Revisions to:

Recommendations for Design, Manufacture, and Installation of Concrete Piles

Reported by ACI Committee 543

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Extensive revisions to the Committee 543 report published in the August 1973 ACI JOURNAL are presented; each is identified as to the paragraph or section in the original report which it supplants. Many of the revisions are made to improve clarity of the original, or to provide added information. Where significant technical reasons for the changes are not apparent in the revised text, comments from the committee are presented following the modified section.

Keywords: augered piles; bearing capacity; composite construction (concrete and steel); concrete construction; **concrete piles;** corrosion; foundations; harbor structures; installing; loads (forces); manufacturing; materials handling; **pile driving;** pile extraction; **piles; precast concrete; prestressed concrete;** quality control; reinforcing steels; repairs; sheet piling; **soil mechanics;** splicing; storage; stresses; structural design; tolerances (mechanics).

Preface, first paragraph

This paragraph has been revised as follows:

ACI Committee 543 was organized in 1961. Carrol Wakeman served as its first chairman until 1967. William Talbot was chairman until March 1973 at which time the committee's report had been submitted for initial publication in the ACI JOURNAL August 1973. The committee's mission is to prepare recommendations for the design, manufacture and installation of all types of concrete piles.

Preface, fifth paragraph

At the end of the sentence, "material" has been changed to "specifications and standards."

Preface, concluding paragraph

Fifth line from the end, "is" is changed to "are." Seventh line from the end, "strands" is changed to "cores."

Section 1.1, first paragraph

Third sentence: "both in the United States and abroad" is changed to "throughout the world."

Section 1.1.1, first paragraph

Second sentence: "slipforming" has been added after "centrifugal casting."

Section 1.1.1.1

At the end of the sentence, "spirals" has been changed to "a spiral."

Section 1.1.1.2, second paragraph

The last sentence has been changed to read: "Post-tensioned piles are usually manufactured in sections and assembled and prestressed to the required pile lengths in the manufacturing plant or on the job site."

Section 1.1.2.2

The section has been revised to read:

1.1.2.2 *A drilled-in-caisson* is a special type of cased cast-in-place concrete pile which is installed as a high capacity unit carried down to and socketed into bedrock. These foundation units are formed by driving a heavy-wall open-end pipe to bedrock, cleaning out the pipe, drilling a socket into the bedrock, inserting a structural steel section (caisson core) extending from the bottom of the rock socket to either the top of or part way up the pipe and filling the entire socket and pipe with concrete. The depth of the socket depends on the design load, the pipe diameter and the nature of the rock.

Comment: The words "of relatively large diameter" were somewhat misleading considering the size of some foundation units in use. The structural steel core does not always extend for the full length of the drilled-in-caisson.

Section 1.1.2.5, third paragraph

The second sentence of the paragraph has been revised to read: "However, as the pile shaft is being formed, the level of the concrete must be kept just above the bottom of the drive casing to avoid discontinuities in the pile shaft."

Section 1.1.2.6

The section is revised as follows:

1.1.2.6 *Auger grout or concrete injected piles* are usually installed by turning into the ground a continuous-flight hollow-stem auger to the required depth and, as the auger is withdrawn, pumping grout or concrete through the hollow stem, filling the hole from the bottom up.

Extreme care must be taken during the installation process to insure a continuous and full size shaft. If the auger is withdrawn too rapidly, the surrounding soil could squeeze into the hole thus reducing the cross section of the pile, or in extreme cases, creating discontinuities in the shaft.

Frequently vertical reinforcing steel rods are pushed down into the grout or concrete shaft before it sets.

Grout or concrete shafts are usually formed to well above cutoff grade and, after setting, the excess grout or concrete is removed.

Section 1.1.2.7

The following new section is added and old Section 1.1.2.7 becomes Section 1.1.2.9:

1.1.2.7 *Drilled and grouted piles* are installed by rotating into the soil a casing having a cutting edge, removing the soil cuttings with circulating drilling fluid, inserting reinforcing steel, pumping a sand-cement grout through a tremie, filling the hole from the bottom up, and withdrawing the casing. Such piles are used principally for underpinning work, often being installed through the existing foundation.

Section 1.1.2.8

A new section is added as follows:

1.1.2.8 *Preplaced aggregate piles* are installed by drilling a hole to the required depth, filling the hole with coarse aggregate, and pumping grout into the column of aggregate, filling it from the bottom up. Sufficient grout pipes are installed at the time the aggregate is placed and these pipes are withdrawn as the grouting proceeds.

Section 1.1.2.9

Section 1.1.2.7 becomes Section 1.1.2.9 and is revised as follows:

1.1.2.9 *Cast-in-drilled hole piles** (also known as drilled piers) are installed by mechanically drilling a hole to the required depth and filling the hole thus formed with reinforced or plain concrete. Sometimes an enlarged base is formed mechanically to increase the bearing area. Where the side of the hole is unstable, a temporary steel liner is inserted and later withdrawn as the concrete is placed. Extra care must be taken in withdrawing the liner to insure that the bottom of the liner is kept well below the surface of the concrete being placed to prevent intrusion of soil. The slump of the concrete must be high enough to prevent arching in the liner which could create discontinuities in the pile shaft as the liner is withdrawn.

Section 1.1.2.9, footnote

The footnote pertaining to Sections 1.1.2.6 and 1.1.2.7 now applies only to new Section 1.1.2.9. In addition, the first sentence is deleted.

Section 1.2

The second paragraph is revised to read:

The specifications listed were the latest editions at the time this report was initially published. Since these specifications are revised from time to time, the user of this report should check directly with the sponsoring group if it is desired to refer to the latest edition.

In the list of ACI reports and standards, the following changes are made:

1. References to ACI 304-73 and ACI 305-72 are moved to their proper numerical locations.

2. The reference to ACI 315-65 is revised to: ACI 315-74 "Manual of Standard Practice for Detailing Reinforced Concrete Structures."

3. The following is added: ACI 318-71 "Building Code Requirements for Reinforced Concrete."

The following ASTM references are added in correct alpha-numeric sequence:

ASTM C 78-64, "Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam With Third Point Loading)."

ASTM C 496-71, "Standard Method of Test for Splitting Tensile Strength of Cylindrical Concrete Specimens."

ASTM D 1143-74, "Standard Method of Testing Piles Under Axial Compressive Load."

Section 2.0

For the present A_s the following is substituted: A_{sc} = area of structural steel caisson-core, in.^{2}

For the present f_{pc} the following is substituted: f_{pe} = effective prestress after losses, lb/in.^{2}

For the present f_s the following is substituted: f_{sc} = allowable steel stress for structural caisson-core lb/in.^{2}

The following have been inserted in proper sequence:

A_{ps} = area of prestressing steel, in.^{2}

f_{ps} = ultimate tensile strength prestressing steel, lb/in.^{2}

f_t = direct tensile strength of concrete, lb/in.^{2}

f_{sp} = splitting tensile strength of concrete, lb/in.^{2}

f_r = flexural strength of concrete or modulus of rupture, lb/in.^{2}

S = relative stiffness factor for preloaded clay, in.

