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February 21, 2013

Wayne Thorne CBO
Building Official
Town of Longboat Key
501 Bay Isles Road
Longboat Key, FL 34228-3196

RE: Code Review / Foundation Nomenclature Determination
KEG File # 10RS-0362

Dear Mr. Thorne:

Further to our discussion on February 20, 2013, I have reviewed the 2010 Florida Building Code (FBC), 2007 FBC, 1971 Standard Building Code (SBC) and several other resources to identify further guidance in the characterization of certain structural components. Of critical importance is 2010 FBC Section 3109 Structures Seaward of a Coastal Construction Control Line and specifically 3901.1.1 Scope. Exception: which reads, "*The standards for buildings seaward of a CCCL area do not apply to any modification, maintenance or repair of any existing structure within the limits of the existing foundation which does not require, involve, or include any additions to, or repair or modification of, the existing foundation of that structure.*"

As we discussed, the villa structures at the project in question are comprised of spread footing foundations, piers/columns, steel beams, conventional lumber joist floors, conventionally framed wood walls, and conventionally framed/trussed roofs. The purpose of this correspondence is to identify whether or not the piers/columns between the spread footings and steel beams are part of "foundations" under the code and therefore repairing them would trigger 2010 FBC 3109. Unfortunately, 2010 FBC does not specifically define or address the configuration at the project in question, so we must consider other relevant resources in determining the intent of the code. As documented below, a reasonable consideration of 2010 FBC, 2007 FBC, 1971 SBC, standard definitions of construction terminology and along with numerous published engineering resources as further referenced below, the piers/columns in this specific case need not be considered foundations and labeling them "piers" does not render them foundation elements. Consequently, the vertical structural elements may be repaired under the 2010 FBC, Existing Buildings without triggering 2010 FBC 3109.

Standard Definitions (Layman's Terminology)

The word "pier" is defined as an intermediate support of two bridge spans, a structure extending into navigable water as a mooring place or promenade, or a vertical support, usually square and often masonry that resists vertical loads, in some references, the vertical support definition also includes that part of walls between window openings and auxiliary masonry used to stiffen walls. These definitions are taken from Mirriam-Webster, Oxford, Random House Webster' College, Princeton's WorldNet, Kernerman English Learner's and Webster Dictionaries. None of the layman's terminology definitions includes or mentions "foundation". Conversely, most of the standard definitions refer to wall, window or roof support.

Standard Engineering/Foundation Engineering Texts

In standard engineering terminology, foundations are identified as deep or shallow, but in all cases are structural elements that bear on the earth. "Piers" are deep foundation elements similar to piles or caissons that bear directly on competent rock or soil strata beneath the surface. These types of piers are distinguished from footings in that their depth is large compared to their width (4 times greater or more). Under the standard engineering/foundation engineering terminology, the foundations at the project in question are spread footings and do not satisfy the definition of piers. Further, the vertical elements whether they are labeled columns or piers in the layman's (non-engineering) terminology are supported by the footings and therefore are not the foundations.

Cheng Liu and Jack Evett, *Soils and Foundations*, Prentice Hall 1992, an engineering textbook, contains relevant excerpts including the definition of the word "foundation" in engineering terms. It is generically simply that which supports something. In buildings, foundations may be either deep foundations or shallow foundations. Shallow foundations are further defined as either a footing, which may be an enlargement of the base of the column or wall which is supported [and is considered separately], or a mat or raft foundation in which a number of columns are supported by a single slab. Figures 9-1 and 9-2 clearly indicate the footing and the column as described separately and configured comparably to the project in question. Deep foundations are defined as pier, caisson or groups of piles.

Edwin H. Gaylord, Jr., and Charles Gaylord, *Structural Engineering Handbook*, McGraw Hill, 1990, a standard engineering reference text, contains relevant excerpts including descriptions of "footing foundations" distinct from "piers". Footing foundations are shallow, located at the highest level where adequate supporting soils are present but below frost. Individual (isolated) footings support a single column. Figure 39 indicates the footing as distinct from the column it supports. Pier footings are principally different from footings in that the piers must have considerable depth to reach suitable bearing stratum, generally greater than four times the width of the pier.

Robert W. Day, *Foundation Engineering Handbook*, McGraw Hill/ASCE Press, 2005, a standard engineering reference text, contains relevant excerpts including definitions of common types of foundations, including spread footings identified as shallow foundations, and piers identified as deep foundations. 5.4.2 defines piers as deep foundations similar to auger-cast-in-place piles and includes illustrations of pier construction.

<u>2010 Florida Building Code</u>

The 2010 FBC does not define piers as necessarily foundations. The 2010 does not refer to pier foundations according to standard engineering terminology. The 2010 FBC refers to piers as foundations only in the context of the layman's (non-engineering) terminology, and further only related to masonry construction. The Piers are foundations when they are bearing directly on the soil.

1802.1 defines foundations. The section explicitly defines the foundation as footing, mat, slab-on-grade or similar foundation element.

2121.2.6.1 refers to piers in the context of the layman's (non-engineering) terminology as the vertical elements between windows on enclosed sections, requiring that the piers be more than 16 inches if masonry, and steel or reinforced concrete if less than 16 inches.

2121.2.6.2 refers to piers in the context of the layman's (non-engineering) terminology as the vertical masonry elements supporting the roof beam, requiring that they be not taller than 10 times least horizontal dimension and with continuous reinforcing from the beam to the foundation below the pier.

1808.9 makes it clear that the FBC considers piers as vertical masonry structural members, and not necessarily foundations. It is a section that is written to provide direction on the design of foundation elements that don't meet the definition of "foundation pier" to be designed as piers, walls or columns as applicable and in accordance with ACI 530/ASCE 5/TMS 402. The definition of "foundation pier" in FBC Section 2102 matches that in ACI 530/ASCE 5/TMS 402. In other words, if the masonry foundation element which is in contact with the soil doesn't meet the dimensional requirements of a foundation pier (which has empirical design parameters) it must be designed the same way as a masonry non-foundation vertical member (which has analytical design requirements) in accordance with the referenced standard.

1809.9 as with 1808.9, this section refers to a pier, like a column or wall, as a vertical element supported by a footing, in this case a footing constructed of masonry units.

ACI 530/ASCE 5/TMS 402 – Masonry Design Code

This code referenced by the 2010 FBC governs the design of masonry. It includes definitions of columns, piers, and foundation piers. Under the masonry code, piers match the layman's definition. The difference between columns and piers is strictly dimensional. The differences between piers and foundation piers are that foundation piers are foundation elements, piers are more rectangular, and that foundation pier height is limited more than pier height. As "foundations" are elements that bear on the soil, it is reasonable to interpret this difference as indicating "foundation piers" bear on soil rather than footings. It is noteworthy that this code concerns masonry and not reinforced concrete. The following excerpts are directly quoted:

1.6 Definitions:

Column — An isolated vertical member whose horizontal dimension measured at right angles to its thickness does not exceed 3 times its thickness and whose height is greater than 4 times its thickness.

Pier — An isolated vertical member whose horizontal dimension measured at right angles to its thickness is not less than 3 times its thickness nor greater than 6 times its thickness and whose height is less than 5 times its length.

Foundation pier — An isolated vertical foundation member whose horizontal dimension measured at right angles to its thickness does not exceed 3 times its thickness and whose height is equal to or less than 4 times its thickness.

ACI 318 Concrete Design Code and Commentary

The vertical structural elements at the project in question are columns and are not piers or footings under ACI 318. The 2008 edition of the reinforced concrete design code referenced by 2010 FBC includes reference to "piers" as deep foundations as in the standard engineering terminology established above. The term "pier" used in ACI 318 does not apply to the vertical structural elements at the project in question. The 2011 edition (not yet adopted) adds "wall piers", which matches the layman's terminology. This term also does not apply to the vertical structural elements at the project in question.

1.1.6 indicates that piers are governed by ACI 318 only in seismic regions. The commentary also identifies foundation piers as 2-1/2 feet in diameter or larger made by excavating a hole in the soil and then filling it with concrete.

2.2 – Definitions (2008 Edition) defines a column. The vertical structural elements at the project in question fit the definition precisely.

2.2 — Definitions (2011 Edition) defines "wall piers" and is the only other pier referenced in ACI 318 that is not a deep foundation.

Chapter 15 governs the design of footings. It does not reference piers. The chapter applies to the design of the footing only, and not the supported vertical elements. The footings excluding the vertical structural elements at the project in question fit the chapter precisely. The vertical structural elements are not governed by the chapter at all, but in fact are governed by Chapter 10 which concerns columns and beams.

2007 Florida Building Code

Though no longer in effect, the 2007 FBC included a definition of "pier foundations" and dimensional constraints that exclude the vertical structural elements at the project in question, which are 10" x 10" square columns.

1808.1 defines "pier foundations" as foundation elements that extend into bearing strata and derive their capacity from end bearing on the strata and/or skin friction against the strata.

1812.2 says that piers that are used as foundations shall have a minimum dimension of at least 2 feet.

1971 Standard Building Code

Additional guidance can be derived from the 1971 SBC, which was in effect when the building was designed. The provisions cited herein are also unchanged in the 1973 SBC. The SBC identifies the foundation as being the footing that is not less than 12" below grade. The SBC uses "pier" in both the layman's (non-engineering) terminology and in the standard engineering terminology. It identifies "pier" in the layman's (non-engineering) terminology as masonry vertical elements that are not foundations. It describes piers as foundations in the standard engineering definition terminology as deep foundations under the Caisson section with our without a bell at the base.

1302 says that buildings shall be supported by footings or foundations not less than 12" below grade.

1304 identifies the requirements of pier foundation (in standard engineering terminology) construction as deep caissons, not shallow footings.

1402 Table 3 identifies "Footings" under the heading of "Foundations" and "Piers" under the heading of "Masonry Other Than Foundation Masonry"

1405.6 identifies lateral support requirements for masonry piers to be spaced such that the unsupported height is not less than 10 times the least dimension, so for a 16" pier, the unsupported height could be 13'-4" as in a wall between windows.

1701.3 states that "spot piers" can be used as foundations for wood construction. "Spot piers" is not defined but presumably refers to foundation piers in the modern sense, that is, piers that don't have footings and therefore act as the foundations bearing on the soil.

Conclusion

As identified in the references cited herein, the villa structures at the project in question include footings as their shallow foundations, which support separately constructed vertical members that are columns under ACI 318. These elements may be labeled columns or mis-labeled piers, but in either case are not required to be considered "part of the foundation". The columns are not "foundation piers" as they are not masonry and they do not bear on the soil, either vertically or horizontally, and do not meet the dimensional constraints of foundation piers. In any case, the foundation is the footing that supports the vertical members.

There are three types of "piers" defined in the technical and non-technical documents: 1) vertical load carrying elements that are not foundations and are only partially distinguished from "columns" by material, dimensional proportionality and colloquialism, 2) deep foundations distinguished from auger-cast piles and caissons by dimensional proportionality, inspect-ability, and colloquialism, 3) dimensionally specific masonry "foundation piers" that do not have footings and therefore are foundations. Foundation piers are successful as foundations because their relatively stout dimensions and restricted loading results in soil bearing and skin friction pressures lower than the capacities of the soil.

At the project in question, the vertical elements between the foundations and beams do not conform precisely to any of the defined pier types. They are closest to type 1) but do not fit its definitions. Because these vertical structural elements do not fit the definitions of "foundation piers, or "piers", but do precisely fit the definition of "columns", they should correctly be considered columns.

Based on reasonable consideration of, 2010 FBC, 2007 FBC, 1971 SBC, standard definitions of construction terminology and numerous published engineering resources, the piers/columns in this specific case need not be considered foundations. Labeling them "piers" does not render them foundation elements. Because the footings are undeniably foundations, and the piers/columns may be reasonably excluded from the foundations, and the footings are undamaged with no repair contemplated, the piers/columns may reasonably be repaired under the 2010 FBC, Existing Buildings without triggering 2010 FBC 3109, provided the repair is in accordance with 2010 FBC, Existing Buildings.

Thank you for your ongoing support and assistance with this complex project. We continue to appreciate both your commitment to the public safety and welfare, and your sensitivity to the unit owners. We trust this information is helpful, should questions arise, please do not hesitate to call.

Sincerely,
Karins Engineering Group, Inc.

2/21/13

David G. Karins, P.E.
President
Florida Registration # 52677

DAVID G. KARINS
LICENSE
No 0052677
STATE OF
FLORIDA
PROFESSIONAL ENGINEER

pier

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pier

Definition of PIER

Like

1 : an intermediate support for the adjacent ends of two bridge spans

2 : a structure (as a breakwater) extending into navigable water for use as a landing place or promenade or to protect or form a harbor

3 : a vertical structural support: as

a: the wall between two openings

b: PILLAR, PILASTER

c: a vertical member that supports the end of an arch or lintel

d: an auxiliary mass of masonry used to stiffen a wall

4 : a structural mount (as for a telescope) usually of stonework, concrete, or steel

See pier defined for English-language learners »
See pier defined for kids »

Examples of PIER

<tied the boat up at the *pier*>

Origin of PIER

Middle English *per,* from Old English, from Medieval Latin *pera*

First Known Use: 12th century

Related to PIER

Synonyms: float jetty landing levee dock quai quay wharf

[+]more

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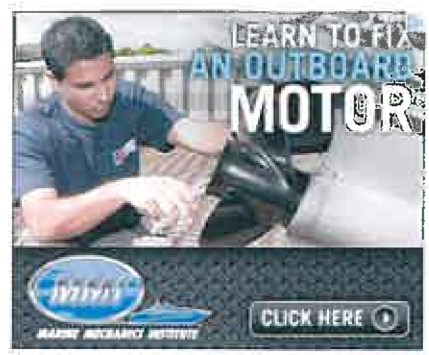

Other Nautical Terms

avast aweigh flotsam jib keel lee port starboard stay

Rhymes with PIER

beer bier blear cere cheer clear dear deer Deere drear ear fear fere fleer gear hear here jeer leer mere mir near pe

[+] more

pier noun (Concise Encyclopedia)

In building construction, a vertical load-bearing member such as an intermediate support for adjacent ends of two BAYS or spans. Bulkier than a column but smaller than a wall, a pier can support an arch or beam. The lower portion of a pier may be widened to better distribute the downward pressure of a massive overlying structure. In Romanesque and Gothic architecture, a feature of the NAVE arcade is the compound pier, which is cross-shaped in cross section, with shafts placed in the recesses.

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What made you want to look up *pier*? Please tell us where you read or heard it (including the quote, if possible).

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Also trying to discover the difference between a pier and a wharf -- and a quay -- and a dock.

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Shirley Wicker

Living in Washington, a state having one of the longest shorelines and natural deed water ports, I've heard the term "piered" used many times-eg."They sailed in to anchor at a piered docking area instead of anchoring offshore." So I tried to play the word in "Words With Friends", a game much like "Scrabble", and was very surprised to find it's not in the dictionary!

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Bob Lacson

Want to find out the difference between pier and wharf.

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pier

Pronunciation /pɪə/

Translate **pier** | into French | into German | into Italian | into Spanish

Definition of **pier**

noun

1 a platform on pillars projecting from the shore into the sea, typically incorporating entertainment arcades and places to eat
- a structure projecting from the shore into a river, lake, or the sea, used as a landing stage for boats
- a breakwater or mole

2 *British* a long, narrow structure projecting from an airport terminal, giving passengers access to an aircraft

3 a solid support designed to sustain vertical pressure, in particular:
- the pillar of an arch or supporting a bridge
- a wall between windows or other adjacent openings.

Origin

Middle English: from medieval Latin ***pera***, of unknown origin

pier in other Oxford dictionaries

Definition of **pier** US English

Nearby words

Piedmont
piedmont
pieman
Piemonte
piemontite
pier
pier glass
pier table
pierce
pierce someone's heart
Pierce, Franklin

Word of the day

guyliner
/ˈɡʌɪlʌɪnə/
noun
eyeliner that is worn by men ...
See full definition »

SIGN UP

Random House Webster's College Dictionary

pier pɪər *(n.)*

1. a structure built on posts extending from land out over water, used as a landing place for ships, an entertainment area, etc.
   Category: Civil Engineering
2. (in a bridge or the like) a support for the ends of adjacent spans.
   Category: Civil Engineering
3. a square pillar.
   Category: Building Trades
4. a portion of wall between doors, windows, etc.
   Category: Building Trades, Architecture
5. a pillar or post on which a gate or door is hung.
   Category: Building Trades
6. a support of masonry, steel, or the like for sustaining vertical pressure.
   Category: Civil Engineering, Building Trades, Architecture

Origin of **pier**:
bef. 1150; ME *pere* < AL *pera, pera* pier of a bridge, of obscure orig.

