

2.3 *Pile Shoes.* Use pile shoes, for all types of piles, at the locations specified. Provide piles shoes of the type specified. Fabricate pile shoes from cast steel conforming to Subsection 725.03.

(c) **Driving.**

1. *General.* Drive piles to the minimum tip elevations and required ultimate capacity shown in the contract documents or approved by the Engineer. Do not drive piles after practical refusal has been obtained. Splice piles not obtaining the required ultimate capacity at the ordered length and drive with an impact hammer until the required ultimate pile capacity is achieved. Monitor the performance of the hammer and other driving equipment to ensure the expected driving energy is used for each pile throughout driving.

When using the wave equation to determine bearing resistance, adequate penetration will be considered obtained when the specified wave equation resistance criterion is achieved within 5 feet (1.5m) of the designated tip elevation. Drive piles that do not achieve the specified resistance within these limits to a penetration determined by the Engineer.

Place individual piles in pile groups either starting from the center of the group and proceeding outward in both directions or starting at the outside row and proceeding progressively across the group. Redrive piles that heave more than 1/4 inch upward during the driving of adjacent piles.

Make the heads of all piles plane and perpendicular to the longitudinal axis of the pile. Coordinate pile driving so not to damage other parts of the completed work.

2. *Test Piles.* When specified in the contract documents, furnish test piles to the lengths specified and drive test piles at the locations and to the depths specified or directed. Usually, test piles will be longer than the estimated length of permanent piles to provide for variation in soil conditions. Prepare for driving as specified in Subsection 514.04(b). Drive test piles with the same equipment as the permanent piles.

Drive test piles to the required ultimate capacity at the estimated tip elevation. Allow test piles that do not attain the required ultimate capacity at 12 inches (300mm) above the estimated tip elevation to *"set up"* for 24 hours before redriving. If possible, warm the hammer before redriving begins by applying at least 20 blows to another pile. If the required ultimate capacity is not attained on redriving, drive a portion or all of the remaining test pile length and repeat the *"set up"* and redrive procedure as directed. Splice and continue driving until the required ultimate pile capacity is obtained.

Test piles to be used in the completed structure shall conform to the requirements for permanent piles. Remove test piles not incorporated in the completed structure to at least 2 feet (0.5m) below finished grade.

3. *Accuracy of Driving.* Drive piles so that the axial alignment is within 1:50 from the vertical or the batter shown in the contract documents. Horizontally, keep the top of the pile within 2 inches (50mm) of plan location for bent caps and within 6 inches (150 mm)of plan location for piles capped below finished ground. The pile shall not be closer than 4 inches (100mm) to any cap face. The Department will not pay for additional costs of increased footing dimensions due to out-of-position piles.

   The Engineer may stop driving to check the pile alignment. Check the alignment of piles that cannot be internally inspected after installation before the last 6 feet (2m) are driven. Do not pull laterally on piles or splice to correct misalignment. Do not splice a properly aligned section on a misaligned pile.

   Correct all piles driven improperly, driven out of proper location, misaligned, or driven below the designated cutoff elevation in an approved manner. Replace piles damaged during handling or driving. Obtain approval for the proposed method(s) of correcting or repairing deficiencies.

4. *Timber piles.* Do not use piles with checks wider than $^1/_2$ inch (12mm) . Drive treated timber piles within six months after treatment. Handle and care for pressure-treated piles according to AWPA Standard M 4.

5. *Steel piles.* Furnish steel piles with as few splices as practicable, not exceeding the limits defined in Table 514-3.

Table 514-3
Steel Pile Splices

Plan Length, ft(m)	Maximum Number of SplicesAllowed to Make Plan Length (per pile)
0 to 40 (0 to 12)	1
40 to 80 (12 to 24)	2
80 or more (24 or more)	3

   The number of splices in extensions beyond plan length shall not be limited by Table 514-3. Use cutoff lengths of steel piles for extensions where practicable.

   Load, transport, unload, store, and handle steel piles so that the metal is kept clean and free from damage. Do not use piles that exceed the camber and sweep permitted by allowable mill tolerance. Steel piles damaged during installation are considered unsatisfactory unless the bearing capacity is 100% of the required ultimate capacity by load tests. Load tests performed will be at no cost to the Department.