T = relative stiffness factor for normally loaded clay, granular soils, silt and peat, in.

Section 2.1.1, second paragraph

This paragraph is revised to read:

Commonly used methods to evaluate the bearing capacity of the pile-soil system include load testing, dynamic driving formulas, analysis based on the one-dimensional wave equation, and static resistance analyses. All four methods have their place in the design and installation of pile foundations, and must be used with careful judgment of a qualified engineer. Frequently load testing is used in conjunction with dynamic formulas or static analyses to evaluate the load-settlement response of the pile under test conditions.

Comment: The use of the wave equation is fairly common today and should be included in the methods listed for evaluating the bearing capacity of the pile-soil system.

Section 2.1.1, third paragraph

The following is added between the third and fourth sentences: "It should be noted that the magnitude of loading (e.g., column load) may also influence the choice of a pile design capacity."

Section 2.1.1, fourth paragraph

The following sentence is added to the end of the paragraph: "A wave equation analysis with a factor of safety of two can generally provide a reasonable driving criterion, providing proper recognition is given to the possible effect of soil freeze or relaxation (see Section 2.4.5)."

Comment: A wave equation analysis is a form of "dynamic" formula, but not to be classified with other type dynamic formulas. A wave equation analysis can be used with more assurance than other dynamic formulas.

Section 2.1.1.1, second paragraph

The second sentence is revised to read, in part: "When pile capacity is to be determined by a Newtonian type dynamic driving formula . . ."

The following is added to the end of the paragraph: "When the required pile penetration resistance is determined by a wave equation analysis, it is often advisable to verify the results of such analysis and the pile capacity by load test."

Section 2.1.1.1, fourth paragraph, subparagraph (c)

This subsection is revised to read:

(c) Testing piles driven both into and just short of a point bearing stratum to approximate the frictional resistance of the overlying soil as well as the capacity of the bearing stratum.

Section 2.1.1.1, fifth paragraph

This paragraph has been deleted.

Section 2.1.1.1, sixth paragraph

The following has been added to the end of the paragraph: "This report does not cover the various methods for testing piles nor the methods and instrumentation used to measure the pile response under test. (See ASTM D 1143 and Reference 22)."

Section 2.1.1.2, first paragraph

The concluding sentence is changed to read: "In effect, adherence to an established driving resistance permits each pile to seek its own required capacity regardless of variations in depth, density, and quality of the bearing strata or variations in pile length."

Section 2.1.1.2, fourth paragraph

The first sentence now reads: "The dynamic formulas in general use today, in their simplest form, are based on equating the energy used to the work done in moving the pile a distance (set) against the soil resistance; the more complicated formulas also involve Newtonian impact principles."

Section 2.1.1.2, seventh paragraph

The paragraph is revised as follows:

For a given set of conditions and for a succession of assumed ultimate resistances R_u, computer calculations are made of the required final penetration resistance (blows per inch) as well as the resulting compression and tension stresses in the pile. Routine input data include such things as hammer ram weight and impact velocity; spring constant and coefficient of restitution of the capblock or hammer cushion (and pile cushion if used); pile type, material, dimensions, weight, and length; soil quake and damping factors, percentage of pile capacity developed by friction and point bearing; length of pile over which frictional resistance occurs; and type of frictional distribution (uniform, triangular, parabolic, etc.). Assumptions made regarding point bearing and frictional resistance are based on various factors such as soil conditions and pile type. For certain type piles, such as mandrel driven pipe piles, the computer program must be designed to handle the special input data required.

Section 2.1.1.2, eighth paragraph

In the first sentence, "ultimate dynamic capacity" is changed to "ultimate capacity." The last sentence is changed to read: "The wave equation is a reliable and rational* 'dynamic formula' and takes into account most of the factors not included in other type formulas."

Section 2.1.1.2

The following new paragraph is added after the eighth paragraph:

It should be noted that the use of the term "dynamic formula" is misleading if one assumes it implies a determination of the dynamic capacity of the pile. Actually, such formulas have been developed to reflect the static capacity of the pile-soil system as measured by the dynamic resistance during driving. This also is true of the wave equation analysis.

Section 2.1.1.3

The section is revised to read:

2.1.1.3 *Static resistance analysis.* The application of static analysis utilizes various soil properties determined from laboratory and field tests or as assumed from boring data. The pile capacity is estimated by applying the shearing or frictional resistance (adhesion) along the embedded portion of the pile and adding the bearing capacity of the soil at the pile point. Such analysis, insofar as possible, should reflect the effects of pile taper, cross-sectional shape (square, round, etc.) and surface texture, the compaction of loose granular soils by driving displacement type piles, and the effects of installation methods used. Each of these factors could have an influence on the final load carrying capacity of a pile.[23]

Section 2.1.6, second paragraph

The concluding sentence is changed to read: "Bending stresses due to the weight of the pile itself, such as occur for a long free-standing portion of a batter pile in marine structures, should be taken into consideration."

Section 2.1.7

The first sentence is replaced by "Axial load distribution includes both rate of transfer of load from pile to soil and distribution of load between friction and point bearing (soil resistance distribution). The distribution of load can be approximated by theoretical analysis or by special load test methods or by properly instrumenting load test piles."

Section 2.1.8.2

In the second sentence, "either by" is changed to "by such things as."

Section 2.1.8.4

The third sentence has been revised to read: "If such compressible strata surround and underlie the piles, then consolidation may sometimes result in negative friction loads or settlement of the foundations."

The following is added at the end of the paragraph: "If swelling of the soil could occur before the full load is on the pile or for lightly loaded

*Nonempirical, arrived at through reasoning.

piles, it may be necessary to provide some tension reinforcement in the pile."

Comment: Soil consolidation may cause negative friction thus increasing the load on the pile without causing settlement. A word of caution on possible tension in piles under these conditions is advisable.

Section 2.1.9, third paragraph

This paragraph is changed to read:

In evaluating the lateral capacity of vertical piles, the soil resistance against the pile, pile cap, and foundation walls should be considered. Such soil resistance can contribute substantially to the lateral capacity of a pile group or pile foundation. Also, axial compressive loads can contribute to the pile's lateral (bending) capacity by reducing tension stresses caused by bending due to lateral loads. The use of design methods for lateral loading of piles without consideration of axial compression load and soil resistance results in ultraconservative and uneconomical design.

Section 2.2.2.1, fourth paragraph

A citation to References 24-30 is added at the end of the paragraph.

Section 2.3, first paragraph

The second sentence is revised to read: "The design stresses for concrete reflect a minimum safety factor of 2.2 (based on ultimate strength) for laterally supported piles and include an accidental eccentricity factor of 5 percent."

Table 2.3.1

Under the heading "Tension," a footnote citation (‡) is added to the word "prestressed" and "$4.5\sqrt{f_c'}$" changed to "$3\sqrt{f_c'}$."

In the column "Conditions" under the heading "Flexure," the title "Concrete tension" is arranged on one line above "plain."

At the bottom, the following footnote is added:

‡The ultimate capacity of the prestressing steel should be equal to or greater than 1.2 times the cracking load, i.e., $f_{ps}A_{ps} \geqq 1.2(f_{pc} + 7.5\sqrt{f_c'})A_c$.