Princeton's WordNet

1. **pier, wharf, wharfage, dock** *(noun)*
   a platform built out from the shore into the water and supported by piles; provides access to ships and boats
2. **pier** *(noun)*
   (architecture) a vertical supporting structure (as a portion of wall between two doors or windows)
3. **pier** *(noun)*
   a support for two adjacent bridge spans

Kernerman English Learner's Dictionary

1. **pier** *(noun)* ɪər
   a long structure built out from the shore into water
   people fishing on the city pier

Webster Dictionary

1.
   Pier *(noun)*

   any detached mass of masonry, whether insulated or supporting one side of an arch or lintel, as of a bridge; the piece of wall between two openings

2.
   Pier *(noun)*

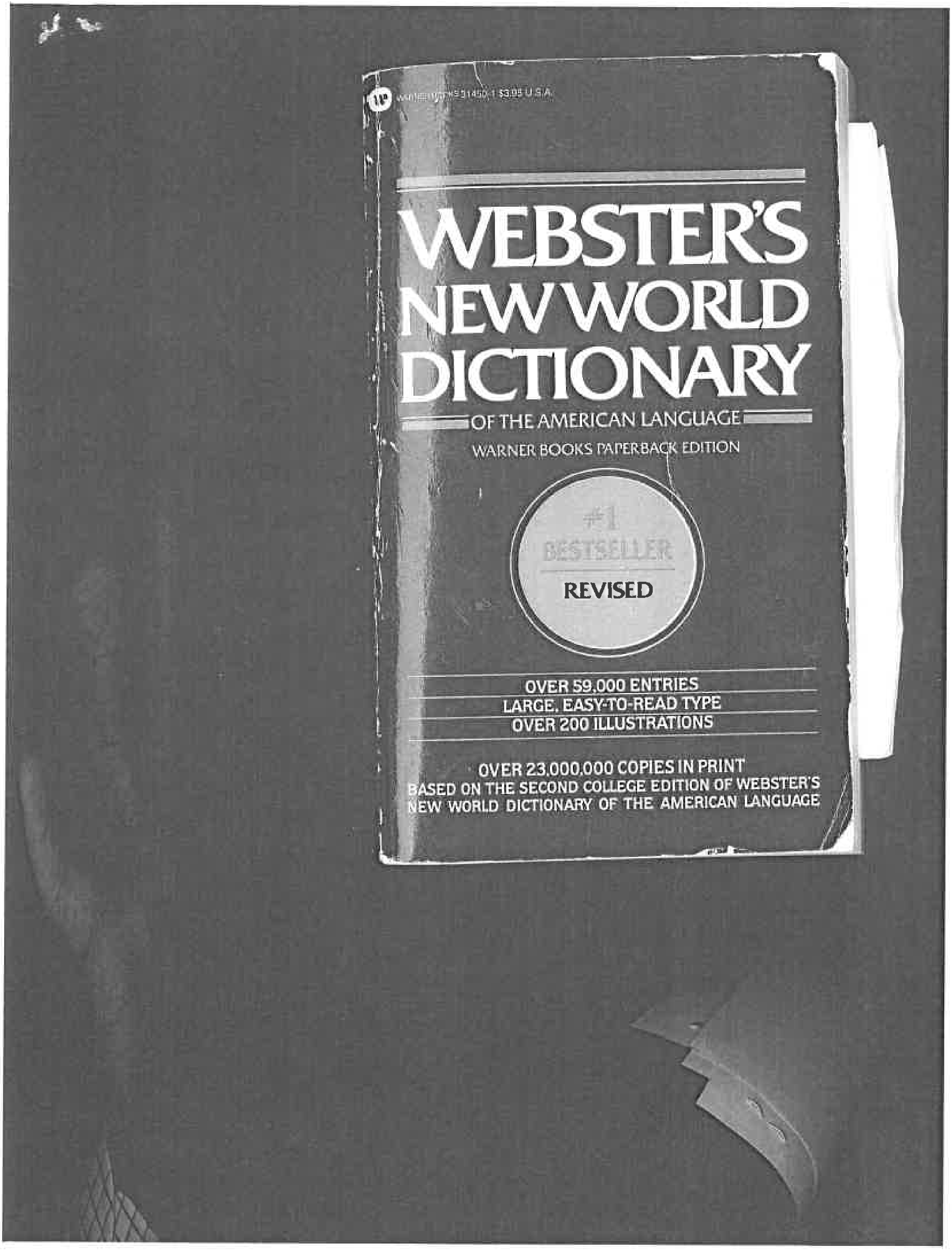
   any additional or auxiliary mass of masonry used to stiffen a wall. See Buttress

3.
   Pier *(noun)*

   a projecting wharf or landing place

pick·le (pik′'l) *n.* [< MDu. *pekel*] 1. any brine, vinegar, etc. used to preserve or marinate food 2. a vegetable, esp. a cucumber, preserved in this 3. [Colloq.] an awkward situation —*vt.* **-led, -ling** to put in a pickle solution
pick′pock′et *n.* a thief who steals from pockets, as in a crowd
pick′up′ *n.* 1. a picking up 2. the process or power of increasing speed 3. a small, open delivery truck 4. [Colloq.] a casual acquaintance 5. [Colloq.] improvement 6. a device for producing electric currents from the vibrations of a phonograph needle
pick·y (pik′ē) *adj.* **-i·er, -i·est** [Colloq.] overly fastidious; fussy
pic·nic (pik′nik) *n.* [< Fr.] a pleasure outing at which a meal is eaten outdoors —*vi.* **-nicked, -nick·ing** to have a picnic —**pic′nick·er** *n.*
pi·cot (pē′kō) *n.* [< Fr. *pic*, a point] any of the small loops forming a fancy edge as on lace
pic·to·graph (pik′tə graf′) *n.* 1. a picture or picturelike symbol used in a system of writing 2. a graph using pictures to give data
pic·to·ri·al (pik tôr′ē əl) *adj.* 1. of, containing, or expressed in pictures 2. suggesting a mental image; vivid —**pic·to′ri·al·ly** *adv.*
pic·ture (pik′chər) *n.* [< L. *pingere*, to paint] 1. a likeness of a person, scene, etc. produced by drawing, painting, photography, etc. 2. a perfect likeness or image [the *picture* of health] 3. anything suggestive of a beautiful painting, drawing, etc. 4. a vivid description 5. a motion picture 6. the image on a TV screen —*vt.* **-tured, -tur·ing** 1. to make a picture of 2. to show visibly 3. to describe 4. to imagine —**in** (or **out**) **of the picture** considered (or not considered) as involved in a situation
pic′tur·esque′ (-chə resk′) *adj.* like or suggestive of a picture; beautiful, vivid, quaint, etc.
picture window a large window that seems to frame the outside view
pid·dle (pid′'l) *vi., vt.* **-dled, -dling** [< ?] to dawdle; trifle
pidg·in (pij′in) *n.* [supposed Chin. pronun. of *business*] a jargon for trade purposes, using words and grammar from different languages: **pidgin English** uses English words and Chinese or Melanesian syntax
pie (pī) *n.* [ME.] a baked dish of fruit, meat, etc., with an under or upper crust, or both —**(as) easy as pie** [Colloq.] extremely easy
pie·bald (pī′bôld′) *adj.* [< *pie*, magpie + BALD] covered with patches of two colors —*n.* a piebald horse, etc.
piece (pēs) *n.* [OFr. *pece*] 1. a part broken or separated from the whole 2. a section of a whole regarded as complete in itself 3. any single thing, specimen, example, etc. [a *piece* of music] 4. a quantity, as of cloth, manufactured as a unit —*vt.* **pieced, piec′ing** 1. to add pieces to, as in repairing 2. to join (*together*) the pieces of —**go to pieces** 1. to fall apart 2. to lose self-control
‡**pièce de ré·sis·tance** (pyes′ də rā zēs tāns′) [Fr., piece of resistance] 1. the principal dish of a meal 2. the main item in a series
piece goods *same as* YARD GOODS
piece′meal′ (-mēl′) *adv.* [< ME. *pece*, a piece + *-mele*, part] piece by piece —*adj.* made or done piecemeal
piece′work′ *n.* work paid for at a fixed rate per piece of work done
pied (pīd) *adj.* [< *pie*, magpie] spotted with various colors
pie′-eyed′ *adj.* [Slang] intoxicated
pier (pir) *n.* [< ML. *pera*] 1. a structure supporting the spans of a bridge 2. a structure built out over water and supported by pillars: used as a landing place, pavilion, etc. 3. *Archit.* a heavy column used to support weight
pierce (pirs) *vt.* **pierced, pierc′ing** [< OFr. *percer*] 1. to pass into or through as a pointed instrument does; stab 2. to make a hole in 3. to force a way into; break through 4. to sound sharply through 5. to penetrate with the sight or mind —*vi.* to penetrate
Pierce (pirs), **Franklin** 1804–69; 14th president of the U.S. (1853–57)
Pierre (pir) capital of S.Dak.: pop. 10,000
pi·e·ty (pī′ə tē) *n., pl.* **-ties** [< L. *pius*, pious] 1. devotion to religious duties, etc. 2. devotion to parents, family, etc. 3. a pious act
pif·fle (pif′'l) *n.* [Colloq.] anything considered trivial or nonsensical —**pif′fling** *adj.*
pig (pig) *n.* [OE. *picge*] 1. a domesticated animal with a broad snout and a fat body; swine; hog 2. a young hog 3. a greedy or filthy person 4. an oblong casting of metal poured from the smelting furnace
pi·geon (pij′ən) *n.* [< LL. *pipire*, to chirp] any of various related birds with a small head, plump body, and short legs
pi′geon·hole′ *n.* a small open compartment, as in a desk, for filing papers, etc. —*vt.* **-holed′, -hol′ing** 1. to put in the pigeonhole of a desk, etc. 2. to put aside indefinitely 3. to classify
pi′geon-toed′ (-tōd′) *adj.* having the toes or feet turned in
pig·gish (pig′ish) *adj.* like a pig; gluttonous; filthy —**pig′gish·ness** *n.*
pig·gy (pig′ē) *n., pl.* **-gies** a little pig —*adj.* **-gi·er, -gi·est** *same as* PIGGISH
pig′gy·back′ *adv., adj.* 1. on the shoulders or back 2. of or by a transportation system in which loaded truck trailers are carried on railroad cars
pig′head′ed *adj.* stubborn
pig iron [see PIG, sense 4] crude iron, as it comes from the blast furnace
pig·ment (pig′mənt) *n.* [< L. *pingere*, to paint] 1. coloring matter used to make paints 2. any coloring matter in the tissues of plants or animals
pig·men·ta·tion (pig′mən tā′shən) *n.* coloration in plants or animals due to pigment in the tissue
Pig·my (pig′mē) *adj., n., pl.* **-mies** *same as* PYGMY

pig′pen′ *n.* a pen where pigs are confined: also **pig′sty′** (-stī′) *pl.* **-sties′**
pig′skin′ *n.* 1. leather made from the skin of a pig 2. [Colloq.] a football
pig′tail′ (-tāl′) *n.* a long braid of hair hanging at the back of the head
pike[1] (pīk) *n. clipped form of* TURNPIKE
pike[2] (pīk) *n.* [Fr. *pique*] a former weapon consisting of a metal spearhead on a long wooden shaft (**pikestaff**)
pike[3] (pīk) *n., pl.* **pike, pikes** [ME. *pik*] a slender, freshwater fish with a pointed head
pik·er (pī′kər) *n.* [< ? *Pike* County, Missouri] [Slang] one who does things in a petty or niggardly way
pi·laf, pi·laff (pi läf′, pē′läf) *n.* [Per. & Turk. *pilāw*] rice boiled in a seasoned liquid and usually containing meat or fish: also **pi·lau′** (-lô′)
pi·las·ter (pi las′tər) *n.* [< L. *pila*, a pile] a supporting column projecting slightly from a wall
Pi·late (pī′lət), **Pon·tius** (pän′shəs, -chəs) Rom. procurator of Judea who condemned Jesus to be crucified
pil·chard (pil′chərd) *n.* [< ?] 1. a small saltwater fish of the herring family, the commercial sardine of W Europe 2. any of several related fishes; esp., the **Pacific sardine** found off the W coast of the U.S.
pile[1] (pīl) *n.* [< L. *pila*, a pillar] 1. a mass of things heaped together 2. a heap of wood, etc. on which a corpse or sacrifice is burned 3. a large building 4. [Colloq.] a large amount 5. *earlier name for* NUCLEAR REACTOR —*vt.* **piled, pil′ing** 1. to heap up 2. to load 3. to accumulate Often with *up* —*vi.* 1. to form a pile 2. to move confusedly in a mass (with *in, out, on*, etc.)
pile[2] (pīl) *n.* [< L. *pilus*, a hair] a soft, velvety, raised surface of yarn loops, often sheared, as on a rug
pile[3] (pīl) *n.* [OE. *pil*] a long, heavy beam driven into the ground to support a bridge, dock, etc.
pile driver (or **engine**) a machine for driving piles by raising and dropping a heavy weight on them
piles (pīlz) *n.pl.* [< L. *pila*, a ball] *same as* HEMORRHOIDS
pile′up′ *n.* 1. an accumulation of tasks, etc. 2. [Colloq.] a collision involving several vehicles
pil·fer (pil′fər) *vt., vi.* [< MFr. *pelfre*, booty] to steal (esp. small sums, etc.) —**pil′fer·age** (-ij) *n.* —**pil′fer·er** *n.*
pil·grim (pil′grəm) *n.* [< L. *peregrinus*, foreigner] 1. a wanderer 2. one who travels to a shrine or holy place as a religious act 3. [**P-**] one of the band of English Puritans who founded Plymouth Colony in 1620
pil′grim·age (-ij) *n.* 1. a journey made by a pilgrim to a shrine or holy place 2. any long journey
pill (pil) *n.* [< L. *pila*, ball] a small ball, tablet, etc. of medicine to be swallowed whole —**the pill** (or **Pill**) [Colloq.] any contraceptive drug for women, in pill form
pil·lage (pil′ij) *n.* [< MFr. *piller*, rob] 1. a plundering 2. loot —*vt., vi.* **-laged, -lag·ing** to plunder
pil·lar (pil′ər) *n.* [< L. *pila*, column] 1. a slender, vertical structure used as a support or monument; column 2. a main support of something
pill′box′ *n.* 1. a small box for holding pills 2. an enclosed gun emplacement of concrete and steel
pil·lion (pil′yən) *n.* [< L. *pellis*, a skin] an extra seat behind the saddle on a horse or motorcycle
pil·lo·ry (pil′ər ē) *n., pl.* **-ries** [< OFr. *pilori*] a device with holes for the head and hands, in which petty offenders were formerly locked and exposed to public scorn —*vt.* **-ried, -ry·ing** 1. to punish by placing in a pillory 2. to lay open to public scorn
pil·low (pil′ō) *n.* [OE. *pyle*] a cloth case filled with feathers, etc. used esp. to support the head in sleeping —*vt.* to rest as on a pillow
pil′low·case′ *n.* a removable covering for a pillow: also **pil′low·slip′**
pi·lot (pī′lət) *n.* [< Gr. *pēdon*, oar] 1. a steersman; specif., one licensed to steer ships into or out of a harbor or through difficult waters 2. a qualified operator of aircraft 3. a guide; leader —*vt.* 1. to act as a pilot of, on, etc. 2. to guide —*adj.* serving as a trial unit in testing
pilot film (or **tape**) a film (or video tape) of a single segment of a projected television series
pi′lot·house′ *n.* an enclosure for the helmsman on the upper deck of a ship
pilot light a small gas burner which is kept lighted to rekindle the principal burner when needed
pi·men·to (pi men′tō) *n., pl.* **-tos** [< Sp. < L. *pigmentum*, pigment] a variety of sweet red pepper: also **pi·mien′to** (-myen′-, -men′-)
pimp (pimp) *n.* [< ?] a prostitute's agent —*vi.* to act as a pimp
pim·ple (pim′p'l) *n.* [< ?] a small, often inflamed, swelling of the skin —**pim′ply** *adj.* **-pli·er, -pli·est**
pin (pin) *n.* [OE. *pinn*] 1. a peg, as of wood, or a pointed piece of stiff wire, for fastening things together, etc. 2. anything like a pin 3. an ornament or badge with a pin or clasp for fastening to clothing 4. *Bowling* one of the clubs at which the ball is rolled —*vt.* **pinned, pin′ning** 1. to fasten as with a pin 2. to hold firmly in one position —**on pins and needles** anxious —**pin down** 1. to get (someone) to commit himself as to his plans, etc. 2. to establish (a fact, etc.) —**pin (something) on someone** [Colloq.] to lay the blame for (something) on someone
pin·a·fore (pin′ə fôr′) *n.* [prec. + archaic *afore*, before] a sleeveless garment worn over a dress
pin′ball′ machine a game machine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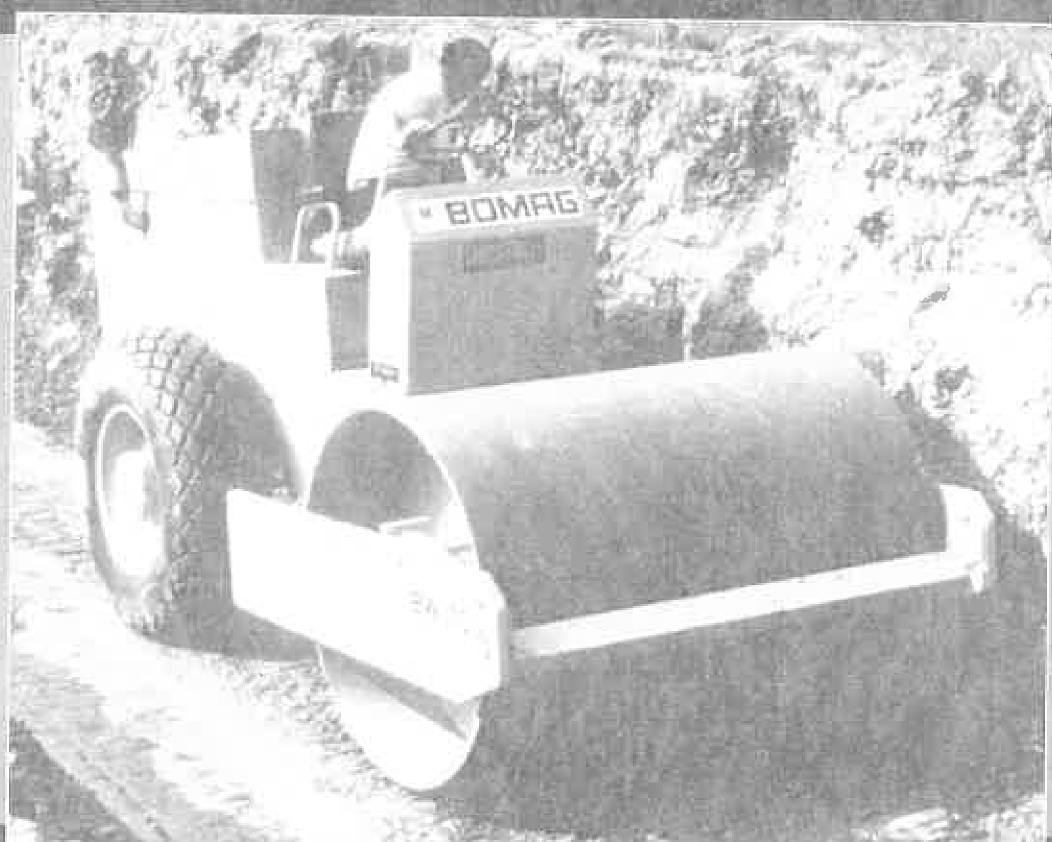