6. *Precast and prestressed concrete piles.* Support concrete piles during lifting or moving at the points shown on the plans or, if not so shown, provide support at the quarter points. Provide slings or other equipment when raising or transporting concrete piles to avoid bending the pile or breaking edges.

   Protect the heads of concrete piles with a pile cushion as specified for pile cushions in Subsection 514.03(c)3.

   A concrete pile is defective if any defect is observed that will affect the strength or long term performance of the pile.

7. *Concrete filled pipe or steel shell piles.* Furnish and handle the steel shells or pipes as specified for steel piles in Subsection 514.04(c)5. Cutting shoes for shells or pipes may be inside or outside the shell. Use high-carbon structural steel with a machined ledge for shell bearing or cast steel with a ledge designed for attachment with a simple weld.

   Provide for inspection and concrete placement as specified for cast-in-place concrete piles in Subsection 514.04(a)2. Do not drive any pile shell or pipe after it is filled with concrete.

   Remove and replace all shells with breaks, bends, or kinks determined to be unacceptable for use.

(d) **Determination of Bearing Capacity.**

1. *General.* Use the appropriate form of the Engineering News-Record (ENR) formula in Table 514-4 to determine bearing resistance of the in-place pile unless the wave equation is required for this purpose. When specified, use dynamic or static load tests to verify bearing resistance of piles.
2. *Practical Refusal.* Practical Refusal is defined as four consecutive sets of 10 blows having no more than $^1/_2$ inch (12mm) of penetration per each 10-blow set. Discontinue driving before practical refusal is reached if driving is causing damage to the pile.
3. *Engineering News-Record (ENR) Formula Method.* Use Table 514-4 to determine bearing resistance by the ENR formula method.

Table 514-4
Engineering News-Record (ENR) Formulas

Pile Hammer Type	Bearing Resistance, P, pounds	Metric Bearing Resistance, J, Joules
Diesel Hammers	2E / (S + 0.15)	E/(6S + 24)
Air or Steam Hammers (Single or Double Acting)	2E / (S + 0.1)	E/(6S + 15)
Gravity Hammers	2E / (S + 1.0)	E/(6S + 150)

where: E= Energy produced by the hammer per blow in foot-pounds (joules, J) . Value based on actual hammer stoke or bounce chamber pressure observed (double acting diesel hammer).

S= Average penetration in inches (mm) per blow for the last 5 to 10 blows for gravity hammers and the last 10 to 20 blows for all other hammers.

The formulas in Table 514-4 are applicable only when:

- the hammer has a free fall (gravity and single acting hammers only),
- the head of the pile is not broomed, crushed, or otherwise damaged,
- the penetration is quick and uniform,

- there is no appreciable rebound of the hammer, and
- a follower is not used.

The penetration per blow may be measured either during initial driving or by redriving with a warm hammer operated at full energy after a pile set period, as determined by the Engineer.

If water jets are used in connection with the driving, determine the bearing resistance by the formulas in Table 514-4 after the jets have been withdrawn.

4. *Wave Equation Method.* When wave equation analysis is required, use the soil, pile, and drive equipment properties as shown in the contract document and as approved to determine bearing resistance. Reduce bearing resistance to 80 percent of its calculated value unless the wave equation analysis was calibrated to the results of a dynamic pile test. Apply any additional factors of safety specified in the contract documents to all bearing resistances calculated by the wave equation.

5. *Dynamic load tests.* Comply with the following requirements when dynamic load tests are specified in the contract documents.

Use a qualified pile specialty consultant with at least 3 years experience in dynamic load testing and analysis to perform the dynamic load test, the case pile wave analysis program (CAPWAP), and the wave equation analysis including the initial wave analysis specified for the equipment submittal. Submit a resume of the specialty consultant for approval.

Furnish a shelter to protect the dynamic test equipment from the elements. Locate the shelter within 50 feet (14m) of the test location. Provide a shelter with a minimum floor size of 65 ft^2 ($6m^2$) and minimum ceiling height of $6^1/_2$ feet (2m) . Maintain the inside temperature between 50°F (10°C) and 100°F (40°C) .