Comment: The change in the allowable temporary tension stress yields a more conservative value.

Section 2.3.1

This section is revised as follows:

2.3.1 *Allowable design stresses*—The allowable design stresses of Table 2.3.1 are recommended for the conditions involved. The allowable compressive stresses for concrete are applicable to foundation piles. They have been developed using ultimate strength design principles from ACI 318 but no attempt has been made to completely follow ACI 318 concrete column design because of the fundamental differences between foundation piles and columns. Although both are "structural" elements, the piles to which the basic allowable stresses apply are fully laterally supported whereas columns may be laterally unsupported or sometimes supported only at intervals. The failure of a column would be due to structural inadequacy whereas, in general, pile foundation failures are caused by inadequate capacity of the pile-soil system. A column is usually a more critical structural element than an individual pile. A column is an isolated unit which, if it fails, probably causes collapse of that portion of the structure supported by the column. However, a single structural column is often supported by a group of four or more piles with the column load shared by several piles. If an individual pile in the group cannot carry its full design load, the load in excess of the pile's actual capacity is shared by the other piles with a remote chance of catastrophic collapse.

For piles used in trestles or supporting marine structures which could occasionally receive large overloads, the allowable design stresses in Table 2.3.1 are reduced by 10 percent. The allowable load is further reduced by a reduction factor depending on the l/r ratio and the head and end conditions. In addition, for unsupported piles not spirally reinforced, a further 15 percent reduction in allowable load is recommended. (See Section 2.3.2.2).

It should be noted that the unsupported portion of a foundation pile is an extension of the laterally supported portion which generally is several times longer than the unsupported portion. Thus such a pile is deeply embedded for its lower length, and at some depth below ground surface could be considered to be 100 percent fixed. In comparison, it is difficult to achieve 100 percent end fixity for a building column. Furthermore, for many structures using unsupported pile lengths, the pile tops are framed into the structure much more heavily than most building columns with a resulting greater end fixity at the top.

Section 2.3.2.1

The first sentence is changed to read in part: "The allowable axial compressive. . . ."

The second paragraph now reads as follows:

If the reinforcement is used in determining the allowable compressive load and if the concrete in reinforced precast and cast-in-place piles is not confined or spirally reinforced, the allowable load should be 85 percent of that computed by Eq. (2-5).

In Eq. (2-6), "f_{pc}" is changed to "f_{pe}."

In Eq. (2-8), "$f_r A_r$" is changed to "$f_{sc} A_{sc}$."

Comment: For clarification. Generally the allowable compressive loads for concrete piles are determined by applying the allowable compressive stress for concrete to the gross cross-sectional area of the pile. Precast piles are reinforced primarily to withstand handling and driving stresses. Cast-in-place piles (laterally supported) are reinforced primarily to resist uplift loads and large lateral loads not taken by batter piles. This section deals with laterally supported piles. A provision for tied versus spirally reinforced *unsupported* pile lengths is being reinserted under Section 2.3.2.2.

Section 2.3.2.2, first paragraph

At the end of the paragraph a citation to References 31, 32, and 33 is added.

Table 2.3.2.2a, footnote

A citation to Reference 34 is added at the end of the footnote.

Section 2.3.2.2, third paragraph

The subheadings are changed from *"For stiff cohesive soils"* and *"For granular soils, silt and peat"* to *"For preloaded clay"* and *"For normally loaded clay, granular soils, silt, and peat,"* respectively.

Section 2.3.2.2, fourth paragraph

The paragraph is corrected to read:

The horizontal subgrade modulus k is equal to 67 times the undrained shear strength of the soil. It is assumed to be constant with depth for preloaded clay and varies with depth for normally loaded clay. The value of the coefficient of horizontal subgrade modulus n_h for normally loaded clay is equal to k divided by the depth and can be approximated by the best triangular fit (slope of line through the origin) for the top 10-15 ft on the k versus depth plot. (See Reference 24.) Representative values of the coefficient of horizontal subgrade modulus n_h for other soils are shown in Table 2.3.2.2b. These values also apply to submerged soils. The embedded portion of the pile must be longer than $4S$ and $4T$ for this analysis to be valid, otherwise, a more refined analysis is required.

Table 2.3.2.2b

The table now appears as shown below, and the note has been added.

TABLE 2.3.2.2b—VALUES OF n_h

Soil type	n_h
Sand and inorganic silt	
Loose	1.5
Medium	10
Dense	30
Organic silt	0.4 to 3.0
Peat	0.2

Note: Values given for granular soils are conservative. Higher values require justification by lateral load test. (See Reference 24.)

Section 2.3.2.2, new paragraph

The following is added as the sixth paragraph:

If the structural length L of an unsupported concrete pile is not confined in a steel pipe or shell with a minimum wall thickness of 0.1 in. or spirally reinforced, the allowable load should be reduced by 15 percent.

Section 2.3.2.3

A new section is added as follows:

2.3.2.3 *Direct tension loads*—Cast-in-place concrete piles subjected to axial tension (uplift) loads are designed for the full tension load to be resisted by the reinforcing steel (Section 2.5.3.4). However, when the design uplift load results in a tensile stress in the concrete less than about $3\sqrt{f_c'}$, both concrete and steel behave elastically and the possible elongation may be estimated considering the design uplift load to act over the gross cross-sectional area A_c of the concrete.

Comment: There have been occasions where engineers have computed the elongation of a pile resulting from an uplift load by considering the full-length reinforcing steel acting alone in resisting uplift which resulted in some cases in excessive theoretical elongations. Many uplift tests and countless uplift loads on reaction piles have demonstrated the actual elongation of the pile is substantially less than the theoretical elongation of the steel bar. Although the mechanics may not be clear as to the interaction of the steel, concrete and soil, it is quite evident that some method should be used for determining more realistic axial elongations due to uplift loads on piles. The above suggested wording recognizes that the concrete does possess some tensile strength and although not used in the design could be considered in computing elongation of the pile.

Section 2.4.5, first paragraph

The first sentence is replaced with the following: "If soil relaxation or freeze can occur, the final penetration resistance during initial *driving* of the pile is generally not an indication of the actual pile static capacity."

Section 2.4.5, third paragraph

The following sentence is added to the end of the paragraph: "Retapping of piles produces more valid information if the hammer-cushion-pile system is the same as for initial driving."

Section 2.4.6

The first sentence is expanded as follows: "... are installed without excessive preexcavation such as jetting or predrilling." The following is added at the end of the section: "(See Sections 5.1.6 and 5.1.7.)"

Section 2.4.7

The last sentence is deleted and the following added in its place: "Liquefaction generally does not occur below a depth of 30 ft and, at most, 50 ft. Further, it is not likely to occur within a pile group because of the soil compaction resulting from pile driving. It may, however, occur around the perimeter of a pile group; therefore, under these conditions the stability of the group should be evaluated.

"Some soils exhibit temporary liquefaction during pile driving with corresponding reduction in penetration resistance. The reestablishment of the soil resistance can be detected by moderate redriving of the pile, but under severe conditions where redriving immediately creates liquefaction, the capacity of the pile may have to be determined by load testing."