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9

Shallow Foundations

9-1 INTRODUCTION

The word *foundation* might be defined in general as "that which supports something." Many universities, for example, have an "athletic foundation," which supports in part the school's sports program. In the context of this book, foundation normally refers to something that supports a structure, such as a column or wall, along with the loads carried by the structure.

Foundations may be characterized as shallow or deep. *Shallow foundations* are located just below the lowest part of the superstructures they support; *deep foundations* extend considerably down into the earth. In the case of shallow foundations, the means of support is usually either a *footing,* which is often simply an enlargement of the base of the column or wall it supports, or a *mat* or *raft foundation,* in which a number of columns are supported by a single slab. This chapter deals with shallow foundations—primarily footings. For deep foundations, the means of support is usually either a pier, caisson, or group of piles. These will be covered in Chaps. 10 and 11.

An individual footing is shown in Fig. 9-1a. For purposes of analysis, a footing such as this may be thought of as a simple flat plate or slab, usually square in plan, acted on by a concentrated load (the column) and a distributed load (soil pressure) (see Fig. 9-1b.). The enlarged size of footing (compared to the column it supports) gives an increased contact area between footing and soil; the increased area serves to reduce pressure on the soil to an allowable amount, thereby preventing excessive settlement or bearing failure of the foundation.

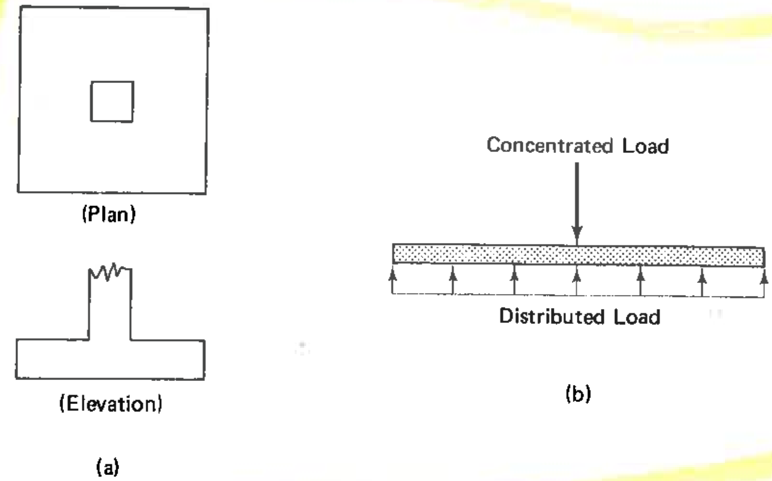


FIGURE 9-1 Individual footing.

Footings may be classified in several ways. For example, the footing depicted in Fig. 9-1a is an *individual footing.* Sometimes one large footing may support two or more columns, as shown in Fig. 9-2a. This is known as a *combined footing.* A footing extended in one direction to support a long structure such as a wall is called a *continuous footing,* or *wall footing* (Fig. 9-2b). Two or more footings joined by a beam (called a *strap*) are called a *strap footing* (Fig. 9-2c). A large slab supporting a number of columns not all of which are in a straight line is called a *mat* or *raft foundation* (Fig. 9-2d).

Foundations must be designed to satisfy three general criteria:

1. They must be located properly (both vertical and horizontal orientation) so as not to be adversely affected by outside influences.
2. They must be safe from bearing capacity failure (collapse).
3. They must be safe from excessive settlement.

Specific procedures for designing footings are given in the remainder of this chapter. For initial orientation and future quick reference, the following steps are offered at this point:

1. Calculate loads acting on the footing—Sec. 9-2.
2. Obtain soil profiles along with pertinent field and laboratory measurements and testing results—Chap. 3.
3. Determine depth and location of the footing—Sec. 9-3.
4. Evaluate bearing capacity of the supporting soil—Sec. 9-4.
5. Determine the size of footing—Sec. 9-5.

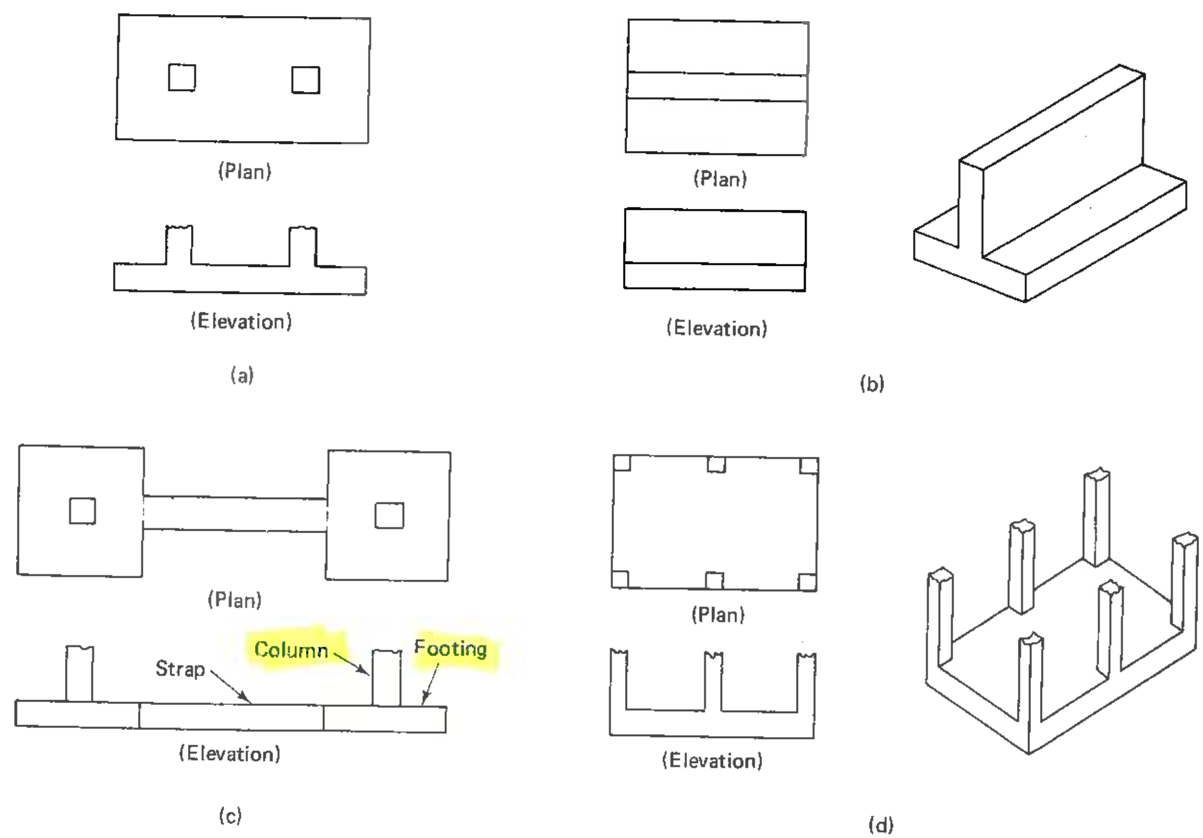
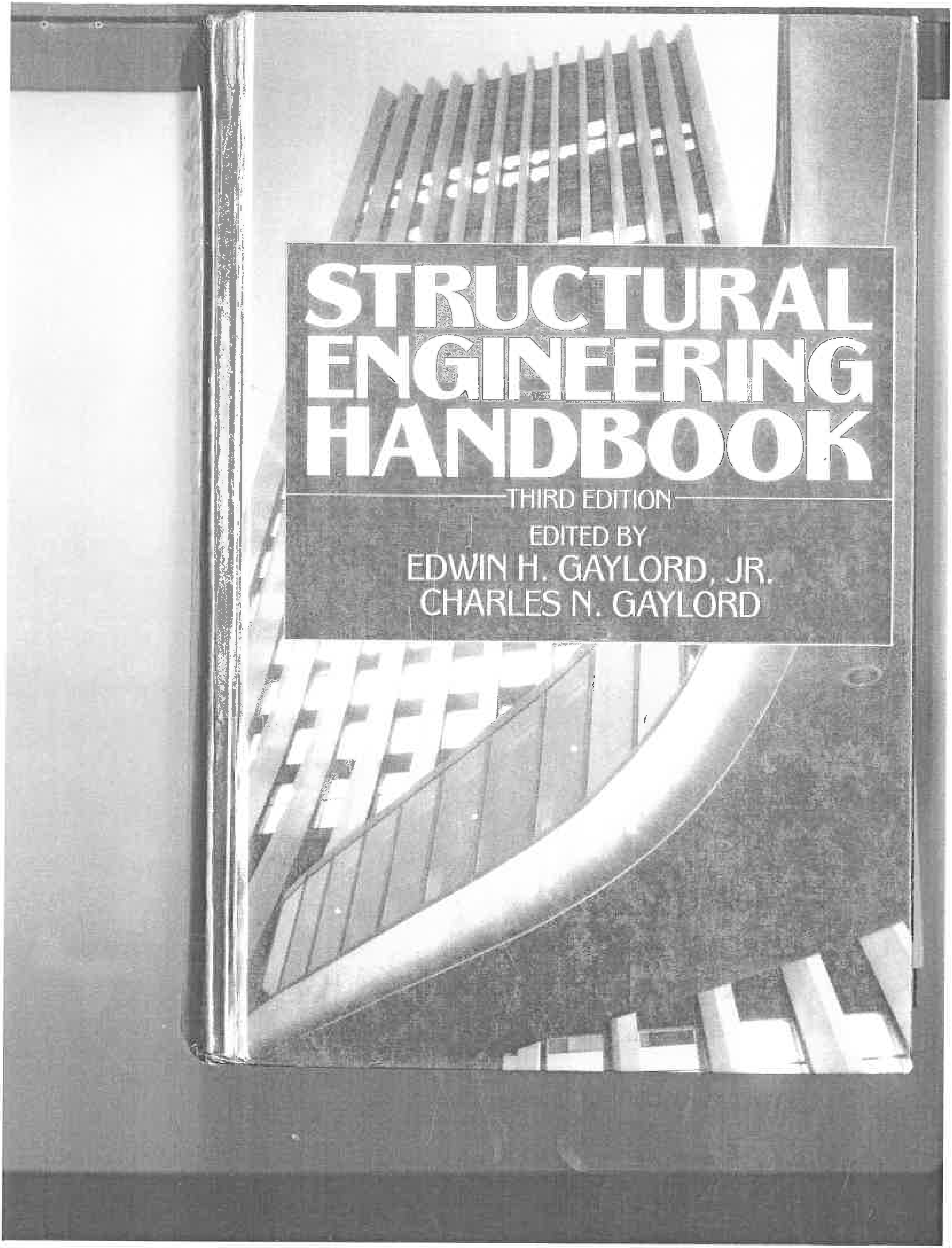


FIGURE 9-2 Classification of footings: (a) combined footing; (b) wall footing; (c) strap footing; (d) mat or raft foundation.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Contents

Particular care should be exercised in designing the anchor and anchor rods because, in reality, the anchor pull may be somewhat greater than computed. Therefore, it is prudent to be conservative in choosing allowable stresses in the anchor rods, and to make sure that the full cross section of the anchor rod is provided in every detail. The anchor block must be located far enough from the bulkhead to be outside the zone of the active earth pressure, and it must develop sufficient passive resistance to withstand the anchor pull. The passive resistance of the anchor block may be computed by using suitable soil constants from Table 2. If the anchor block is located below a line inclined at an angle ϕ with the horizontal and rising from the bottom of the sheeting (Fig. 14), the zone of passive earth pressure will not interfere with the zone of active earth pressure in a cohesionless soil, provided the anchor is located within a depth $h_1 = H \tan^2 (45° - \phi/2)$ from the ground surface, where H is the height of the sheet-pile wall. For a clay, the anchor block should be at a distance of at least $2H$ from the wall.

In many instances it is necessary to provide pile support for the anchorage. If the ground surface behind the anchored bulkhead is to be subjected to heavy surcharge

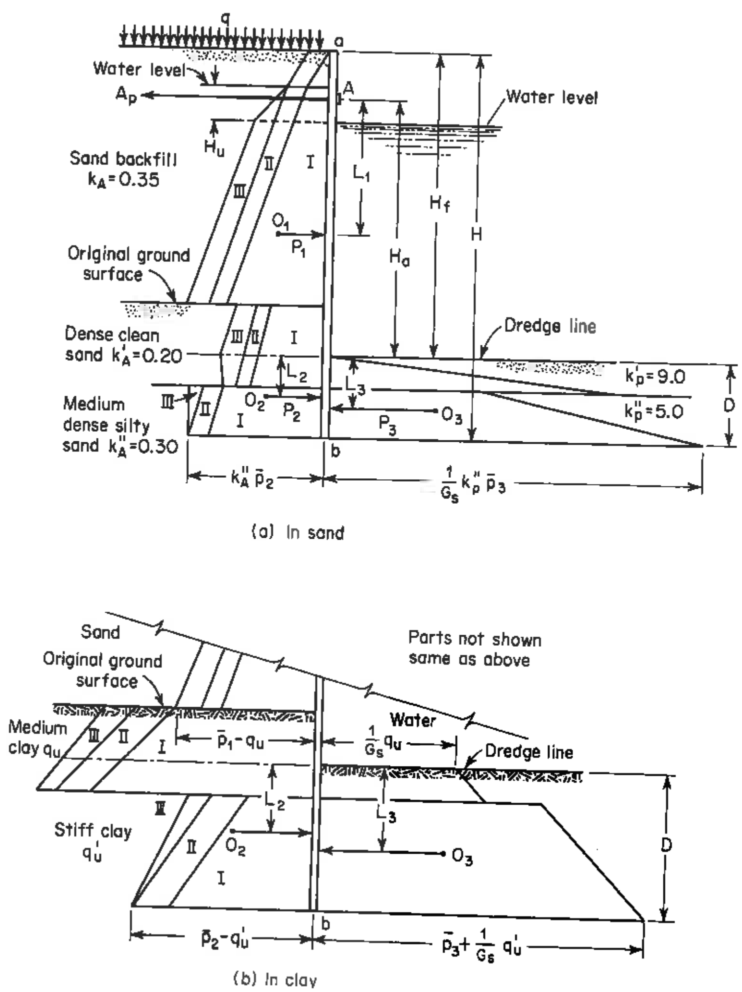

Fig. 13 Forces acting on bulkheads consisting of sheet piles driven into sand and into clay. *(From Ref. 4.)*

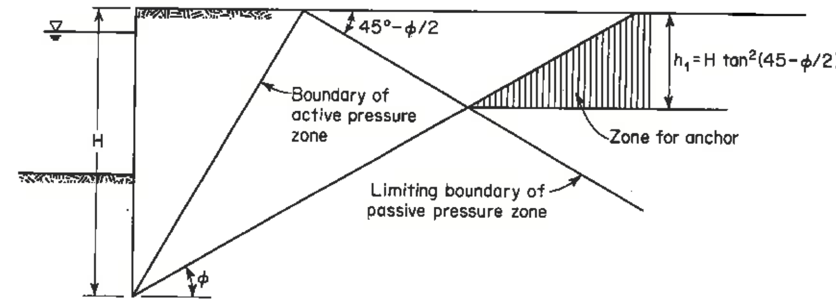

Fig. 14 Location of bulkhead anchor in cohesionless soil.

loads, it is advisable to enclose the anchor rods in pipes or conduits to prevent their being subjected to vertical loads due to the effects of differential settlement in the backfill.