Furnish equipment and perform dynamic load tests according to ASTM D 4945 under the supervision of the Engineer.

Place the piles designated as dynamic load test piles in a horizontal position and not in contact with other piles. Drill holes for mounting instruments near the head of the pile. Mount the instruments and take wave speed measurements. Place the designated pile in the leads. Provide at least a 4 foot (1.2m) by 4 foot (1.2m) rigid platform with a 42-inch (1.1m) safety rail that can be raised to the top of the pile.

Provide a suitable electrical power supply for the test equipment. If field generators are used as the power source, provide functioning meters for monitoring power voltage and frequency.

Drive the pile to the depth at which the dynamic test equipment indicates that the required ultimate pile capacity is achieved. If necessary to maintain stresses in the pile below the values in Subsection 514.03(a)2, reduce the driving energy transmitted to the pile by using additional cushions or reducing the energy output of the hammer. If nonaxial driving is indicated, immediately realign the driving system.

At least 24 hours after the initial driving, redrive each dynamic load test pile with instrumentation attached. Warm the hammer before redriving by applying at least 20 blows

to another pile. Redrive the dynamic load test pile for a maximum penetration of 6 inches (150 mm) or a maximum of 50 blows, whichever occurs first.

Verify the assumptions used in the initial wave equation analysis submitted according to Subsection 514.03(a) using CAPWAP. Analyze one blow from the original driving and one blow from the redriving for each pile tested.

Perform additional wave equation analyses with adjustments based on the CAPWAP results. Provide a graph showing blow count versus ultimate capacity. For open-ended diesel hammers, provide a blow count versus stroke graph for the ultimate capacity. Provide the driving stresses, transferred energy, and pile capacity as a function of depth for each dynamic load test.

Based on the results of the dynamic load testing, CAPWAP analyses, and wave equation analysis, the order list and production driving criteria may be approved and the required cut-off elevations provided, or additional pile penetration and testing specified. This information will be provided within seven calendar days after receipt of the order list and all required test data for the test piles driven.

6. *Static load tests.* When specified in the contract documents, perform static load tests according to ASTM D 1143 using the quick load compression test method except as modified herein. Submit drawings of the proposed loading apparatus for approval according to the following:

- Have a licensed professional engineer prepare the drawings.
- Furnish a loading system capable of applying 150% of the ultimate pile capacity or 1000 tons (9000kN) , whichever is less.
- Construct the apparatus to allow increments of load to be placed gradually without causing vibration to the test pile.

When tension (anchor) piles are required, drive tension piles at the location of permanent piles when feasible. Do not use timber or tapered piles installed in permanent locations as tension piles. Take the test to plunging failure or the capacity of the loading system.

The safe axial pile load is defined as 50% of the failure load. The failure pile load is defined as follows:

- For piles 24 inches (600mm) or less in diameter or diagonal width, the load that produces a settlement at failure of the pile head equal to:

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

- For piles greater than 24 inches (600 mm) in diameter or diagonal width:

$$S_f = S + D/30$$

where:

S_f = Settlement at failure in inches (millimeters) ,

D= Pile diameter or diagonal width in inches (millimeters) ,

S= Elastic deformation of total unsupported pile length in inches (mm),

a= 0.15 (3.8)

Determine top elevation of the test pile immediately after driving and again just before load testing to check for heave. Wait a minimum of 3 calendar days between the driving of any anchor or the load test piles and the commencement of the load test. Before testing, redrive or jack to the original elevation any pile that heaves more than 1/4 inch (6 mm) .

After completion of static testing, remove or cut off any test or anchor piling not a part of the finished structure at least 2 feet (0.5 m) below either the bottom of the footing or the finished ground elevation.

Based on the results of the static load testing, the order list and production driving equipment may be approved and the required cut-off elevations provided or additional tests may be specified. This information will be provided within seven calendar days after receipt of the order list and all required test data for the test piles driven.

(e) **Splices.** Align and connect pile sections so the axis of the spliced pile is straight.

1. *Steel piles.* Submit a welder certification for each welder. Use welders certified for structural welding under Section 724.

   Make surfaces to be welded smooth, uniform and free from loose scale, slag, grease, or other material that prevents proper welding. Steel may be oxygen cut. Carbon-arc gouging, chipping, or grinding may be used for joint preparation.