Section 2.4.8, third paragraph

The last sentence is expanded as follows: "... heave conditions unless positive measures are taken to prevent heave."

Section 2.4.8, fourth paragraph

The paragraph is revised as follows:

If pile heave occurs, the unfilled shells or casings for cast-in-place concrete piles and most precast concrete piles can be redriven to compensate for heave. Uncased cast-in-place concrete piles containing full length reinforcement may be subjected to a limited amount of redriving to reseat the pile. Uncased cast-in-place concrete piles without internal reinforcement should be abandoned if heaved. Sectional precast concrete piles having slip-type joints may be redriven to verify that they are sound and that the joints are closed. However, in the case of sectional piles, all of the heave should be considered to have occurred at a single joint and the joint must not have been completely opened as a result of pile heave. If necessary, cased cast-in-place piles can be redriven to compensate for heave *after* the shell is filled with concrete if proper techniques are used. A wave equation analysis can be used to design the hammer-cushion combination required for such redriving.

Section 2.4.9, third paragraph

The paragraph is revised as follows:

The placing of concrete in steel pile casings should be kept approximately 10 ft from pile driving except where ground heave or relaxation occur. In such cases, the concreting operation must not be closer to the pile driving than the heave range or the range within which redriving is required. Uncased cast-in-place concrete piles should be installed on a stagger system to avoid damage to freshly placed concrete by the driving of adjacent piles.

Section 2.5.1, second paragraph

The paragraph is revised as follows:

Except for auger-injected piles and drilled and grouted piles, drilled type piles are usually a minimum of 16 in. in diameter except that if construction or inspection personnel must enter the shaft, the minimum diameter should be at least 30 in.

Section 2.5.2, first paragraph

The paragraph is revised to read:

2.5.2 *Pile shells*—Pile shells or casings driven without a mandrel should be of adequate strength and thickness to withstand the driving stresses and to transmit the driving energy without excessive losses. Proper selection can be made with a wave equation analysis. Pile shells driven with a mandrel should be of adequate strength and thickness to maintain the cross section of the pile after the mandrel is withdrawn.

Section 2.5.3

In the first sentence "compressive stress" is changed to "compressive load." In the third sentence "short dowels" is changed to "dowels."

The second sentence of the second paragraph is changed to read: "Longitudinal bars used to carry a portion of the axial load may be discontinued along the pile shaft when no longer required because of load transfer into the soil, but not more than two bars should be stopped off at any one point along the pile."

Section 2.5.3.2, first paragraph

The last sentence is deleted and reference to Section 2.5.3.3 is added at the end of the paragraph.

Section 2.5.3.2, second paragraph

In the first sentence "is usually" is changed to "should be."

Section 2.5.3.3

The following new section is added:

2.5.3.3 *Effective prestress*—For prestressed concrete piles the effective prestress after all losses should not be less than 700 psi. During the manufacturing of prestressed piles which may be subjected to direct tensile stresses, the ratio of tensile strength f_t to compressive strength f_c' of the concrete should be determined at least every 3 months or with any change in aggregate source or preparation (see Section 3.1.5.4). If the tensile strength f_t is less than $7.5\sqrt{f_c'}$, the effective prestress should be increased to provide the difference between f_t and $7.5\sqrt{f_c'}$.

Section 2.5.3.4, first paragraph

Section 2.5.3.3 becomes Section 2.5.3.4 and the first paragraph revised to read:

2.5.3.4 *Reinforcement for cast-in-place concrete piles.* Except for pipe and tube piles of adequate wall thickness and not exposed to detrimental corrosion, reinforcement is required in cast-in-place concrete piles for any unsupported section of the pile, uplift loads, or lateral loads when the analysis indicates.

Section 2.5.3.4, third paragraph

The following is added to the third paragraph of the new Section 2.5.3.4: "For pipe or tube piles, dowels embedded in the concrete or welded to the shell may be used to transfer the uplift loads from structure to pile."

Section 2.5.3.5

Section 2.5.3.4 becomes Section 2.5.3.5. In the table, a footnote reference is added to "Precast reinforced piles—Normal exposure" and the following footnote added to the table: "A cover of 1.5 in. has been used for precast piles 12 in. and smaller in diameter which are cast vertically and internally vibrated from the bottom up as the concrete is placed."

Section 2.5.5, second paragraph

In the last sentence, the words "some of the present local building codes" are changed to "the applicable building code."

Section 3.1.1.1

The section is revised as follows:

3.1.1.1—Except for the limitations herein and in Sections 3.1.1.2 and 3.1.1.3, portland cement should conform to one of the following specifications:

1. Portland cement: ASTM C 150 Types I, II, III, or V.
2. Blended hydraulic cement: ASTM C 595 Types IS, IS (MS), or IP.

If pozzolan cement is used, the pozzolan content should not exceed 20 percent by weight.

Section 3.1.1.2

This section is revised as follows:

3.1.1.2—For concrete piles used in soil containing from 0.10 to 0.20 percent water soluble sulfate (as SO_4) or used in water containing from 150 to 2000 ppm (as SO_4) the concrete should be made with cement containing not more than 8 percent tricalcium aluminate (C_3A) such as Type II or a moderate sulfate (MS) resistant cement. In environments where the water soluble sulfate exceeds 0.20 percent or the sulfate solution contains from 2000 to 10,000 ppm, portland cement with the tricalcium aluminate content limited to 5 percent (e.g., Type V) should be used. For very severe sulfate exposure (more than 10,000 ppm) Type V cement with a fly ash admixture should be used.[35]

Comment: Blended hydraulic cements are now included in Section 3.1.1.1. Section 3.1.1.2 covers the environmental requirements formerly in Section 3.1.1.1. Specific cements for marine exposure have been deleted in preference to general requirements concerning the C_3A limitations. Types II and V cements are very difficult to obtain in many places and the same results as Type II can be achieved with any moderate sulfate (MS) resistant cement. Also Type I can be obtained with C_3A content not exceeding 8 percent. The revised sulfate contents come from latest study by Bureau of Reclamation and will be published in the 8th Edition of the *Concrete Manual* of the U. S. Bureau of Reclamation.

Section 3.1.1.3

The following new subsection has been added:

3.1.1.3—Where silica in the aggregates is reactive with alkali of the cement, a cement containing less than 0.60 percent alkali should be used.

Section 3.1.2

The following is added as the second sentence in the paragraph: "In general the use of reactive aggregates in concrete piles should be avoided."

Section 3.1.3, second paragraph

The last part of the "note" is revised to read: "... of higher cement content or more cover over reinforcement."

Section 3.1.4, first paragraph

The first two sentences of the paragraph are deleted.

Comment: Air entrainment should be obtained by means of admixtures rather than air-entraining cements because of the greater control obtainable with admixtures. Furthermore the amount of air required could vary with job specifications, etc., and therefore the use of admixtures provides for greater flexibility as compared to the air-entraining cement in bulk.