The batter-pile bulkhead can be analyzed in a similar fashion. However, instead of providing anchor rods, the anchor pull is resisted by batter piles. The approximate resistance of a batter pile to tensile forces can be estimated by computing the shearing resistance on the embedded portion of the pile resulting from the adhesion between the soil and the pile. This resistance can be realistically determined only by conducting pulling tests on typical piles at the site. The horizontal component of the axial resistance of the batter pile must be adequate to develop the anchor pull with a factor of safety of at least 2.

Although the batter-pile anchorage eliminates some of the problems with conventional anchor rods, the margin of safety may be unusually low. It is customary to assume that the adhesion between a pile and the adjacent soil is equal to the cohesion of the soil. However, if the soil is relatively stiff, this assumption may seriously overestimate the adhesion. Furthermore, in the event a batter-pile anchorage approaches its ultimate capacity, there is no reserve strength once movement has started. The connection of the batter-pile anchorages to the sheet-pile wall is relatively complicated and should be carefully planned to ensure that every detail can properly transmit the loads that may come on it.

FOOTING FOUNDATIONS

Spread footings and column footings (isolated footings) usually support a single column, while combined footings usually support more than one. The combined footing is sometimes called a cantilever footing. However, the cantilever footing usually consists of two spread footings connected by a beam, with the column supported at or near the outside edge of one of the footings. A continuous (wall) footing usually extends for a considerable length and generally supports a load-bearing wall. With the exception of some lightly loaded footings, most are constructed of reinforced concrete. Typical examples are shown in Sec. 12, Fig. 39.

Ordinarily, footings are located at the highest level where adequate supporting material may be found, but precautions should be taken to ensure that they are located below the depth of seasonal volume change as a consequence of frost penetration or, in semiarid regions, seasonal changes in moisture that cause appreciable shrinkage and swelling of the soil. Even in the more humid regions soil-shrinkage problems frequently occur where foundations have been established at too shallow a depth, particularly if adjacent vegetation, such as trees, may place a demand on the available soil moisture during times of drought. The extreme depth of frost penetration in the United States is shown in Sec. 5, Fig. 1, but local experience is often the best criterion.

The size of a footing foundation for the support of a given load depends on the bearing capacity or settlement characteristics of the underlying subsoil. Since different procedures are used for clays, in contrast to sands, it is customary to classify the subsoil into one of these two categories.

The use of presumptive bearing pressures that appear in most building codes is not recommended except as a general guide or for unimportant structures where the cost of an engineering subsoil investigation would be disproportionate to the cost of the structure.

21. Footings on Clay The ultimate bearing capacity for a shallow footing on clay is

$$q_d = 2.5q_u\left(1 + \frac{0.2B}{L}\right)\left(1 + \frac{0.2D_f}{B}\right)$$

where q_u = average unconfined compressive strength within a depth equal to the width of the largest footing
B = width of footing
D_f = depth of footing
L = length of footing

A factor of safety of at least 3 should be provided; thus, the allowable bearing pressure is

$$q_a = 0.83q_u\left(1 + \frac{0.2B}{L}\right)\left(1 + \frac{0.2D_f}{B}\right) \tag{17}$$

It follows that q_u is often taken as the allowable bearing pressure for a square footing at shallow depths. Although correlations have been presented that relate q_u to the results of the standard penetration test (Sec. 5, Art. 7), such correlations are relatively crude and should not be used to determine the bearing capacity of footing foundations on clay.

If the footing is subjected to a resultant load at an eccentricity e, the width B should be replaced by an effective width $B' = B - 2e$. If there is also eccentricity about the second axis, it is sufficiently accurate to determine similarly an effective length L'. It is assumed that the total vertical load is uniformly distributed over the correspondingly reduced effective area.

At a factor of safety of 3, the stresses in the underlying clay are not likely to cause differential settlement between adjacent footings in excess of the generally accepted tolerable value of ¾ in, provided the footings are sufficiently far apart so that there is no overlap in the underlying stress patterns (Figs. 15 and 16) and provided that the underlying clay has an unconfined compressive strength greater than 2 tons/sq ft.

To forecast the magnitude of settlement or, more importantly, the differential settlement for foundations underlain by compressible clays generally requires laboratory consolidation tests on undisturbed samples. The settlement is given by

$$S = \frac{\Delta e}{1 + e_0} H \tag{18}$$

where Δe is the change in void ratio at the center of the compressible layer as a consequence of an increase in the original effective overburden pressure p_0 by an amount Δp, e_0 is the initial void ratio of the clay, and H is the thickness of the layer. Δe is best taken from the e-log p curve (Sec. 5, Fig. 9) obtained from a laboratory consolidation test. However, if the clay has a sensitivity (ratio of undisturbed to remolded strength) less than 4

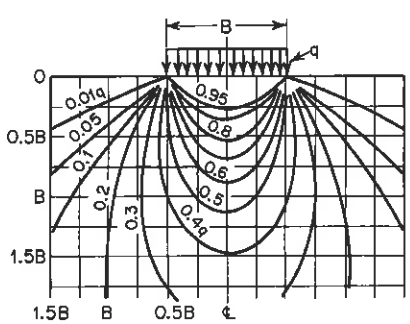

Fig. 15 Stresses beneath continuous footing.

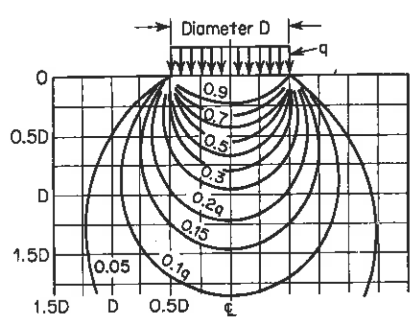

Fig. 16 Stresses beneath circular footing.

and has never been subjected to an overburden pressure greater than at present, i.e., is normally consolidated, a useful relationship is

$$\Delta e = C_c \log \frac{p_0 + \Delta p}{p_0} \tag{19}$$

The compression index C_c may be determined from a statistical relationship $C_c = 0.009 (L_w - 10 \text{ percent})$, where L_w is the liquid limit. For a normally consolidated clay the natural water content is generally closer to the liquid limit than the plastic limit.

The value of Δp is sometimes estimated by considering the surface load to be distributed uniformly on an area limited by a boundary that makes an angle of 30° with the vertical (Sec. 5, Fig. 10). However, a better procedure is to use the graphical representation of Boussinesq's equation, which is based on the theory of elasticity, commonly known as Newmark's influence chart (Fig. 17). This chart is prepared in such a way that a uniform load q covering any one of the influence areas will change the pressure at a depth AB below the center of the chart by $0.005q$. A drawing of the footing plan is prepared on transparent paper to a scale so that the distance AB shown on the chart is equal to the distance from the base of the foundation to the depth where the change in pressure is desired. The point at the ground surface where settlement is to be determined is then placed over the center of the chart, and the number of influence areas covered by loaded areas is determined separately for each. Then $\Delta p = \Sigma(0.005q$ times the number of influ-

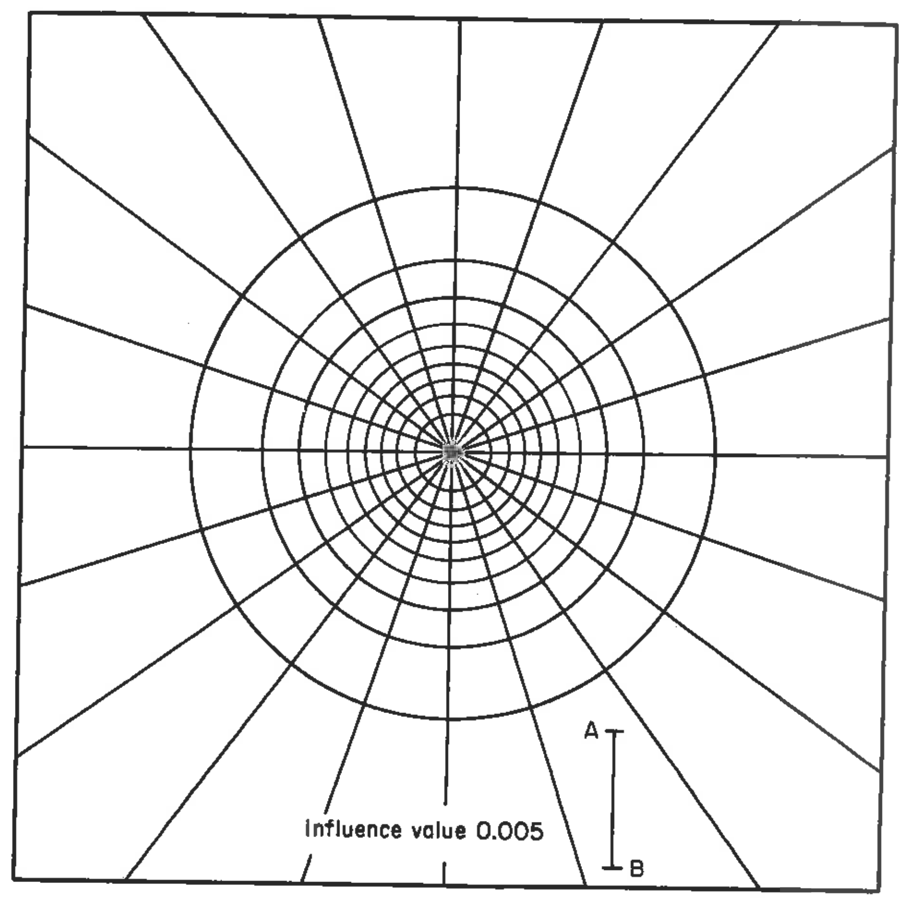

Fig. 17 Influence chart for computation of vertical pressure. *(After N. M. Newmark.)*

ence areas involved). If the pressure is desired at a different depth, a new drawing must be prepared to the appropriate scale AB = depth.

The loads that should be considered to determine the size and probable settlement of a foundation on clay are sustained loads that cause a change in stress beneath the foundation. Exceptional values of live load that may be present for a short time, such as wind loads, snow loads, and earthquake forces, should not be included. However, the factor of safety should not be less than 2 for the most unlikely combinations of loading specified in the building code.

The time required for a predicted settlement to develop is difficult to determine with much accuracy, as it depends to a large extent on the distance between drainage layers in situ. A rate-of-consolidation theory is discussed in Sec. 5, Art. 15, but it usually suffices for practical purposes to use

$$t_{\text{field}} = t_{\text{lab}} \frac{H_{\text{field}}^2}{H_{\text{lab}}^2} \qquad (20)$$

where t_{field} = time required in the field to obtain the same degree of consolidation as represented by the corresponding time in the laboratory
t_{lab} = time in laboratory from time vs. degree of consolidation curve
H_{lab} = thickness of laboratory sample
H_{field} = thickness between drainage layers in the field

This assumes that the sample and the stratum in the field have drainage at both the top and bottom. Otherwise, H should be taken as the greatest vertical-flow path required for water to reach a drainage surface in both sample and stratum.

22. Footings on Sand (See also Sec. 5, Art. 12.) The allowable soil pressure for a shallow footing on sand or other granular material depends on the relative density of the sand, the least width B of the footing, the depth of the foundation D_f, and the position of the groundwater table. The relative density is most readily investigated by means of the standard penetration test (Sec. 6, Art. 13). The standard penetration resistance N has been empirically related to the bearing capacity as the basis for Fig. 18. The value of N to be used in these charts is the average value in the poorest boring within a depth below the largest footing equal to its width B. However, for very fine or silty sands which are below the water table this value must be reduced as follows:

$$N' = 15 + \tfrac{1}{2}(N - 15) \qquad \text{for } N > 15$$

If the depth of the water table is within a depth B below the base of the footing, the values obtained from Fig. 18a must be multiplied by a correction factor which can be obtained from Fig. 19, where D_w is the distance from the base of the footing to the

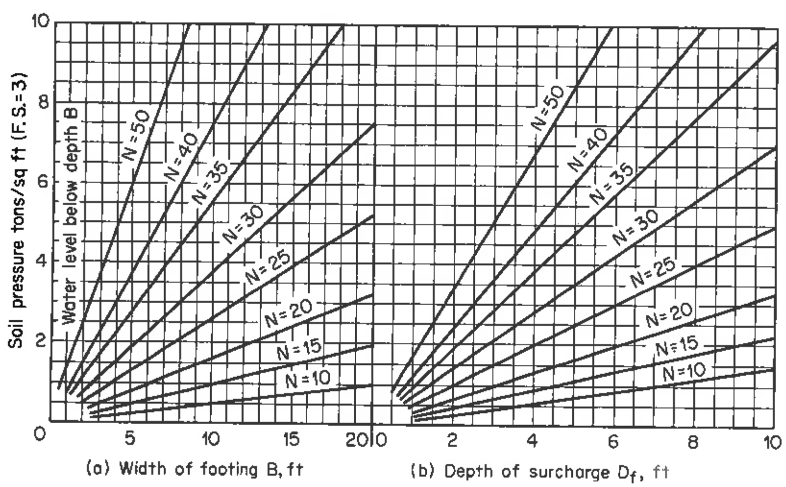

Fig. 18 Bearing-capacity charts for sand. (*From Ref. 5.*)

groundwater table as shown. If the groundwater level is above the base of the footing, the values of Fig. 18a should be multiplied by 0.5 and the values from Fig. 18b should be reduced by a correction factor from Fig. 19. The allowable bearing capacity is the sum of the corrected values from Fig. 18a and b.

The settlement of a footing on sand is similarly predicted from empirical procedures based upon the N value as a measure of the relative density in situ. Figure 20 shows the relationship between the N value and width of foundation for a limiting settlement of 1

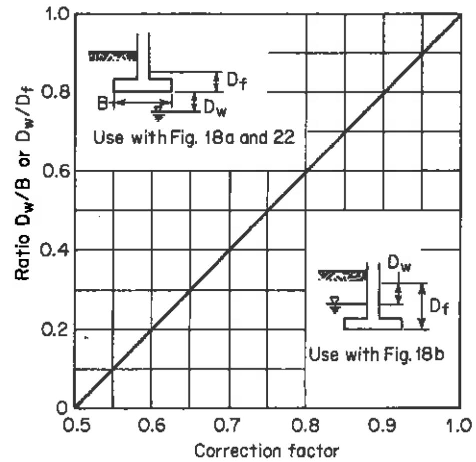

Fig. 19 Water-table correction chart.