   Weld according to AASHTO/AWS D 1.5 Bridge Welding Code except inspection requirements. Weld the entire pile cross-section using prequalified AWS groove weld butt joints. The arc method of welding is preferred for splicing. Weld so there is no visual evidence of cracks, lack of fusion, undercutting, excessive piping, porosity, or inadequate size. Manufactured splices may be used in place of full penetration groove butt welds. When in conflict, comply with the welding requirements shown on the plans.

2. *Concrete pile splices and extensions.* Do not splice concrete piles. Extend concrete piles after driving is completed; do not drive extended concrete piles.

   2.1 *Precast concrete piles.* Extend precast concrete piles by removing the concrete at the end of the pile and leaving 40 diameters of reinforcement steel exposed. Remove the concrete to produce a face perpendicular to the axis of the pile. Securely fasten reinforcement of the same size as that used in the pile to the projecting reinforcing steel. Form the extension to prevent leakage along the pile. Place concrete of the same mix design and quality as that used in the pile. Keep forms in place for not less than seven calendar days after the concrete has been placed. Cure and finish according to Section 509.

   2.2 *Prestressed piles.* Submit drawings of proposed extensions for approval. Use dowels or other acceptable mechanical means to splice precast concrete or precast prestressed concrete piles. The splice shall develop strengths in compression, tension, and bending

equal to or exceeding the strength of the pile being spliced. Include reinforcement bars in the pile head for splicing to the extension bars.

3. *Timber piles.* Do not splice timber piles.

(f) **Pile Cutoffs.** Cut off the tops of all permanent piles and pile casings at the required elevation. Cut off the piles clean and straight parallel to the bottom face of the structural member in which they are embedded. All cutoff lengths of piling shall remain the property of the Contractor and shall be properly disposed of.

Saw timber piles which support timber caps or grillage to conform to the plane of the bottom of the superimposed structure. The length of the pile above the elevation of cutoff shall be sufficient to permit the complete removal of all material injured by driving.

Immediately after making final cutoff on treated timber foundation piles, give the cut area two liberal application of preservative followed by a heavy application of coal-tar roofing cement or other approved sealer. Treat the heads of all treated timber piles that are not embedded in concrete with three coats of a compatible preservative material meeting the requirements of American Wood Preservers Association Standard M4. Allow a minimum of two hours between applications.

(g) **Defective Piles.** Correct, by an approved method, piles driven out-of-position (beyond specified limits), or having crushed, cracked, or spalled concrete, splintered or broomed wood, excessively deformed steel, or otherwise deemed defective. Methods of correcting unsatisfactory piles may include one or more of the following:

- Use pile at a reduced capacity,
- Install additional piles,
- Repair damaged piles,
- Replace damaged piles.

Do not force out-of-position piles into the proper position. All remedial materials and work shall be furnished at the Contractor's expense. Piles used at a reduced capacity with no other remedial work shall be accepted at a reduced price under Subsection 105.03.

514.05. METHOD OF MEASUREMENT.

(a) **General.** For pay items, *piles, furnished and piles, driven,* individual pile lengths will be measured and summed to the nearest hundredth of a foot (meter) and the overall total for each pile type will be rounded to the nearest hundredth of a foot (meter) . Remedial piling work will not be measured for payment. Only work accepted by the Engineer will be measured for payment.

(b) **Piles, Furnished.** For each pile type indicated in the contract documents, pile lengths furnished and stockpiled at the site of the work will be measured under the corresponding *piles, furnished* pay item. The *piles, furnished* quantity will be limited by the total plan length with increases for approved extensions as follows. (The total plan length is defined as the sum of all planned pile lengths for a pile type, where planned pile lengths are either shown on the plans or determined by the Engineer after driving test piles.) For concrete piles, furnished extensions,

not exceeding the length ordered in writing by the Engineer, will be added to the total pile length. For steel piles, the *piles, furnished* quantity will equal the *piles, driven* quantity when the as-built *piles, driven* quantity exceeds the total plan length.