Section 3.1.5.1, first paragraph

The last sentence is changed and a sentence is added to the end of the paragraph as follows: "For structural concrete, 752 lb per cu yd is considered a reasonable maximum. Reduced coarse aggregate concrete (see Section 5.5) requires an increased cement content and mixes containing as much as 846 lb of cement per cu yd have been used."

Comment: A reduced coarse aggregate content has been found to be very beneficial in filling cast-in-place concrete pile shells under difficult placement conditions.

Section 3.1.5.3

The last sentence of the section is revised to read: "It is desirable to limit the slump of a concrete mix to a minimum consistent with placement requirements and methods. For cast-in-place piles, the usual slump for structural concrete is 4 to 6 in. and for reduced coarse aggregate concrete from 3 to 5 in. For precast piles, a slump of from 0 to 3 in. is recommended."

Section 3.1.5.4

The third sentence of this section is revised to read: "At least one set of tests consisting of not less than two test specimens should be made for every 20 cu yd of concrete placed, but not less than one set for each day's concreting."

The following is added to the last sentence: "... as the concrete piles except in the case of cast-in-place concrete piles where this procedure is not practical."

Section 3.1.5.4, new paragraph

The following paragraph is added to Section 3.1.5.4:

The direct tensile strength of concrete f_t may be determined by measuring the splitting tensile strength f_{sp} in accordance with ASTM C 496 or by measuring the flexural tensile strength f_r in accordance with ASTM C 78 assuming that $f_t = 0.5f_{sp}$ or $f_t = 0.4f_r$. Specimens should be made in accordance with ASTM C 31 and for flexural tests should be 6 x 6 in. The tensile strength should be based on the average of tests on at least ten specimens. For verification of the ratio of tensile to compressive strength, the corresponding compressive strength should be based on the average of at least eight standard compression tests (ASTM C 39).

Comment: This relates to the requirement that the ultimate strength of the prestressing steel be checked to see that it is greater than the cracking load on the concrete. In connection with this, the ratio of tensile strength to compressive strength is to be checked periodically. However, this would require coverage of tensile tests in Chapter 3 per above. The relationship between the ultimate tensile strength and the splitting tensile strength or the flexural tensile strength is taken from *Design of Concrete Structures* by Winter and Nilson.

Section 3.1.5.5

A new Section 3.1.5.5 is added as follows:

3.1.5.5 *Sulfate exposure*—Concrete used for piles which will be exposed to a sulfate environment such as seawater should be made with a portland cement having a limited C_3A content in accordance with Section 3.1.1.2. However the quality of such concrete is of equal or greater importance and a rich mix with a low water-cement ratio should be used. Concrete with a low absorption factor (low permeability) is less susceptible to sulfate attack. The use of air-entraining admixtures is recommended to reduce the water-cement ratio and the permeability of the concrete.

Comment: This added section emphasizes the importance of high quality concrete for sulfate exposure.

Section 3.1.5.6

A new Section 3.1.5.6 is added as follows:

3.1.5.6 *Exposure to freezing and thawing*—Concrete used for piles which will be exposed to freezing and thawing should contain an air-entraining admixture.

Comment: Although this was covered in the former Section 3.1.4 it was more or less buried in a section on admixtures. It is felt that this topic deserves a separate section because of its importance.

Section 3.5

The section is revised as follows:

Grout used for auger-injected piles, for pre-placed aggregate piles and for drilled and grouted piles should consist of a mixture of approved portland cement, sand, admixtures, and water proportioned and mixed so as to provide a grout capable of maintaining the solids in suspension without appreciable water gain, which may be pumped without difficulty and which will laterally penetrate and fill any voids in the soil or preplaced aggregate. Admixtures should include pozzolan and grout fluidifier possessing characteristics which will increase the flowability of the mixture, assist in the dispersal of cement grains and neutralize the setting shrinkage of the cement mortar. Under certain conditions it may be advisable to include an admixture which will produce expansion not exceeding 4 percent. Grout used to fill sheet-pile interlocks should consist of a pumpable mix of sand, cement, and water. Grout used to fill the prestressing ducts for post-tensioned prestressed piles usually consists of a mixture of portland cement and water proportioned to produce a pumpable mix.

Section 4.2.5, second paragraph

The paragraph is changed to read:

Where severe freezing conditions exist and hollow piles may have water inside the pile, subsurface vents or holes should be provided to permit circulation or drainage of the water.

Comment: The deleted sentences relate to pile installation and not pile manufacturing. The subject will be covered in Chapter 5.

Section 4.3.3

The second sentence of this section is deleted:

Comment: The deleted portion does not relate to placement of prestressed reinforcement and is covered in a revised Section 4.6.

Section 4.5.3.1, fourth paragraph

In the third sentence, "enclosures" is changed to "embedded items."

Section 4.5.3.2

This four-paragraph section is deleted.

Section 4.5.3.3

This section is renumbered as Section 4.5.3.2. In the third paragraph, "of the mass" is deleted from the second sentence and the entire last sentence is deleted.

Section 4.5.4.4, third paragraph

In the first sentence, "shape of the unit" is changed to "shape of the pile." In the fourth sentence "curing operation" is changed to "curing chamber."

Section 4.5.6

This section is deleted.

Section 4.6

This section is given a new title, "Pile manufacturing," and extensively revised as follows:

4.6.1 *Post-tensioned piles.* Post-tensioned piles are often manufactured in sections from 12 to 16 ft long, and may be either centrifugally cast or cast in vertical forms. During casting, longitudinal holes are formed for the prestressing steel which is stressed after the sections are assembled to make up the required pile length.

Individual sections should be lined up so that the maximum deviations in the alignment of the outside surfaces at the joint between any two adjacent sections will not exceed ¼ in. and the maximum deviation circumferentially in the alignment of the holes for prestressing steel will not exceed ¼ in. at the joint.

The abutting joint surfaces should be covered by a sealing material of sufficient thickness to fill all voids between end surfaces except at the prestressing steel ducts. After the sealing material is applied, pile sections should be brought into contact and held together by compression while the sealing material sets.

After completion of the prestressing, the ducts should be pressure grouted and both the grout pressure and the stress in the prestressing steel maintained until the grout has attained sufficient strength. Piles should not be handled or moved in any way detrimental to the pile during this period. Prestressing steel ducts should be grouted in accordance with the provisions of Chapter 26 of ACI 318-63 and Chapter 3 of this report.

4.6.2 *Prestressing*—Minimum concrete strengths should be 3500 psi for pretensioned piles at the time of stress transfer and 4000 psi for post-tensioned piles at the time of prestressing unless higher strengths are required by the design. For post-tensioned piles, grout must have sufficient strength to prevent slippage of prestressing steel at the time of stress transfer.

4.6.3 *Tolerances*—Unless otherwise specified, concrete piles should be manufactured to the following dimensional tolerances:

1. Length: ± ⅜ in. per 10 ft of length.
2. Cross section: −¼ in. to +½ in.
3. Wall thickness of hollow sections: −¼ in. to +⅜ in.
4. Deviation from straight line: not more than ⅛ in. per 10 ft of length.