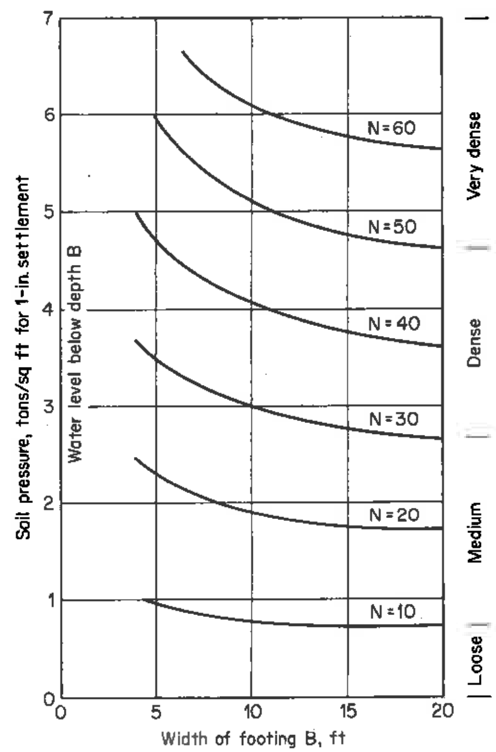

Fig. 20 Settlement chart for foundations on sand. (*From Ref. 5.*)

in. It is based on the condition that the groundwater is below the base of the footing a distance greater than the width *B*. Otherwise, the allowable soil pressure obtained from Fig. 20 must be corrected in the same fashion as previously described for Fig. 18*a*. If the allowable soil pressure based on settlement of the largest footing is used for proportioning all other foundations in the same structure, it is anticipated that the differential settlement between adjacent footings will not exceed three-fourths of the settlement of the largest footings, i.e., ¾ in. If a larger differential settlement is tolerable, the values taken from Fig. 20 may be modified by assuming that the settlement varies linearly with the intensity of the bearing pressure. Thus, if a differential settlement of 1½ in is tolerable, which corresponds to a maximum settlement of the largest footing of about 2 in, the values from Fig. 20 may be doubled.

Since the deformation of sand occurs almost instantaneously with application of load, settlement should be based upon the full dead load plus normal live load and snow or wind load, whichever is greater. This should be the maximum load that may ever reasonably be expected to act upon the footing. The same loads are suitable for the bearing-capacity determination, except that a factor of safety of 2 should be used under the most severe combination of loadings.

In the majority of cases the settlement of a foundation on sand will govern the design, as the corresponding factor of safety against a bearing-capacity failure will be quite large. The usual exceptions involve lightly loaded or wall footings which are often relatively narrow. In most cases, the soil pressure corresponding to a 1-in maximum settlement for the largest footing should be used to proportion all the smaller footings, with the precaution that the narrow footings be checked against the safe pressure obtained from Fig. 18. Whenever the allowable bearing capacity is smaller than the bearing pressure obtained from Fig. 20, the footings involved should be proportioned on the basis of the smaller value.

In earthquake regions, foundations should not be established on sand with an *N* value less than 25 blows per ft, because of the likelihood of spontaneous liquefaction due to seismic shocks. However, shallow foundations may prove satisfactory if the *N* value is at least 15 blows per ft, but these criteria are based on limited information and should be considered tentative.

23. Footings on Silt and Loess Footings on silt may be proportioned by assigning the silt to the category of either a sand or a clay (Sec. 5, Art. 12) and proceeding with the corresponding method for determining the foundation size. For important structures, a more elaborate procedure may be indicated wherein the shear strength of the silt is determined by either field vane tests (Sec. 6, Art. 14) or appropriate laboratory triaxial tests.

The behavior of loessial deposits may be quite different from that of either sand or clay, and the final foundation design requires a program of standard load tests (Sec. 6, Art. 17). The allowable soil pressure should not exceed one-third the failure load, as represented by the poorest load-settlement curve, or one-half the load at which ½ in of settlement was obtained in the load test, whichever is smaller.

Inasmuch as loessial deposits usually have a relatively loose structure which is likely to collapse under moderate loads if the natural water content increases, unusual precautions must be taken to ensure adequate surface drainage to prevent, insofar as possible, changes in the water content. A procedure reported by Kezdi as developed in Hungary is based upon a so-called index of collapsibility:

$$i = \frac{\Delta e}{1 + e_1} \qquad (21)$$

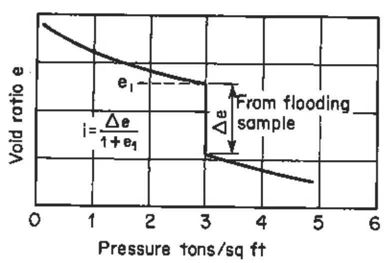

Fig. 21 Index of collapsibility for loess. *(After Kezdi.)*

where Δe is the change in void ratio in a consolidation test as a consequence of adding water when the consolidation pressure is 3 tons/sq ft, and e_1 is the void ratio just prior to adding water (Fig. 21). Experience suggests that for values of i less than 0.02 the structure of the loess is not dangerous for the support of footing foundations, but if it exceeds 0.02 precautions are necessary. This may require the use of deep foundations.

RAFT FOUNDATIONS

A raft foundation is essentially a large combined footing which covers the entire area beneath a structure. It is likely to be more economical than individual footings whenever the total area of the latter exceeds about half the plan area of the building. The raft is designed as an inverted-slab system spanning between columns and walls and carrying the building weight as a load assumed to be uniformly distributed over the soil. Since this method does not take into account the stresses associated with differential settlements, and since every soil has variations in compressibility, the actual distribution of soil pressure is likely to be erratic. It is considered good practice to provide more reinforcement than required by the analysis and to provide the same percentage of reinforcement in both top and bottom of the raft. Where a raft foundation is intended to bridge local soft spots in the subsoil, it may be necessary to stiffen it to prevent unusual differential settlements between adjacent columns. Stiffening may be accomplished by providing ribs either above or below the mat and continuous with it so that they function as T-beams. In some instances these may be incorporated into interior partitions.

24. Raft on Clay The allowable bearing pressure for a raft on clay is the same as for a footing [Eq. (17)]. The value of q_a in this expression is the allowable increase in pressure at the base of the raft. Soil that is excavated can be replaced with building load without changing the pressure. Therefore, by increasing the depth of excavation the total building load that can be supported is correspondingly increased. This can be accomplished by increasing the depth and number of basements. However, the depth of excavation in soft clays must be limited to prevent a base failure. In general, the weight of adjacent surcharge loads plus the soil above the bottom of the excavation should not exceed $2q_u$

The settlement of a raft on clay is predicted in accordance with the method for footing foundations.

25. Rafts on Sand The width *B* of a raft foundation is not much greater than the width of the structure and cannot be less. Furthermore, a raft foundation is usually established at a minimum depth of about 8 ft. As a consequence, the allowable pressure based on bearing capacity is always very large and the design soil pressure is governed by settlement. Because of the large size of rafts and their structural integrity, differential settlements are likely to be less than those of a footing foundation at the same soil pressure. Therefore, larger design soil pressures are permissible. Since the soil pressure corresponding to a given settlement is nearly independent of the width of a foundation when the latter is greater than about 20 ft, the allowable design soil pressure for a differential settlement of ¾ in can be written

$$q_a = \frac{N - 3}{5} \qquad (22)$$

where q_a is the allowable bearing pressure in tons per sq ft, and *N* is the average penetration resistance in blows per ft obtained from the standard penetration test. The value of q_a must be reduced when the water table is within a depth *B* below the raft. This reduction is obtained from the water-table correction chart (Fig. 19).

The loads that should be used to determine the actual bearing pressure are the dead load of the structure including the raft and the maximum live load that is reasonably expected to act at any time. This load should be reduced by the weight of the soil excavated below the level of the adjacent ground surface in order to obtain the change in stress in the subsoil.

PIER FOUNDATIONS

Pier foundations are often used where it is necessary to carry the foundation to a considerable depth in order to reach a suitable bearing stratum. The principal difference between a footing and a pier foundation is that the depth of the latter is generally greater than 4*B*. In order to reach the bearing stratum a variety of construction procedures have been developed. These are important because the behavior of a pier foundation may depend primarily on the details of construction.

26. Open Excavations Perhaps the commonest method of pier construction is in an open excavation. This is often accomplished by making a braced excavation to the bearing stratum and forming a pier therein. Care must be taken in the design of the bracing to provide adequate support for the earth pressures and added hydrostatic pressures that may exist. In the case of large piers which are surrounded by water, excavation is frequently accomplished within the protection of a cellular cofferdam.

A common method of pier construction by hand excavation was developed in Chicago, where it is inappropriately called a caisson. A circular shaft corresponding to the final dimensions of the pier is excavated and lined with vertical boards, or lagging, which are held in place by circular steel rings that are placed as the excavation advances. At the bearing stratum the bottom may be enlarged or belled out to increase the bearing area. On completion the entire excavation is filled with concrete; the rings and lagging are normally left in place. This method is suitable only for clays which do not contain water-bearing seams or pockets. Where such materials are encountered, the sheeting is sometimes driven ahead of the bottom of the excavation to seal off the water. Although timber sheetpiling is often used for this purpose, the Gow method may be more suitable. Circular steel shells about 6 ft long are driven into the ground and the soil within the shell is excavated. Succeeding sections about 2 in smaller in diameter are then driven and the process is repeated until the water-bearing layers are passed. The excavations can then be advanced as in the Chicago method, including the formation of a bell. If it is necessary to drive sheeting or a casing to advance through a water-bearing stratum, it is essential that this protection remain in place as the concrete shaft is cast. The pier must extend far enough into the bearing stratum to ensure that the soil in which the bell is to be formed can stand without support until the concrete can be placed.

27. Drilled Piers Several different types of machines have been developed which can drill holes varying in diameter from about 12 in to as much as 10 ft. When the bearing stratum has been reached, a special belling attachment can be used to enlarge the bottom of the hole and form a bell that may be up to three times the diameter of the pier shaft. For particularly large bells, the final finishing may be done by hand. Under ideal conditions a shaft 50 ft deep can be drilled in about 30 min and a 50- to 75-ft pier is easily completed in one 8-hr shift. When it is necessary to provide lateral support to prevent the intrusion of soft clays or silts, a steel lining may be used in conjunction with the drilling process.

Special techniques have been developed for advancing drilled excavations through running sands located below the water table. Although it is common practice to salvage the lining, this may be somewhat hazardous to the integrity of the pier shaft because of the possibility that the running sand and silt, or soft clay, may squeeze the pier shaft, or actually intrude completely across it should there be momentary arching of the concrete within the casing as the latter is removed. The presence of an intrusion is usually not known until the structure begins to show signs of distress. Therefore, if a lining is required to prevent the intrusion of cohesionless or very soft soils, it should generally be left in place to become a part of the completed pier. Care should be exercised that the bottom of the bell is free of loose or compressible materials which may otherwise cause settlement of the completed pier.

28. Piers on Clay The allowable bearing pressure q_a for a pier founded on clay is

$$q_a = 1.25q_u\left(1 + \frac{0.2B}{L}\right) \tag{23}$$

where q_u = average unconfined compressive strength within a depth below pier equal to its width
B = width of base
L = length of base

This provides a factor of safety of 3 against a bearing-capacity failure. No additional support should be assigned because of the shearing resistance that might develop between the pier shaft and the adjacent soil.

The settlement of a pier foundation in clays may be predicted by the procedure for footing foundations. However, in general, a bearing stratum that is adequate for the support of pier foundations is likely to be overconsolidated and not cause differential settlement between adjacent footings in excess of ¾ in.

29. Piers on Sand The bearing pressure for a pier on sand is usually governed by considerations of settlement because the effect of depth is to increase the factor of safety against a bearing-capacity failure. Experience has shown that the settlement of a pier is about half that of a footing of the same dimensions at the same unit pressures, provided the relative densities of the subsoil are equal. Therefore, the allowable soil pressure can be determined from Fig. 20 appropriately corrected for the position of the water table. As a consequence of the smaller settlement of a pier compared with a footing, these values may be doubled unless there is a possibility that scour may remove most of the materials above the base of the pier.

30. Caisson Foundations A caisson is a special type of pier consisting of a hollow shell that is sunk into position to form a major part of the completed foundation. There are three principal types.

Box caissons are open at the top and closed at the bottom. They are usually constructed on land, floated to the site, and sunk on a previously prepared bearing surface. Sinking is generally accomplished by filling the box with concrete, stone masonry, or, exceptionally, sand and gravel.

Open caissons are open at both top and bottom and are sunk by dredging out the enclosed material. They are usually the size of the completed foundation and must be provided with a number of wells, extending from top to bottom, large enough to provide easy passage for the excavating buckets. Construction is started directly over the area where the caisson is to be permanently located. If the ground surface is below water, the caisson may be raised by forming a sand island and starting it on the fill. As the caisson is sunk, the upper portion is built up with concrete.

Caissons must be fairly massive in order to overcome the side friction, and occasionally it is necessary to reduce side friction by jetting. When the founding elevation has been reached, the bottom is carefully cleaned, sometimes with the assistance of a diver, and a concrete seal of thickness sufficient to resist uplift of the external water is cast prior to pumping out the caisson. After dewatering, the surface of the seal is inspected before concreting the remainder of the caisson. Open caissons have been sunk to depths in excess of 200 ft.

Pneumatic caissons are closed at the top and open at the bottom and are filled with compressed air. They are generally used where the depth below water is between 40 and 110 ft, which is about the maximum depth people can work advantageously under compressed air. Air locks must be provided for passage of workers and materials, and the bottom must have clearance sufficient to provide adequate headroom in the working chamber for the muckers. The pneumatic caisson can be controlled more precisely than the open caisson because selective excavation is possible and the bearing surface can be more suitably prepared and inspected before concrete is placed.

31. Foundation Requirements The allowable bearing pressures for caisson foundations are essentially the same as those for piers. However, because of their size and importance, caisson foundations are generally founded on very hard soils or rock where the strength of the subsoil may be secondary in importance to the allowable stresses permitted in the concrete of the caisson itself.

PILE FOUNDATIONS

Bearing pile foundations are columns that transmit load to some depth in soil. Piles are classified as shown in Table 3. They may be used singly or in groups of several, although it should be recognized that the capacity of a group is not necessarily that of a single pile times the number of piles in the group. Because the final location of any pile may be 3 in or more from its desired location, it is not good practice to use fewer than three piles for the support of a column unless lateral structural framing capable of withstanding the bending moments due to the possible eccentricity is provided. Piles supporting walls are customarily driven in pairs or staggered. The minimum center-to-center spacing of piles is usually 30 in, although they are customarily driven at a spacing of about three times the butt diameter.

32. Pile-Driving Equipment Table 4 shows a number of hammers and their principal characteristics. Drop hammers are frequently used for relatively small jobs where their slow-

22. Column Footings Individual footings for columns may be square, rectangular, polygonal, round, or irregular to suit the space available (Fig. 39). Square footings are the simplest. Theoretically, footings could taper in depth to a working minimum at the periphery, but as they are frequently constructed by placing a prepared mat of reinforcing bars in a neatly excavated pit and filling to the required level with concrete, such tapering involves more labor than the value of the concrete saved.

Combined footings (Fig. 39*d*, *e*) may be rectangular or trapezoidal in plan. The trapezoidal footing is used when it is impossible to extend the footing sufficiently beyond the more heavily loaded column. The centroid of the bearing pressure should coincide as nearly as is practicable with that of the loads. In the absence of specific recommendations to the contrary by a soils engineer, the soil pressure may be assumed uniform over the contact surface. Cantilevered footings (Fig. 39*g*) may be used in place of the combined footing.

The main requirement for footings is that they be safe, simple, and economical. They should be proportioned to produce substantially equal settlements of the supported columns.

Example 19 Design a square footing to support a column load of 200 kips dead + 260 kips live load on 5000-psf soil. f'_c = 3000 psi, f_y = 60,000 psi, column 18 in square.

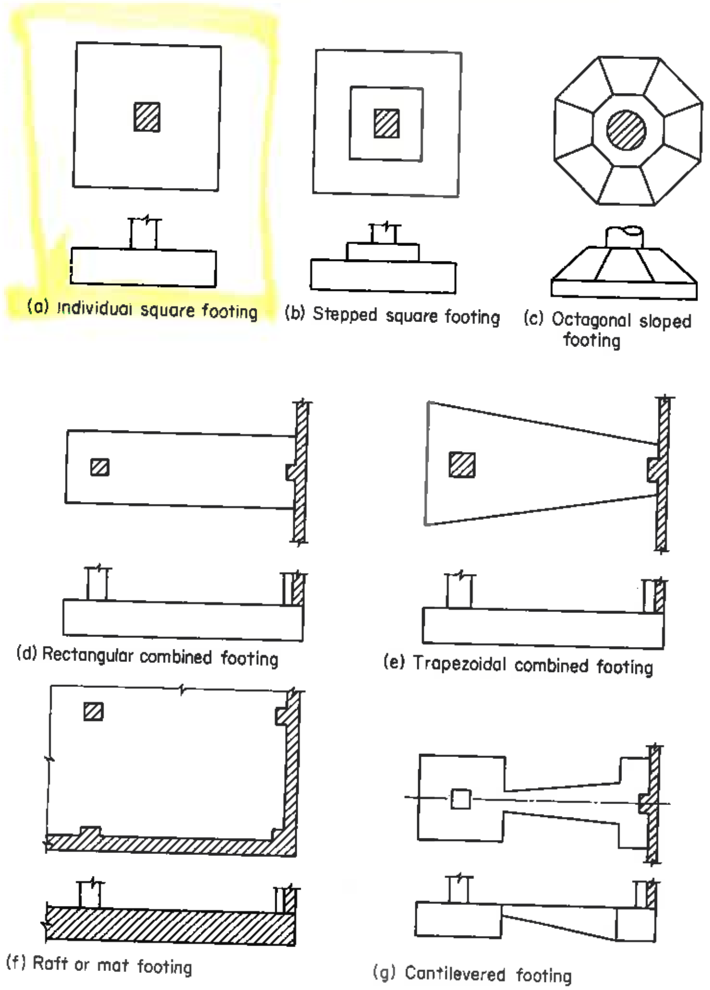

Fig. 39 Typical column footings.