(c) **Piles, Driven.** For each pile type indicated in the contract documents, pile lengths driven will be measured under a corresponding pay item, *piles, driven.* The *piles, driven* quantity will be determined by measuring the actual pile lengths in place. Preboring, jetting or other methods used for facilitating pile driving procedures when either required or permitted will not be measured, and payment shall be considered included in the unit price bid for the piles driven.

(d) **Splices for Steel Piling.** Each splice made in a steel pile will be measured for payment except as limited by Table 514-5.

Table 514-5
Maximum Number of Splices Measured for Payment

Plan Length, ft (m)	Actual Pile Length is: Plan Length or less	Over Plan Length
0 to 40 (0 to 12)	1	2
40 to 80 (12 to 24)	2	3
80 or more (24 or more)	3	4

Each accepted steel pile splice, measured as provided above, will be paid for at the contract price for three feet (one meter) of *piles, driven*.

(e) **Test Piles.** Test piles, furnished and driven, will be measured using the same method of measurement as specified above for piles.

(f) **Load Tests.** The number of each type of load test listed in the bid schedule that is completed and accepted will be measured for payment.

(g) **Metal Pile Shoes.** When metal pile shoes are listed in the bid schedule, the number of metal pile shoes furnished and accepted will be measured for payment.

514.06. BASIS OF PAYMENT.

The accepted quantities, measured as provided above, will be paid for at the contract price per unit of measurement for the pay items listed below that are shown in the bid schedule.

(A) PILES, FURNISHED ..... LINEAR FOOT (METER)
(B) PILES, DRIVEN ..... LINEAR FOOT (METER)
(C) TEST PILES, FURNISHED ..... LINEAR FOOT (METER)
(D) TEST PILES, DRIVEN ..... LINEAR FOOT (METER)
(E) PILE LOAD TEST (STATIC) ..... EACH
(F) PILE LOAD TEST (DYNAMIC) ..... EACH
(G) METAL PILE SHOES ..... EACH

Payment for furnishing piles includes full compensation for all costs involved in the furnishing and delivery of all piles, including steel shells for cast-in-place driven piles, to the project site and all costs involved in the furnishing and placing of concrete and reinforcing steel for cast-in-place

concrete piles. For each size of steel pile listed in the bid schedule, the price bid for furnishing may not exceed 70% of the combined price bid for furnishing and driving.

Payment for driving piles includes full compensation for all costs involved in the actual driving and cutting off piles and pile shells, and for all costs for which compensation is not provided for under other pay items involved with the furnishing of labor, equipment, and materials used to construct the piles as shown in the contract documents.

Payment for load tests includes full compensation for providing labor, equipment, and materials needed to perform the load tests as specified.

Payment for metal pile shoes includes full compensation for all costs involved with furnishing all materials and performing the work involved with installing metal pile shoes.

SECTION 515
PENETRATING WATER REPELLENT TREATMENT

515.01. DESCRIPTION.

This work consists of furnishing necessary labor, materials, and equipment to treat concrete surfaces with a penetrating water repellent treatment solution according to the contract documents.

515.02. MATERIALS.

Penetrating water repellent treatment solution shall meet the requirements of Subsection 701.12.

515.03. EQUIPMENT.

(a) **General.** Furnish equipment meeting the requirements of Subsection 108.06 and the treatment solution manufacturer's recommendations.

(b) **Surface Preparation.** Use one or more of the following types of equipment for surface preparation.

1. *Sand Blasting.* A compressed air pressure type sand blasting equipment of proper size and capacity to clean concrete surfaces as specified.
2. *Shot Blasting.* A portable type machine designed especially for cleaning horizontal concrete surfaces utilizing recyclable steel shot blast techniques.
3. *Hot Water Pressure Washers.* A hot water pressure system for cleaning concrete surfaces as specified, utilizing 160°F (70°C) minimum water temperature at 2500 psi (17 MPa) nozzle pressure.
4. *Hydroblast Washer.* A high pressure cold water washer unit for cleaning concrete surfaces as specified, using 7000 psi (48 MPa) nozzle pressures.
5. *Steam Cleaning.* A steam jet cleaning equipment for preparing concrete surfaces as specified, utilizing 320°F (160°C) water temperature under 300 psi (2 MPa) operating pressure.