5. Deviation of internal core or void from true position: ±3/8 in.

6. Pile head: ±1/4 in. per ft of head dimension from true right angle plane. Surface irregularities: ±1/8 in.

7. Location of reinforcing steel: Main reinforcement cover, −1/8 in. +1/4 in.; Spacing of spiral, ±1/2 in.

Comment: Revised Section 4.6 contains the provisions of former Section 4.5.3.2. It also contains formed Section 4.5.6 and the provisions deleted from Section 4.3.3. These have been modified to include the required concrete strength at the time of stress transfer for pretensioned piles, at the time of prestressing for post-tensioned piles, and the grout strength at stress transfer for post-tensioned piles. The section on manufacturing tolerances has been revised to include tolerances for cross section of both solid and hollow piles.

Section 5.1.1.0

This section is revised as follows:

5.1.1.0 *General.* The most common method of installing concrete piles is by means of hammer blows. Pile driving hammers are of several different types and have rated energies presently ranging from 356 ft-lb to 632,000 ft-lb per blow. The size of the hammer (rated energy) should be commensurate with the pile size, length, and weight and the driving requirements. The proper selection can be guided by a wave equation analysis. If the cushioning material including the capblock is held constant, a heavy ram with a relatively low impact velocity is more desirable than a light ram with a high impact velocity for controlling the peak stresses, especially when driving long piles. However any combination of ram weight and stroke can be used with the proper cushioning material to insure that the duration and magnitude of the peak force avoids damaging tensile and compressive stresses, and yet is adequate to develop the required pile capacity and penetration. The design of the hammer-cushion-pile system for a given set of conditions can be done with a wave equation analysis. See Section 5.2 where driving stresses are discussed.

Section 5.1.1.2

This section is revised as follows:

5.1.1.2 *Single acting hammers.* The single acting hammer uses steam or air pressure to raise the ram; the ram then falls under gravity, imparting its blow to the head of the pile. Sufficient pressure must be supplied to raise the ram to the top of its stroke, and thus trip the valve. External valve slide bars can sometimes be modified or adjusted so as to intentionally reduce the height of fall (ram velocity). Thus the delivered energy can be reduced to meet special driving conditions.

Section 5.1.1.4

This section is revised as follows:

5.1.1.4 *Differential acting hammers.* Differential acting hammers utilize steam, air, or hydraulic pressure to raise the ram and then to force it down. This type hammer differs from a double acting hammer in that on the down stroke the cylinder, both above and below the piston, is under equal pressure and the hammer exhausts only on the upward stroke. The downward force results from gravity and from the top of the piston being of larger area than the bottom (difference equals area of piston rod). For steam or air operated hammers, the exhaust is to the atmosphere, but for hydraulically powered hammers there is no exhaust because the hydraulic fluid is circulated through a closed system. These hammers have shorter strokes than comparable single acting hammers. The energy (velocity) is a function of the operating pressure. Control of the energy and ram velocity may thus be affected by the throttle. Correct operating pressure is indicated by a slight raising of the hammer base at each upward stroke. The maximum energy that a differential hammer can deliver is equal to the total weight of the hammer times the stroke of the hammer ram. The more rapid action of differential hammers, approximately twice that of single acting hammers, often results in easier penetration, particularly of clays, and in minimizing the total time of driving.

Section 5.1.1.5

In this section, the last two sentences are deleted and replaced with: "Although diesel hammers have relatively lighter rams and longer strokes than single acting, double acting, or differential hammers, the ram velocity at impact is less than the velocity resulting from the height of fall because of the cushioning effect in compressing the air in the combustion chamber. Some diesel hammers have a fuel throttle adjustment for controlling the ram stroke and thus the pile stresses during easy driving. The selection of the proper hammer-cushion-pile system for the driving conditions can be guided by special diesel hammer wave equation analysis."

Comment: The sentences were deleted because they were misleading in that they implied that diesel hammers are not recommended for driving prestressed piles whereas many piles are driven with such hammers. If the proper hammer-cushion system is used, it is not necessary that the ram weight be at least one-quarter of the pile weight. Recently some 160 ft prestressed concrete piles weighing about 80,000 lb were driven with a diesel hammer having a ram weight of 13,000 lb. The piles were driven to the required penetration without any problems. The required driving resistance may be altered but this is something that is readily adjustable for the conditions involved.

Section 5.1.1.6, first paragraph

This paragraph is revised as follows:

5.1.1.6 *Vibratory driving.* Rapid vibration of a pile will cause it to sink in certain soils, especially those which are cohesionless, such as sands and silts. Bias weight or down-crowd may be required in addition to the weight of the pile and the vibratory driver to achieve penetration during vibration. Predrilling or jetting may also be used.

Comment: Vibratory driving is not used as a supplement to jetting or direct load methods, but rather in most cases extra weight or force may be necessary to achieve penetration during vibration. The other sentence deleted was misleading in that the upward and downward forces are equal; therefore although axial impulses may be transmitted to the tip, the tip is also raised by opposite forces thus the downward vibratory force is not causing the penetration.

Section 5.1.1.6, fifth and sixth paragraphs

These two paragraphs are transposed so that the present sixth paragraph comes before the present fifth paragraph.

Section 5.1.2, second paragraph

This paragraph is revised as follows:

Concrete piles may be jacked down by hydraulic rams reacting against weights or anchors, or against previously installed piles. One recently developed machine uses long-stroke hydraulic rams reacting against the heavily loaded carriage of the machine. Another machine attaches itself hydraulically to several adjoining piles and then pushes on one while holding onto several, this being done alternately in a rhythm that moves the entire group of piles down. This type of machine is used primarily to install steel sheet piles.

Section 5.1.4, second paragraph

This paragraph is expanded by adding the following sentence: "However, where a 'soft' capblock is needed to control stresses and its disadvantages are not critical, a wood capblock may be the most economical material."

Section 5.1.4, fourth paragraph

This paragraph is revised as follows:

Pile cushions are used between the concrete pile and the driving head and are generally required for all types of precast piles to distribute the hammer blow, to protect the pile head, and to control driving stresses in the pile. They are usually of laminated construction consisting of softwood or hardwood boards often combined with plywood. The required thickness of cushioning material could be determined by a wave equation analysis for the driving conditions involved.

Comment: To include a discussion on the purpose for using pile cushions. The wave equation analysis is a useful tool in matching the amount of cushioning material with the required driving resistance for the hammer-pile-soil system.

Section 5.1.6.1

The following sentence is added at the end of the section: "In boulder or large-gravel soils, jetting may result in the collection of stones at the bottom of the jetted hole making it difficult to drive the pile through the concentration of boulders or gravel."

Section 5.1.6.2, first paragraph

The following sentence is added at the end of the first paragraph: "When installing open-end hollow concrete piles, high pressure internal jetting should not be used."

Comment: A word of caution is necessary to prevent buildup of jet water pressure inside of hollow concrete piles which could cause bursting or longitudinal splitting. This is industry practice.

Section 5.1.6.3

This section is revised as follows:

5.1.6.3 Antifriction jets are often grouped in pairs, or as a ring, so as to provide uniform distribution of water around the pile. Internal jets may have multiple nozzles to distribute the water around the pile.

Section 5.1.6.4

This section has been deleted.