SOLUTION. Column load + estimated weight of footing = 460 + 40 = 500 kips. Required size of footing = 500/5 = 100 sq ft = 10 ft square.

Try a footing 1 ft 10 in deep with 3 in clear cover for placement on earth. With bars in two directions, d for the upper layer will be about 17.5 in.

Effective soil pressure w = (200 × 1.4 + 260 × 1.7)/100 = 7.22 ksf. Except on long narrow footings, punching shear around the column usually determines necessary depth. This is calculated around a perimeter located $d/2$ from the column face (Code 11.10b).

$$\text{Perimeter} = b_0 = 4(18 + 2 \times 17.5/2) = 4 \times 35.5 = 142 \text{ in or } 2.96 \text{ ft per side}$$
$$V_u = 7.22(10^2 - 2.96^2) = 659 \text{ kips}$$
$$v_u = V_u/(\phi b_0 d) = 659{,}000/(0.85 \times 142 \times 17.5) = 312 \text{ psi}$$

Allowable $v_u = 4\sqrt{3000}$ = 219 psi = 0.7 of that needed.

Noting that b_0 also increases as d is increased, try d = 22.5 in = 1.88 ft, thickness = 27 in.

b_0 = 4(18 + 22.5) = 162 in or 3.37 ft per side

$V_u = 7.22(10^2 - 3.37^2)$ = 640 kips v_u = 640,000/(0.85 × 162 × 22.5) = 207 psi < 219 O.K.

Beam-type shear per foot of width of footing on plane d = 22.5 in from column:

$$V_u = 7.22 \times 1(5 - 0.75 - 1.87) = 17.2 \text{ kips}$$
$$v_u = 17{,}200/(0.85 \times 12 \times 22.5) = 75 \text{ psi} < 2\sqrt{f'_c} = 109 \text{ psi}$$

Check M_u at column face = $7.22(5 - 0.75)^2/2$ = 65.2 ft-kips/ft

$$M_u/(\phi b d^2) = 65{,}200 \times 12/(0.9 \times 12 \times 22.5^2) = 143$$

From Table 5, ρ = 0.0025, min $\rho = 200/f_y$ = 200/60,000 = 0.0033 = (4/3)0.0025.*

$$A_s = 0.0033 \times 12 \times 22.5 = 0.90 \text{ in}^2/\text{ft}$$

Use 15 No. 7 at 8 in each way (A_s = 0.90 in²).

$$l_d = 0.04A_b f_y/\sqrt{f'_c} = 0.04 \times 0.60 \times 60{,}000/\sqrt{3000} = 26.3 \text{ in}$$

Since footing extends over 4 ft from column face, development is no problem.

The assumed weight of 40,000 lb can now be checked as 10 × 10 × 2.25 × 150 = 33,800 lb. If a higher degree of precision seems desirable, a recomputation can be made. No substantial savings over the present design appear likely.

Example 20 Design a combined footing for a 12-in exterior wall whose outside face is on a property line, 20 ft from the center of a 20- × 20-in interior column (Fig. 40). The load on the wall is 200 kips and that on the column 325 kips. Allowable soil pressure is 5000 psf, f'_c = 4000 psi, and f_y = 60,000 psi. Assume average load factor is 1.65 on both wall and column.

SOLUTION. At service loads, the centroid of the loads is 0.5 + 325 × 19.5/525 = 12.57 ft from the building line, making the length of a concentric, rectangular footing 2 × 12.57 = 25.14 ft, or, say, 25 ft.

Load on exterior wall	= 200,000
Load on interior column	= 325,000
Footing (at 8 to 10 percent of load)	= 50,000
	575,000 lb

b = 575,000/(5000 × 25) = 4.6 ft = 4 ft 8 in. Net soil pressure = 525,000/(4.67 × 25) = 4500 psf at service loads or 4500 × 1.65 = 7420 psf under factored loads.

The distance to the point of zero shear from exterior face is 200,000 × 1.65/(4.67 × 7420) = 9.52 ft. Max negative M_u = −330(9.52 − 0.5) + 34.7 × 9.52²/2 = −1410 ft-kips

Clearances or other constraints sometimes demand minimum member size, but economy of the member itself more often goes with ρ smaller than the maximum. Try ρ = 0.015, for which $M_u/\phi b d^2$ = 781. Then

$$781 = 1410 \times 1000 \times 12/(0.90 \times 4.67 \times 12d^2)$$
$$d = 20.7 \text{ in}$$

Punching shear seems improbable with this d plus the 20-in column using up 41 in of the total 56-in width. Hence, check flexural shear first. Shear usually controls footing depth, since heavy stirrups in wide members are awkward to place. Flexural shear, by inspection, is maximum near the inside face of the wall or the inside face of the column. Net soil pressure on 56-in width is 4.67 × 7.42 = 34.7 kips/ft

$$V_{wall} = 330 - 34.7 \times 1 = 295 \text{ kips}$$

Summing forces from left and including the column,

$$V_{col} = 34.7(5.0 + 10/12) - 1.65 \times 325 = 202 - 536 = -334 \text{ kips}$$

*Whether footings are excluded (as slabs of uniform thickness) from this minimum ρ might be debated legally, but high shear and low ρ are always a bad ...

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Foundation Engineering Handbook

Design and Construction with the 2006 International Building Code

- Seismic Analysis
- Shallow and Deep Foundations
- 2006 International Building Code
- Design and Construction Methods

Robert W. Day

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TABLE 1.1 Common Types of Foundations

Category	Common types	Comments
Shallow foundations	Spread footings	Spread footings (also called pad footings) are often square in plan view, are of uniform reinforced concrete thickness, and are used to support a single column load located directly in the center of the footing.
	Strip footings	Strip footings (also called wall footings) are often used for load-bearing walls. They are usually long reinforced concrete members of uniform width and shallow depth.
	Combined footings	Reinforced-concrete combined footings are often rectangular or trapezoidal in plan view, and carry more than one column load.
	Conventional slab-on-grade	A continuous reinforced-concrete foundation consisting of bearing wall footings and a slab-on-grade. Concrete reinforcement often consists of steel rebar in the footings and wire mesh in the concrete slab.
	Posttensioned slab-on-grade	A continuous posttensioned concrete foundation. The posttensioning effect is created by tensioning steel tendons or cables embedded within the concrete. Common posttensioned foundations are the ribbed foundation, California slab, and PTI foundation.
	Raised wood floor	Perimeter footings that support wood beams and a floor system. Interior support is provided by pad or strip footings. There is a crawl space below the wood floor.
	Mat foundation	A large and thick reinforced-concrete foundation, often of uniform thickness, that is continuous and supports the entire structure. A mat foundation is considered to be a shallow foundation if it is constructed at or near ground surface.
Deep foundations	Driven piles	Driven piles are slender members, made of wood, steel, or precast concrete, that are driven into place by pile-driving equipment.
	Other types of piles	There are many other types of piles, such as bored piles, cast-in-place piles, and composite piles.
	Piers	Similar to cast-in-place piles, piers are often of large diameter and contain reinforced concrete. Pier and grade beam support are often used for foundation support on expansive soil.
	Caissons	Large piers are sometimes referred to as caissons. A caisson can also be a watertight underground structure within which construction work is carried on.
	Mat or raft foundation	If a mat or raft foundation is constructed below ground surface or if the mat or raft foundation is supported by piles or piers, then it should be considered to be a deep foundation system.
	Floating foundation	A special foundation type where the weight of the structure is balanced by the removal of soil and construction of an underground basement.
	Basement-type foundation	A common foundation for houses and other buildings in frost-prone areas. The foundation consists of perimeter footings and basement walls that support a wood floor system. The basement floor is usually a concrete slab.

Note: The terms *shallow* and *deep* foundations in this table refer to the depth of the soil or rock support of the foundation.

a structural floor slab that can transfer loads to the piles is an important design feature for sites having settling compressible soil, such as the peat layer shown in Fig. 5.6.

5.4.2 Pier Foundations

A pier is defined as a deep foundation system, similar to a cast-in-place pile that consists of a column-like reinforced concrete member. Piers are often of large enough diameter to enable down-hole inspection. Piers are also commonly referred to as drilled shafts, bored piles, or drilled caissons. Figure 5.7 shows the typical steps in the construction of a drilled pier.

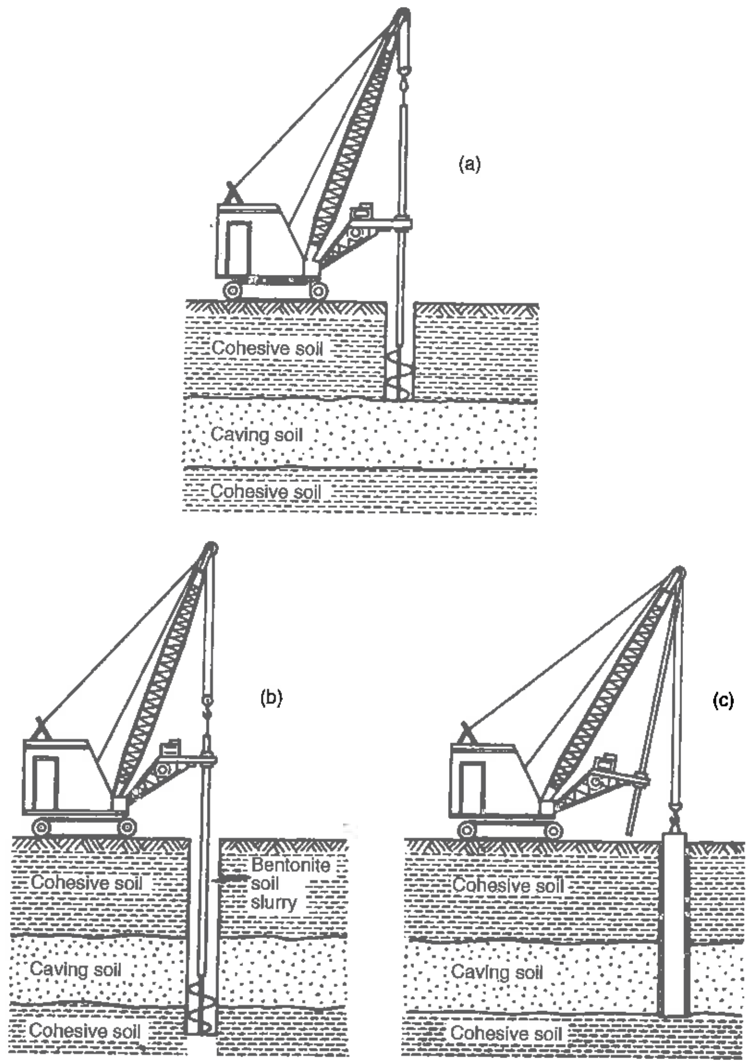

FIGURE 5.7 Typical steps in the construction of a drilled pier. (*a*) Dry augering through self-supporting cohesive soil; (*b*) augering through water-bearing cohesionless soil with aid of slurry; (*c*) setting the casing; (*d*) dry augering into cohesive soil after sealing; (*e*) forming a bell. (*After O'Neill and Reese 1970; reproduced from Peck, Hanson, and Thornburn 1974.*)

Grading contractor A contractor licensed and regulated who specializes in grading work or is otherwise licensed to do grading work.

Grading permit An official document or certificate issued by the building official authorizing grading activity as specified by approved plans and specifications.

Grouting The process of injecting grout into soil or rock formations to change their physical characteristics. Common examples include grouting to decrease the permeability of a soil or rock strata, or compaction grouting to densify loose soil or fill.

Hillside site A site that entails cut and/or fill grading of a slope which may be adversely affected by drainage and/or stability conditions within or outside the site, or which may cause an adverse affect on adjacent property.

Hydraulic fill A fill placed by transporting soils through a pipe using large quantities of water. These fills are generally loose because they have little or no mechanical compaction during construction.

Inspection See Special inspection.

Jetting The use of a water jet to facilitate the installation of a pile. It can also refer to the fluid placement of soil, such as jetting in the soil for a utility trench.

Key A designed compacted fill placed in a trench excavated in earth material beneath the toe of a proposed fill slope.

Keyway An excavated trench into competent earth material beneath the toe of a proposed fill slope.

Lift During compaction operations, a lift is a layer of soil that is dumped by the construction equipment and then subsequently compacted as structural fill.

Mixed-in-place pile A soil-cement pile that is created by forcing grout through a hollow shaft in the ground. As the grout is forced into the soil, an auger-like head (that is attached to the hollow shaft) mixes the soil to create the soil cement.

Necking A reduction in cross-sectional area of a drilled shaft as a result of the inward movement of the adjacent soils.

Open cut An excavation in rock or soil that is made through a hill or other topographic feature in order to construct a highway, railroad, or waterway. The open cut can consist of a single cut slope, multiple cut slopes, and/or benches.

Owner Any person, agency, firm, or corporation having a legal or equitable interest in a given real property.

Permanent erosion control devices Improvements that remain throughout the life of the development. They include terrace drains, down-drains, slope landscaping, channels, storm drains, and the like.

Permit An official document or certificate issued by the building official authorizing performance of a specified activity.

Pier A deep foundation system, similar to a cast-in-place pile, that consists of column-like reinforced concrete members. Piers are often of large enough diameter to enable down-hole inspection. Piers are also commonly referred to as drilled shafts, bored piles, or drilled caissons.

Pile A deep foundation system, consisting of relatively long, slender, column-like members that are often driven into the ground.

Batter pile A pile driven in at an angle inclined to the vertical to provide higher resistance to lateral loads.

Combination end-bearing and friction pile A pile that derives its capacity from combined end-bearing resistance developed at the pile tip and frictional and/or adhesion resistance on the pile perimeter.

and municipal government disaster operations and communication centers deemed to be vital in emergencies. According to the *Standard Specifications for Highway Bridges* (AASHTO, 1996), other facilities that could be classified as essential are military bases, supply depots, and National Guard installations; facilities such as schools and arenas which could provide shelter or be converted to aid stations; major airports; defense industries and those that could easily or logically be converted to such; refineries, fuel storage, and distribution centers; major railroad terminals, railheads, docks, and truck terminals; major power plants including nuclear power facilities and hydroelectric centers at major dams, and other facilities that the state considers important from a national defense viewpoint or during emergencies resulting from natural disasters or other unforeseen circumstances. Essential bridges are defined as those that must continue to function after an earthquake. Transportation routes to critical facilities such as hospitals, police, fire stations, and communication centers must continue to function and bridges required for this purpose should be classified as essential. In addition, a bridge that has the potential to impede traffic if it collapses onto an essential route should also be classified as essential.

Excavation The mechanical removal of earth material, also referred to as cut material.

Fill A deposit of earth material placed by artificial means. An engineered (or structural) fill refers to a fill in which the geotechnical engineer has, during grading, made sufficient tests to enable the conclusion that the fill has been placed in substantial compliance with the recommendations of the geotechnical engineer and the governing agency requirements.

Footing A structural member typically installed at a shallow depth that is used to transmit structural loads to the soil or rock strata. Common types of footings include combined footings, spread (or pad) footings, and strip (or wall) footings.

Forms The purpose of a form is to confine and support the fluid concrete until it hardens. For excavated footings in soil or rock material, the sides and bottom of the excavation serves as the form, provided the soil can remain stable during construction. In other cases, forms are usually constructed out of wood.

Foundation That part of the structure that supports the weight of the structure and transmits the load to underlying soil or rock.

Deep foundation A foundation that derives its support by transferring loads to soil or rock at some depth below the structure.

Shallow foundation A foundation that derives its support by transferring load directly to soil or rock at a shallow depth.

Freeze Also known as setup, an increase in the load capacity of a pile after it has been driven. Freeze is caused primarily by the dissipation of excess pore water pressures.

Geosynthetic A planar product manufactured from polymeric material and typically placed in soil to form an integral part of a drainage, reinforcement, or stabilization system. Types include geotextiles, geogrids, geonets, and geomembranes.

Geotextile A permeable geosynthetic composed solely of textiles.

Grade The vertical location of the ground surface.