Section 5.1.6.5

This section becomes Section 5.1.6.4 and is revised as follows:

5.1.6.4 Driving in some water-bearing sands with a hammer may force the water momentarily away from the sides of the pile, giving very high temporary resistance. Jetting may be beneficial in such cases.

Section 5.1.6.6

This section becomes Section 5.1.6.5. The second sentence is revised to read: "Most soils *may be* reconsolidated after jetting stops by driving on the pile with the hammer." The following is added after the last sentence: "Jetting should not be carried below the final pile tip elevation. The effect of jetting on adjacent structures and previously driven piles should be considered."

Section 5.1.7

This section is revised as follows:

5.1.7 *Predrilling*—In many soils, such as those containing hardpan, cemented strata, hard clay, or dense compacted sand, predrilling is the most effective technique. Dry predrilling can be done with either a continuous-flight auger or a short-flight auger whereas wet predrilling requires a hollow-stem auger or drill stem and various type spade bits. When wet predrilling is used, bentonite slurry or plain water may be used to keep the hole open. When drilling through clay, the clay soils may provide sufficient "mud" to maintain the hole.

Predrilling is a more controllable form of preexcavation than jetting with less possible detrimental effects on adjacent piles or structures or on the frictional capacity of the predrilled pile.

Comment: Jetting is not a form of predrilling whereas it is a form of preexcavation. It should be recognized that both dry and wet drilling are used and that clay soils may aid in keeping the hole open.

Section 5.1.8, third paragraph

The first and second sentences are revised as follows: "Excavating from within pipe piles, especially those of larger diameter, may be performed with air-lift pumps. Alternatively the material may be blown out with high pressure air or a combination of steam and water suddenly injected below the soil plug."

Section 5.1.10

A new section is added as follows:

5.1.10 *Lubrication*—Reverse electro-osmosis on steel shells has been used to draw the water from the soil to the pile, thus lubricating it to facilitate penetration. Sometimes pile lubrication can be achieved with water flowing from a hose around the pile at ground surface during driving.

Section 5.2.1.2

The third sentence is revised as follows: "Compressive stress at the pile tip when driving on bare rock can theoretically be twice the magnitude of that produced at the head of the pile by the hammer impact."

Section 5.2.1.3, first paragraph

The last two sentences are revised as follows: "It also can occur, although rarely, with light hammers when driving resistance is extremely hard at the point, such as bearing on solid rock. It can also occur as a result of jetting or predrilling when soil resistance has been removed from pile tip."

Section 5.2.2, second paragraph of subparagraph 1

This paragraph has been deleted.

Comment: This paragraph has generated several critical comments because of its inaccuracy and ambiguities. The Michigan test, subsequent dynamic measurements during pile driving, and countless wave equation analyses have all shown that both the capblock and the pile cushion reduce the energy delivered by the pile hammer. If excessive cushioning is used, the driving energy could be ineffective. However the report does recommend that cushioning materials be used for various reasons and in no way indicates that such cushioning is detrimental to achieving pile penetration or pile capacity. The report does point out that there are methods available (for example wave equation analysis) for matching the hammer-cushion-pile-soil system. The subject paragraph also points out that the cushion is usually substantially compressed during driving (thus increases the Enthru) whereas the preceding paragraph recommends that a new cushion be used for each pile and if driving is extremely hard the cushion may have to be replaced during driving a single pile. Furthermore, this problem is not too complex for handling by a proper wave equation analysis which should be recognized. The last sentence in the subject paragraph is true only because dynamic formulas do not take into account the elastic properties or amount of the cushioning material. Thus the results in solving such dynamic formulas would be the same regardless of the cushion use.

Section 5.2.2, subparagraph 2

The subparagraph is revised as follows:

2. When using steam-type hammers, driving stresses can be reduced by using a heavy ram with low impact velocity (short stroke) to obtain the desired driving energy rather than a light ram with a high impact velocity (long stroke). Driving stresses are proportional to the ram impact velocity. Driving stresses can also be reduced by using the proper cushioning material.

Section 5.2.3.2

This section is revised as follows:

5.2.3.2 When driving open-ended precast piles in sands, a plug can form and exert a splitting action. The plug can be broken up during driving by careful use of a low pressure jet inside, but the most practicable remedy appears to be the provision of adequate lateral steel in the form of spirals or stirrups.

Comment: When using an internal jet to break up a soil plug it is essential that low pressure be used to prevent bursting of the pile. This is a necessary precaution.

Section 5.2.3.4

A new section is added as follows:

5.2.3.4 Pile breakage may also result from the freezing of free water in the pile. Drain holes through the pile wall should be provided at the groundwater line and the pile filled with free draining material. For piles standing in open water, a concrete plug should be placed from the lowest freeze depth to above the high-water level. Drain holes should be located just above the surface of the plug. Alternatively the entire pile may be filled with concrete.

Section 5.2.5, second paragraph

In the first sentence, the words "or tapered" have been deleted.

Section 5.2.7, first paragraph

The title of the section has been changed to: "Distortion of pile or pile shell."

Section 5.2.7, third paragraph

The second sentence of this section is revised as follows: "Collapse while driving adjacent piles may be prevented by using heavier gage metal in the shells, by increasing the circumferential strength by corrugations, by inserting dummy cores, or by temporarily filling the pile shell with water."

Section 5.2.9, first paragraph

This section is revised as follows:

5.2.9 *Leaking of shells*—Leaking of shells is an indication of rupture. It frequently lets in sand or mud. Many such leaky shells can be properly salvaged if the soil is washed out and all remaining soil and water removed by pumping, siphoning, or bailing and the concrete placed in the dry. Under certain conditions the pile shell can be cleaned by blowing it out with air or steam (see Section 5.1.8). Under severe conditions it may be necessary to thoroughly wash out all foreign material and place the concrete through water by tremie methods. These last two steps require care, skill, and control, and should be permitted only when proper methods can be used and enforced.

Section 5.2.10

The following new section has been added:

5.2.10 *Enlarged tip piles*—When enlarged tip piles are driven through certain type soils it may be necessary to take special measures to reestablish the lateral support of the soil around the pile shaft or to reinforce the pile shaft against column action. The annular space created by the enlarged tip might be filled in by the driving of adjacent piles except that frequently such piles are used with relatively high design loads resulting in the use of single piles or two-pile groups for each column load. Clean sand could be washed and tamped into the annular space. If jetting or predrilling is necessary to achieve penetration of the enlarged tip, the possible loss of lateral support deserves special attention.

Comment: The problems associated with this type pile were not previously discussed in the report, as the problems with other types of piles have been.

Section 5.5, second paragraph

The paragraph has been revised as follows:

Each casing or hole should be inspected before filling with concrete to insure that it has not been closed in or partially filled by soil movements or pressures. Such inspections would also reveal the presence of any foreign material or excessive amounts of water as well as any detrimental damage to any casing used.

Section 5.5.1(a)

The following has been added to the end of the paragraph: "A concrete mix containing 800 lb of coarse aggregate per cu yd (reduced coarse aggregate concrete) with a corresponding increase in sand and cement content has been found to possess excellent cohesiveness and workability with a slump of 4 in. Such concrete mixes are well suited for filling long pile shells and shells under difficult placement conditions (e.g., steeply battered piles containing heavy reinforcement). This mix can be pumped, tremied, or placed by methods normally used. (See Section 3.1.5.1.)"

Comment: Reduced coarse aggregate concrete has had rather extensive use for filling pile shells with concrete and strengths up to 6000 psi have been developed. It is something the report should include to be abreast of latest techniques.

Section 5.5.4

The following is added at the end of the paragraph: "Generally vibration is not necessary if the proper concrete mix and placement techniques are used. Overvibration should be avoided because it may induce excessive bleeding."

Section 5.5.7

This section, including Subsections 5.5.7.1 and 5.5.7.2, is replaced by the following:

5.5.7 *Auger-injected-pile* — When filling the drilled hole as the auger is withdrawn, very careful control is essential to prevent separation or necking of the grout or concrete shaft and to provide a shaft of full cross-sectional area. All oil or other rust inhibitors should be removed from mixing drums and grout or concrete pumps. Grout used should conform to the requirements of Section 3.5, and if concrete is used, it should contain sufficient cement, proper size aggregates and required admixtures to produce a rich pumpable mix. The volume of grout or concrete placed should be measured and be greater than the theoretical volume of the hole created by the auger. Concrete or grout should be pumped under continuous pressure and the rate of withdrawal of the auger should be controlled so that the hole is completely filled as the auger is withdrawn. Unless the soil is sufficiently stable to resist without lateral movement the pressure head from the grout or concrete shaft, adjacent piles should not be installed until the grout or concrete has set. The top of each pile should be cast higher than the required pile cutoff elevation to permit trimming the pile back to sound grout or concrete. If there is evidence that the auger has been withdrawn too rapidly, it should be redrilled to the original tip elevation and the pile recast from the tip upwards. Each pile should be installed in one continuous operation. If reinforcement is required, the reinforcing bars should be accurately positioned and aligned and inserted into the pile shaft while the grout or concrete is still fluid.

Section 5.5.8

The following new section has been added; old Section 5.5.8 becomes Section 5.5.10:

5.5.8 *Preplaced aggregate piles*—When piles are formed by preplacing coarse aggregates in a drilled hole and injecting grout into the aggregates, filling the pile from bottom up, every precaution should be taken to insure a continuous pile shaft of full cross section which is grouted throughout. A sufficient number of grout pipes should be installed in each pile shaft to insure full penetration of the grout throughout the preplaced aggregate. Grout should conform to Section 3.5 and should be sufficiently fluid and placed under adequate pressure. When such piles are installed through unstable soils or where there is a possibility of the sides of the drilled hole sloughing off as the aggregate and grout pipes are placed, a temporary steel liner should be used. As the liner is withdrawn during the placement of aggregates, the bottom of the liner should be kept at least 1 ft below the surface of the aggregates being placed. During withdrawal of the temporary liner, precautions, such as vibration, should be used to prevent arching of the aggregate in the liner and a possibility of the intrusion of soil into voids resulting from such arching.

Section 5.5.9

This new section is added as follows:

5.5.9 *Drilled and grouted piles*—When installing drilled and grouted piles (see Section 1.1.2.7), care should be taken to insure a full size and continuous pile. All soil cuttings should be removed from the casing except those that will remain in suspension and be displaced with the drilling fluid. Reinforcing steel should have sufficient spacers to insure that the steel is maintained in its proper position. This is especially important when installing batter piles. Grout should conform to Section 3.5 and the casing should not be withdrawn faster than the hole is being filled with grout.

Section 5.5.10

Section 5.5.8 is now 5.5.10 and revised as follows:

5.5.10 *Cast-in-drilled-hole piles*—The placing of concrete in cast-in-drilled-hole piles as covered by this report should follow the same basic procedures as that for cased cast-in-place concrete piles. For unstable soils a temporary liner should be installed to prevent collapse of the hole or sloughing off of the soil during concrete placement. Temporary liners should also be used for deep drilled holes when the effects of concrete placement on the sides of the hole cannot be observed. When placing concrete in temporarily lined holes, the top of the concrete should be kept well above the bottom of the steel liner as it is withdrawn. Low slump or stiff concrete should not be used so as to avoid the possibility of arching of the concrete in the liner and possible discontinuities in the pile shaft as the liner is withdrawn. (See also ACI Committee 336 report.[1])

Section 5.6.2, third paragraph

The last sentence of the paragraph is changed to read: "The shoe should have a hole for escape of trapped air and water during casting of the pile."

Section 5.6.3(d)

The term "cushion blocks" has been changed to "pile cushioning material."

Section 5.6.4.1

The first sentence has been revised as follows: "Welded splices in shells or precast pile joints must consider the effect of repeated impact."

Section 5.6.4.3

This section is revised as follows:

5.6.4.3 When splicing load-bearing steel shells, backup plates or other suitable techniques should be employed to insure full weld penetration especially for shells 3/8 in. or thicker.

Section 5.6.5, first paragraph

The second sentence is revised as follows: "They may be used to break up hard strata, such as coral, ahead of the pile or to secure penetration of soft or disintegrated rock."

Section 5.9

A new subparagraph is added as follows:

(f) Wrapping with special fabric closed at top and bottom and pumping grout under pressure, filling space between fabric and pile from bottom up, displacing the water which is forced out through the fabric.

References

Reference 4 is revised and 22 references are added as follows:

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22. Davisson, M. T., "Static Measurements of Pile Behavior," *Proceedings*, Conference on Design and Installation of Pile Foundations and Cellular Structures, Lehigh University, 1970, pp. 159-164.

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2. Peck, R. B.; Hanson, W. E.; and Thornborn, T. H., *Foundation Engineering*, 2nd Edition, John Wiley & Sons, Inc., New York, 1974.

3. Chellis, R. D., *Pile Foundations*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, 1961.

4. Davisson, M. T., "High Capacity Piles," *Proceedings*, Lecture Series, ASCE Illinois Section, 1972.

5. Report on Allowable Stresses in Concrete Piles, Portland Cement Association, Chicago, June 1971.

6. Peck, R. B., "A Study of the Comparative Behavior of Friction Piles," *Special Report* No. 36, Highway Research Board, 1958.

7. Peck, R. B., "Records of Load Tests on Friction Piles," *Special Report* No. 67, Highway Research Board, 1961.

8. ACI Committee 350, "Concrete Sanitary Engineering Structures," ACI Journal, *Proceedings* V. 68, No. 8, Aug. 1971, pp. 560-577. Discussion with corrections: ACI Journal, *Proceedings* V. 69, No. 2, Feb. 1972, pp. 125-132. (Also in *ACI Manual of Concrete Practice*, Part 2.)

METRIC CONVERSION FACTORS

To convert from	To	Multiply by
in.	cm	2.54
in.^{2}	cm^2	6.54
lb	kg	0.4536
psi	kgf/cm^2	0.07031
ft	m	0.3048
ft-lb	m-kgf	0.1383

This report was submitted to letter ballot of the committee which consists of 17 members; 15 members returned ballots, all voted affirmatively.