Existing grade The ground surface prior to grading.

Finished grade The final grade of the site, which conforms to the approved plan.

Lowest adjacent grade The lowest point in elevation of the finished surface of the ground, paving, or sidewalk that is adjacent to the structure.

Natural grade The ground surface unaltered by artificial means.

Rough grade The stage at which the grade approximately conforms to the approved plan.

Grading Any operation consisting of excavation, filling, or a combination thereof.

SECTION 1802 DEFINITIONS

1802.1 Definitions.

The following words and terms shall, for the purposes of this chapter, have the meanings shown herein.

DEEP << FOUNDATION >>. A deep << **foundation** >> is a << **foundation** >> element that does not satisfy the definition of a shallow << **foundation** >>.

DRILLED SHAFT. A drilled shaft is a cast-in-place deep << **foundation** >> element constructed by drilling a hole (with or without permanent casing) into soil or rock and filling it with fluid concrete.

Socketed drilled shaft. A socketed drilled shaft is a drilled shaft with a permanent pipe or tube casing that extends down to bedrock and an uncased socket drilled into the bedrock.

HELICAL PILE. Manufactured steel deep << **foundation** >> element consisting of a central shaft and one or more helical bearing plates. A helical pile is installed by rotating it into the ground. Each helical bearing plate is formed into a screw thread with a uniform defined pitch.

MICROPILE. A micropile is a bored, grouted-in-place deep << **foundation** >> element that develops its load-carrying capacity by means of a bond zone in soil, bedrock or a combination of soil and bedrock.

SHALLOW << FOUNDATION >>. A shallow << **foundation** >> is an individual or strip footing, a mat << **foundation** >>, a slab-on-grade << **foundation** >> or a similar << **foundation** >> element.

2121.2.6 << Piers >>.

2121.2.6.1

In any section of a masonry wall of an enclosed structure where openings are arranged to leave sections of walls less than 16 inches (406 mm), such Sections shall be steel or reinforced concrete.

2121.2.6.2

Isolated masonry << **piers** >> of unenclosed structures shall be so constructed that the height of such << **piers** >> shall not exceed 10 times the least dimension, that the cells are filled with cement grout and reinforced with not less than two #5 bars anchoring the beam to the foundation.

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1808.9 Vertical masonry foundation elements.

Vertical masonry foundation elements that are not foundation << piers >> as defined in Section 2102.1 shall be designed as << **piers** >>, walls or columns, as applicable, in accordance with TMS 402/ACI 530/ASCE 5.

2102

FOUNDATION << **PIER** >> . An isolated vertical foundation member whose horizontal dimension measured at right angles to its thickness does not exceed three times its thickness and whose height is equal to or less than four times its thickness.

1809.9 Masonry-unit footings.

The design, materials and construction of masonry-unit footings shall comply with Sections 1809.9.1 and 1809.9.2, and the provisions of Chapter 21.

Exception: Where a specific design is not provided, masonry-unit footings supporting walls of light-frame construction shall be permitted to be designed in accordance with Table 1809.7.

1809.9.1 Dimensions.

Masonry-unit footings shall be laid in Type M or S mortar complying with Section 2103.8 and the depth shall not be less than twice the projection beyond the wall, << pier >> or column. The width shall not be less than 8 inches (203 mm) wider than the wall supported thereon.

1809.9.2 Offsets.

The maximum offset of each course in brick foundation walls stepped up from the footings shall be $1^1/_2$ inches (38 mm) where laid in single courses, and 3 inches (76 mm) where laid in double courses.

S_n = section modulus of the net cross-sectional area of a member, in.^{3} (mm^3)
s = spacing of reinforcement, in. (mm)
s_l = total linear drying shrinkage of concrete masonry units determined in accordance with ASTM C 426
T = forces and moments caused by restraint of temperature, shrinkage, and creep strains or differential movements
t = nominal thickness of member, in. (mm)
v = shear stress, psi (MPa)
V = shear force, lb (N)
V_{AAC} = shear strength provided by AAC masonry, lb (N)
V_m = shear strength provided by masonry, lb (N)
V_n = nominal shear strength, lb (N)
V_s = shear strength provided by shear reinforcement, lb (N)
V_u = factored shear force, lb (N)
W = wind load or related internal moments and forces
w_{strut} = horizontal projection of the width of the diagonal strut, in. (mm)
w_u = out-of-plane factored uniformly distributed load, lb/in. (N/mm)
β = 0.25 for fully grouted masonry or 0.15 for other than fully grouted masonry
β_b = ratio of area of reinforcement cut off to total area of tension reinforcement at a section
γ = reinforcement size factor
Δ = calculated story drift, in. (mm)
Δ_a = allowable story drift, in. (mm)
δ_{ne} = displacements computed using code-prescribed seismic forces and assuming elastic behavior, in. (mm)
δ_s = horizontal deflection at midheight under service loads, in. (mm)
δ_u = deflection due to factored loads, in. (mm)
ε_{cs} = drying shrinkage of AAC, defined as the difference in the relative change in length between the moisture contents of 30% and 6%
ε_{mu} = maximum usable compressive strain of masonry
μ_{AAC} = coefficient of friction of AAC
ϕ = strength-reduction factor
ρ = reinforcement ratio

1.6 — Definitions

Anchor — Metal rod, wire, or strap that secures masonry to its structural support.

AAC masonry — Masonry made of autoclaved aerated concrete (AAC) units, manufactured without internal reinforcement, and bonded together using thin- or thick-bed mortar.

Anchor pullout — Anchor failure defined by the anchor sliding out of the material in which it is embedded without breaking out a substantial portion of the surrounding material.

Architect/Engineer — The architect, engineer, architectural firm, engineering firm, or architectural and engineering firm issuing drawings and specifications, or administering the work under contract specifications and project drawings, or both.

Area, gross cross-sectional — The area delineated by the out-to-out dimensions of masonry in the plane under consideration.

Area, net cross-sectional — The area of masonry units, grout, and mortar crossed by the plane under consideration based on out-to-out dimensions.

Autoclaved aerated concrete — Low-density cementitious product of calcium silicate hydrates, whose material specifications are defined in ASTM C 1386.

Backing — The wall or surface to which the veneer is secured.

Bed joint — The horizontal layer of mortar on which a masonry unit is laid.

Bonded prestressing tendon — Prestressing tendon that is encapsulated by prestressing grout in a corrugated duct that is bonded to the surrounding masonry through grouting.

Building official — The officer or other designated authority charged with the administration and enforcement of this Code, or the building official's duly authorized representative.

Camber — A deflection that is intentionally built into a structural element to improve appearance or to nullify the deflection of the element under the effects of loads, shrinkage, and creep.

Cavity wall — A multiwythe noncomposite masonry wall with a continuous air space within the wall (with or without insulation), which is tied together with metal ties.

Collar joint — Vertical longitudinal space between wythes of masonry or between masonry wythe and back-up construction, which is permitted to be filled with mortar or grout.

Column — An isolated vertical member whose horizontal dimension measured at right angles to its thickness does not exceed 3 times its thickness and whose height is greater than 4 times its thickness.

Composite action — Transfer of stress between components of a member designed so that in resisting loads, the combined components act together as a single member.

Composite masonry — Multicomponent masonry members acting with composite action.

Compressive strength of masonry — Maximum compressive force resisted per unit of net cross-sectional area of masonry, determined by testing masonry prisms or a function of individual masonry units, mortar, and grout, in accordance with the provisions of ACI 530.1/ASCE 6/TMS 602.

Connector — A mechanical device for securing two or more pieces, parts, or members together, including anchors, wall ties, and fasteners.

Contract documents — Documents establishing the required work, and including in particular, the project drawings and project specifications.

Corbel — A projection of successive courses from the face of masonry.

Depth — The dimension of a member measured in the plane of a cross section perpendicular to the neutral axis.

Design story drift — The difference of deflections at the top and bottom of the story under consideration, calculated by multiplying the deflections determined from an elastic analysis by the appropriate deflection amplification factor, C_d, from ASCE 7-02.

Design strength — The nominal strength of an element multiplied by the appropriate strength-reduction factor.

Diaphragm — A roof or floor system designed to transmit lateral forces to shear walls or other lateral load resisting elements.

Dimension, nominal — The specified dimension plus an allowance for the joints with which the units are to be laid. Nominal dimensions are usually stated in whole numbers. Thickness is given first, followed by height and then length.

Dimensions, specified — Dimensions specified for the manufacture or construction of a unit, joint, or element.

Effective height — Clear height of a braced member between lateral supports and used for calculating the slenderness ratio of a member. Effective height for unbraced members shall be calculated.

Effective prestress — Stress remaining in prestressing tendons after all losses have occurred.

Foundation pier — An isolated vertical foundation member whose horizontal dimension measured at right angles to its thickness does not exceed 3 times its thickness and whose height is equal to or less than 4 times its thickness.

Glass unit masonry — Masonry composed of glass units bonded by mortar.

Head joint — Vertical mortar joint placed between masonry units within the wythe at the time the masonry units are laid.

Header (bonder) — A masonry unit that connects two or more adjacent wythes of masonry.

Laterally restrained prestressing tendon — Prestressing tendon that is not free to move laterally within the cross section of the member.

Laterally unrestrained prestressing tendon — Prestressing tendon that is free to move laterally within the cross section of the member.

Load, dead — Dead weight supported by a member, as defined by the legally adopted building code.

Load, live — Live load specified by the legally adopted building code.

Load, service — Load specified by the legally adopted building code.

Longitudinal reinforcement — Reinforcement placed parallel to the axis of the member.

Masonry breakout — Anchor failure defined by the separation of a volume of masonry, approximately conical in shape, from the member.

Modulus of elasticity — Ratio of normal stress to corresponding strain for tensile or compressive stresses below proportional limit of material.

Modulus of rigidity — Ratio of unit shear stress to unit shear strain for unit shear stress below the proportional limit of the material.

Nominal strength — The strength of an element or cross section calculated in accordance with the requirements and assumptions of the strength design methods of these provisions before application of strength-reduction factors.

Pier — An isolated vertical member whose horizontal dimension measured at right angles to its thickness is not less than 3 times its thickness nor greater than 6 times its thickness and whose height is less than 5 times its length.

Post-tensioning — Method of prestressing in which a prestressing tendon is tensioned after the masonry has been placed.

Prestressed masonry — Masonry in which internal stresses have been introduced to counteract stresses resulting from applied loads.

Pretensioning — Method of prestressing in which a prestressing tendon is tensioned before the transfer of stress into the masonry.

Prestressing grout — A cementitious mixture used to encapsulate bonded prestressing tendons.

Prestressing tendon — Steel elements such as wire, bar, or strand, used to impart prestress to masonry.

Project drawings — The drawings that, along with the project specifications, complete the descriptive information for constructing the work required by the contract documents.

Project specifications — The written documents that specify requirements for a project in accordance with the service parameters and other specific criteria established by the owner or the owner's agent.

Quality assurance — The administrative and procedural requirements established by the contract documents to assure that constructed masonry is in compliance with the contract documents.

Reinforcement — Nonprestressed steel reinforcement.

Running bond — The placement of masonry units such that head joints in successive courses are horizontally offset at least one-quarter the unit length.

Required strength — The strength needed to resist factored loads.

Shear wall — A wall, bearing or nonbearing, designed to resist lateral forces acting in the plane of the wall (sometimes referred to as a vertical diaphragm).

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"Code for Concrete Reactor Vessels and Containments" reported by ACI-ASME Committee 359.[1.3] (Provides requirements for the design, construction, and use of concrete reactor vessels and concrete containment structures for nuclear power plants.)

1.1.5 — This code does not govern design and installation of portions of concrete piles, drilled piers, and caissons embedded in ground except for structures in regions of high seismic risk or assigned to high seismic performance or design categories. See 21.10.4 for requirements for concrete piles, drilled piers, and caissons in structures in regions of high seismic risk or assigned to high seismic performance or design categories.

R1.1.5 — The design and installation of piling fully embedded in the ground is regulated by the general building code. For portions of piling in air or water, or in soil not capable of providing adequate lateral restraint throughout the piling length to prevent buckling, the design provisions of this code govern where applicable.

Recommendations for concrete piles are given in detail in **"Recommendations for Design, Manufacture, and Installation of Concrete Piles"** reported by ACI Committee 543.[1.6] (Provides recommendations for the design and use of most types of concrete piles for many kinds of construction.)

Recommendations for drilled piers are given in detail in **"Design and Construction of Drilled Piers"** reported by ACI Committee 336.[1.7] (Provides recommendations for design and construction of foundation piers 2-1/2 ft in diameter or larger made by excavating a hole in the soil and then filling it with concrete.)

Detailed recommendations for precast prestressed concrete piles are given in **"Recommended Practice for Design, Manufacture, and Installation of Prestressed Concrete Piling"** prepared by the PCI Committee on Prestressed Concrete Piling.[1.8]

1.1.6 — This code does not govern design and construction of soil-supported slabs, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil.

R1.1.6 — Detailed recommendations for design and construction of soil-supported slabs and floors that do not transmit vertical loads or lateral forces from other portions of the structure to the soil, and residential post-tensioned slabs-on-ground, are given in the following publications:

"Design of Slabs on Grade" reported by ACI Committee 360.[1.9] (Presents information on the design of slabs on grade, primarily industrial floors and the slabs adjacent to them. The report addresses the planning, design, and detailing of the slabs. Background information on the design theories is followed by discussion of the soil support system, loadings, and types of slabs. Design methods are given for plain concrete, reinforced concrete, shrinkage-compensating concrete, and post-tensioned concrete slabs.)

"Design of Post-Tensioned Slabs-on-Ground," PTI[1.10] (Provides recommendations for post-tensioned slab-on-ground foundations. Presents guidelines for soil investigation, and design and construction of post-tensioned residential and light commercial slabs on expansive or compressible soils.)

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COMMENTARY

Basic multistrand anchorage device — Anchorage device used with multiple strands, bars, or wires, or with single bars larger than 5/8 in. diameter, that satisfies 18.21.1 and the bearing stress and minimum plate stiffness requirements of AASHTO Bridge Specifications, Division I, Articles 9.21.7.2.2 through 9.21.7.2.4.

Bonded tendon — Tendon in which prestressing steel is bonded to concrete either directly or through grouting.

Boundary element — Portion along structural wall and structural diaphragm edge strengthened by longitudinal and transverse reinforcement. Boundary elements do not necessarily require an increase in the thickness of the wall or diaphragm. Edges of openings within walls and diaphragms shall be provided with boundary elements as required by 21.9.6 or 21.11.7.5. See Chapter 21.

Building official — The officer or other designated authority charged with the administration and enforcement of this Code, or a duly authorized representative.

Building official — The term used by many general building codes to identify the person charged with administration and enforcement of provisions of the building code. Such terms as building commissioner or building inspector are variations of the title and the term "building official" as used in this Code, is intended to include those variations, as well as others that are used in the same sense.

Cementitious materials — Materials as specified in Chapter 3, which have cementing value when used in concrete either by themselves, such as portland cement, blended hydraulic cements, and expansive cement, or such materials in combination with fly ash, other raw or calcined natural pozzolans, silica fume, and/or ground granulated blast-furnace slag.

Collector element — Element that acts in axial tension or compression to transmit earthquake-induced forces between a structural diaphragm and a vertical element of the seismic-force-resisting system. See Chapter 21.

Column — Member with a ratio of height-to-least lateral dimension exceeding 3 used primarily to support axial compressive load. For a tapered member, the least lateral dimension is the average of the top and bottom dimensions of the smaller side.

Column — The term "compression member" is used in the Code to define any member in which the primary stress is longitudinal compression. Such a member need not be vertical but may have any orientation in space. Bearing walls, columns, and pedestals qualify as compression members under this definition.

The differentiation between columns and walls in the Code is based on the principal use rather than on arbitrary relationships of height and cross-sectional dimensions. The Code, however, permits walls to be designed using the principles stated for column design (see 14.4), as well as by the empirical method (see 14.5).

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Special structural wall — A cast-in-place or precast wall complying with the requirements of 21.1.3 through 21.1.7, 21.9, and 21.10, as applicable, in addition to the requirements for ordinary reinforced concrete structural walls.

Tendon — In pretensioned applications, the tendon is the prestressing steel. In post-tensioned applications, the tendon is a complete assembly consisting of anchorages, prestressing steel, and sheathing with coating for unbonded applications or ducts with grout for bonded applications.

Tension-controlled section — A cross section in which the net tensile strain in the extreme tension steel at nominal strength is greater than or equal to 0.005.

Tie — Loop of reinforcing bar or wire enclosing longitudinal reinforcement. A continuously wound bar or wire in the form of a circle, rectangle, or other polygon shape without re-entrant corners is acceptable. See also *Stirrup*.

Transfer — Act of transferring stress in prestressing steel from jacks or pretensioning bed to concrete member.

Transfer length — Length of embedded pretensioned strand required to transfer the effective prestress to the concrete.

Unbonded tendon — Tendon in which the prestressing steel is prevented from bonding to the concrete and is free to move relative to the concrete. The prestressing force is permanently transferred to the concrete at the tendon ends by the anchorages only.

Vertical wall segment — A segment of a structural wall, bounded horizontally by two openings or by an opening and an edge. Wall piers are vertical wall segments.

Wall — Member, usually vertical, used to enclose or separate spaces.

Wall pier — A vertical wall segment within a structural wall, bounded horizontally by two openings or by an opening and an edge, with ratio of horizontal length to wall thickness (ℓ_w/b_w) less than or equal to 6.0, and ratio of clear height to horizontal length (h_w/ℓ_w) greater than or equal to 2.0.

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Special precast structural wall — The provisions of 21.10 are intended to result in a special precast structural wall having minimum strength and toughness equivalent to that for a special reinforced concrete structural wall of cast-in-place concrete.

Wall — Openings in walls create vertical and horizontal wall segments. A horizontal wall segment is shown in Fig. R21.9.4.5.

Wall pier — Wall piers are vertical wall segments with dimensions and reinforcement intended to result in shear demand being limited by flexural yielding of the vertical reinforcement in the pier.

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CHAPTER 15 — FOOTINGS

CODE

15.1 — Scope

15.1.1 — Provisions of Chapter 15 shall apply for design of isolated footings and, where applicable, to combined footings and mats.

15.1.2 — Additional requirements for design of combined footings and mats are given in 15.10.

15.2 — Loads and reactions

15.2.1 — Footings shall be proportioned to resist the factored loads and induced reactions, in accordance with the appropriate design requirements of this code and as provided in Chapter 15.

15.2.2 — Base area of footing or number and arrangement of piles shall be determined from unfactored forces and moments transmitted by footing to soil or piles and permissible soil pressure or permissible pile capacity determined through principles of soil mechanics.

15.2.3 — For footings on piles, computations for moments and shears shall be permitted to be based on the assumption that the reaction from any pile is concentrated at pile center.

COMMENTARY

R15.1 — Scope

While the provisions of Chapter 15 apply to isolated footings supporting a single column or wall, most of the provisions are generally applicable to combined footings and mats supporting several columns or walls or a combination thereof.[15.1,15.2]

R15.2 — Loads and reactions

Footings are required to be proportioned to sustain the applied factored loads and induced reactions which include axial loads, moments, and shears that have to be resisted at the base of the footing or pile cap.

After the permissible soil pressure or the permissible pile capacity has been determined by principles of soil mechanics and in accord with the general building code, the size of the base area of a footing on soil or the number and arrangement of the piles should be established on the basis of unfactored (service) loads such as ***D***, ***L***, ***W***, and ***E*** in whatever combination that governs the design.

Only the computed end moments that exist at the base of a column (or pedestal) need to be transferred to the footing; the minimum moment requirement for slenderness considerations given in 10.12.3.2 need not be considered for transfer of forces and moments to footings.

In cases in which eccentric loads or moments are to be considered, the extreme soil pressure or pile reaction obtained from this loading should be within the permissible values. Similarly, the resultant reactions due to service loads combined with moments, shears, or both, caused by wind or earthquake loads should not exceed the increased values that may be permitted by the general building code.

To proportion a footing or pile cap for strength, the contact soil pressure or pile reaction due to the applied factored loading (see 8.1.1) should be determined. For a single concentrically loaded spread footing, the soil reaction q_s due to the factored loading is $q_s = U/A_f$, where U is the factored concentric load to be resisted by the footing, and A_f is the base area of the footing as determined by the principles stated in 15.2.2 using the unfactored loads and the permissible soil pressure.

q_s is a calculated reaction to the factored loading used to produce the same required strength conditions regarding

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CHAPTER 10 — FLEXURE AND AXIAL LOADS

CODE

10.1 — Scope

Provisions of Chapter 10 shall apply for design of members subject to flexure or axial loads or to combined flexure and axial loads.

10.2 — Design assumptions

10.2.1 — Strength design of members for flexure and axial loads shall be based on assumptions given in 10.2.2 through 10.2.7, and on satisfaction of applicable conditions of equilibrium and compatibility of strains.

10.2.2 — Strain in reinforcement and concrete shall be assumed directly proportional to the distance from the neutral axis, except that, for deep beams as defined in 10.7.1, an analysis that considers a nonlinear distribution of strain shall be used. Alternatively, it shall be permitted to use a strut-and-tie model. See 10.7, 11.8, and Appendix A.

10.2.3 — Maximum usable strain at extreme concrete compression fiber shall be assumed equal to 0.003.

10.2.4 — Stress in reinforcement below f_y shall be taken as E_s times steel strain. For strains greater than that corresponding to f_y, stress in reinforcement shall be considered independent of strain and equal to f_y.

COMMENTARY

R10.2 — Design assumptions

R10.2.1 — The strength of a member computed by the strength design method of the code requires that two basic conditions be satisfied: (1) static equilibrium, and (2) compatibility of strains. Equilibrium between the compressive and tensile forces acting on the cross section at nominal strength should be satisfied. Compatibility between the stress and strain for the concrete and the reinforcement at nominal strength conditions should also be established within the design assumptions allowed by 10.2.

R10.2.2—Many tests have confirmed that the distribution of strain is essentially linear across a reinforced concrete cross section, even near ultimate strength.

The strain in both reinforcement and in concrete is assumed to be directly proportional to the distance from the neutral axis. This assumption is of primary importance in design for determining the strain and corresponding stress in the reinforcement.

R10.2.3 — The maximum concrete compressive strain at crushing of the concrete has been observed in tests of various kinds to vary from 0.003 to higher than 0.008 under special conditions. However, the strain at which ultimate moments are developed is usually about 0.003 to 0.004 for members of normal proportions and materials.

R10.2.4 — For deformed reinforcement, it is reasonably accurate to assume that the stress in reinforcement is proportional to strain below the specified yield strength f_y. The increase in strength due to the effect of strain hardening of the reinforcement is neglected for strength computations. In strength computations, the force developed in tensile or compressive reinforcement is computed as,

when $\varepsilon_s < \varepsilon_y$ (yield strain)

$$A_s f_s = A_s E_s \varepsilon_s$$

when $\varepsilon_s \geq \varepsilon_y$

$$A_s f_s = A_s f_y$$

SECTION 1808 PIER AND PILE FOUNDATIONS

1808.1 Definitions. The following words and terms shall, for the purposes of this section, have the meanings shown herein.

FLEXURAL LENGTH. Flexural length is the length of the pile from the first point of zero lateral deflection to the underside of the pile cap or grade beam.

MICROPILES. Micropiles are 12-inch-diameter (305 mm) or less bored, grouted-in-place piles incorporating steel pipe (casing) and/or steel reinforcement.

PIER FOUNDATIONS. Pier foundations consist of isolated masonry or cast-in-place concrete structural elements extending into firm materials. Piers are relatively short in comparison to their width, with lengths less than or equal to 12 times the least horizontal dimension of the pier. Piers derive their load-carrying capacity through skin friction, through end bearing, or a combination of both.

Belled piers. Belled piers are cast-in-place concrete piers constructed with a base that is larger than the diameter of the remainder of the pier. The belled base is designed to increase the load-bearing area of the pier in end bearing.

SECTION 1812 PIER FOUNDATIONS

1812.1 General. Isolated and multiple piers used as foundations shall conform to the requirements of Sections 1812.2 through 1812.10, as well as the applicable provisions of Section 1808.2.

1812.2 Lateral dimensions and height. The minimum dimension of isolated piers used as foundations shall be 2 feet (610 mm), and the height shall not exceed 12 times the least horizontal dimension.

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tection, for which purpose he shall be afforded the necessary license to enter the premises where such excavation is to be made.

(d) If there is no established curb grade, the depth of excavation shall be referred to the level of the ground at the point under consideration. If an existing building or structure, the footings or foundations of which are required to be underpinned or protected, is so located that the curb grade or level to which it is properly referred is at a higher level than the level to which the excavation is properly referred, then such part of the required underpinning or protection that is necessary due to the difference in these levels shall be made and maintained at the joint expense of the owner of the building or structure and the person causing the excavation to be made. For the purpose of determining such part of the underpinning, or protection that is necessary due to such difference in levels, the level to which a building more than five feet back of the street line is properly referred shall be considered to be the level of the natural ground surface adjoining the building or structure.

(e) A party wall which is in good condition and otherwise suitable for continued use, shall be underpinned or protected as required at the expense of the person causing the excavation to be made.

(f) Where the necessary license has been given to the person making an excavation to enter any adjoining structure for the purpose of underpinning or protecting it, the person receiving such license shall provide for such adjoining structure adequate protection against injury due to the elements resulting from such entry.

(g) Only approved granular materials shall be used for backfill. It shall be properly compacted in order to prevent lateral displacements of the soil of the adjoining property after the removal of the shores or braces.

SECTION 1302 — FOOTINGS AND FOUNDATIONS

1302.1 — GENERAL

Except in the case of temporary structures or secondary buildings not over 1 story in height and not exceeding 400 square feet in area, footings and foundations, unless specifically provided, shall be constructed of grillages of steel, of masonry or of reinforced concrete (one and two family dwellings may not be required to have reinforced concrete footings or grillage of steel) in no case less than 12 inches below grade. Masonry units used in foundation walls and footings shall be laid up in Type M, S, or N mortar. The base areas of all footings and foundations shall be proportioned as specified in Section 1302.3.

1302.2 — BEARING CAPACITY OF SOIL

(a) Footings shall be so designed that the allowable bearing capacity of the soil in pounds per square foot as given below shall not be exceeded unless the particular soil on which the building is to

be placed shows a greater bearing capacity than that specified in this Section, under tests as provided herein.

BEARING CAPACITIES OF VARIOUS SOILS

Foundation-bed	Pounds per sq. ft.
Soft Clay	2,000
Firm Clay	3,000
Wet Sand	4,000
Sand and clay, mixed or in layers	4,000
Fine and dry sand	4,000
Coarse Sand	4,000

(b) Where the bearing capacity of the soil is not definitely known or is in question, the Building Official may require load tests or other adequate proof as to the permissible safe bearing capacity at that particular location. To determine the safe bearing capacity of soil, it shall be tested at such locations and levels as conditions warrant, by loading an area not less than 4 square feet to not less than twice the maximum bearing capacity desired for use. Such double load shall be sustained by the soil for a period of not less than 48 hours with no additional settlement taking place, in order that such desired bearing capacity may be used. Examination of sub-soil conditions shall be made at the expense of the owner, when deemed necessary by the Building Official.

(c) Foundations shall be built upon natural solid ground. Where solid natural ground does not occur at the foundation depth, such foundations shall be extended down to natural solid ground or piles shall be used. Foundations may be built upon mechanically compacted earth or fill material subject to approval by the Building Official upon submittal of evidence that proposed load will be adequately supported.

(d) Where footings are supported by soils of widely different bearing capacity, the allowable bearing values of the more yielding soil shall be reduced or special provisions shall be made in the design to prevent serious differential settlements.

(e) When it is definitely known the top or sub-soils are of a shifting or moving character, all footings shall be carried to a sufficient depth to insure stability. The excavation around piers shall be back filled with soils or materials which are not subject to such expansion or contraction.

1302.3 — FOOTING DESIGN

(a) The base area of the footings of all buildings shall be designed in the following manner: The area of the footing which has the largest percentage of live load to total load shall be determined by dividing the total load by the allowable soil load. From the area thus obtained the dead load soil pressure of such footing is determined and the areas of all other footings of the building shall be determined on the basis of their respective dead loads only and such dead load sized shaft. The diameter of tapered or step-tapered piles cast-in-place shall be not less than 8" at the point and shall have an average diameter of not less than 11". The diameter of piles cast-in-place without permanent steel shells shall be not less than 14".

(d) No precast concrete pile shall be driven before the concrete has attained a compressive strength at least 3,000 lbs. per sq. in., but in all cases concrete shall be sufficiently cured to attain the ultimate strength upon which its use is based, before piles are driven. Such piles shall be reinforced to withstand conditions of handling, driving, and loading, and shall be so handled and driven as not to cause injury or overstressing which will affect their durability or strength. Precast concrete piles shall have a diameter of not less than 10 inches.

(e) Pile reinforcement when required shall have a protective covering of not less than 1½" of concrete except that where a pile has a metal casing, reinforcement shall be kept not less than 1 inch clear of such exterior casing. Reinforcing for cast-in-place concrete piles shall be considered necessary only when uplift, unbalanced lateral forces, or unsupported lengths (see Sec. 1303.1 (b) are to be considered.

1303.4 — WOOD PILES

(a) Wood piles used to support permanent structures shall be pressure impregnated with coal tar creosote to a minimum final retention of 12 lbs. per cu. ft. in accordance with Appendix "C", unless it is established that the cut-off on untreated wood piles will be below lowest ground-water level assumed to exist during the life of the structure. The treated pile cut-off shall have at least two (2) successive coats of hot creosote liberally applied and 1) be encased in masonry footings so that no part of the pile will be exposed to the air or 2) the cut-off shall be exposed and accessible for inspection. The cut-off on all wood piles shall be along a horizontal plane.

(b) The minimum acceptable standards for wood piles in Class B, "Specification for Round Timber Piles, ASTM D25-58." The minimum size of all wood piles shall be at least equal to Class B pile with the following exceptions: 1) Piles having a length of twenty (20) feet or less may have a minimum diameter of ten (10) inches located three (3) feet from butt. 2) Piles used to support five (5) tons or less shall measure at least eight (8) inches in smallest diameter at cut-off and six (6) inches in smallest diameter at the tip.

(c) The maximum allowable load on a timber pile shall meet the requirements of Section 1303.1(b) provided that the design load does not cause a stress in the timber beyond the following limits: 1200 lbs. per sq. in. on piles of Southern pine, Douglas Fir, Cypress, Oak, or any wood of comparable strength; 850 lbs. per sq. in. on piles of Cedar, Norway Pine, Spruce or any wood of comparable strength. Wood piles designed to support a load in excess of forty (40) tons shall be tested in accordance with Section 1303.6.

1303.5 — SPECIAL TYPES OF PILES

The use of types of piles not specifically mentioned herein, and the use of piles under conditions not specifically covered herein, may be permitted, subject to the approval of the Building Official, upon the submission of acceptable test data, calculations and other information relating to the structural properties and/or load-carrying capacity of such piles. Prior to giving such approval, the Building Official may require any information or demonstrations which he deems necessary for the determination of the adequacy of the design or of the suitability of the method of installation. In no case, however, shall the allowable load exceed the limitations specified in the various subsections of Section 1303.

1303.6 — TEST OF PILES

(a) When greater loads per pile than permitted by Section 1303.1 (b) are desired, or when the design load for any pile foundation is in doubt, control-test piles shall be tested in each area by maintaining constant load under increasing settlements. The resulting allowable load shall be not more than one-half of that test load which produces a permanent net settlement per ton of test load of not more than 0.01", but in no case more than one-half inch. In subsequent driving of the balance of foundation piles, all piles shall be deemed to have a supporting capacity equal to the control-pile, when the rate of penetration of such piles is equal to or less than that of the control pile through a comparable driving distance. At least one test pile shall be driven and test loaded in each area of uniform foundation materials and additional piles shall be driven and test loaded if deemed necessary to establish safe pile loading.

(b) When any doubt exists as to the safe load-carrying capacity of any pile the Building Official may order a loading test to be made on the pile. Subject to the limitations prescribed in the various sub-sections of Section 1303, the allowable pile load shall be determined as prescribed in the foregoing paragraph.

SECTION 1304 — CAISSONS

The footings of any structure may be carried down to a firm foundation by isolated piers of reinforced concrete or by open or pneumatic caissons either with or without enlarged base or bell at the bottom. The safe carrying capacity of such shafts or caissons shall not exceed the allowable unit bearing capacity of the soil multiplied by the area of the base or bell at bottom, provided such bell shall have at least 12 inch thickness of concrete at its edge and the sides shall slope at an angle of not less than 60 degrees with the horizontal unless of approved design properly reinforced. In no case shall such piers be of less than 2 feet minimum horizontal dimension.

TABLE 2 — MORTAR PROPORTIONS BY VOLUME*

Mortar Type	Portland Cement Cu. Ft.	Masonry Cement Cu. Ft.	Hydrated Lime or Lime Putty Cu. Ft.	Aggregate Measured in Damp Loose Condition Cu. Ft.
M	1	None	¼	Not less than 2¼ and not more than 3 times the sum of the volumes of cement and lime used.
	1	1	None	
S	1	None	Over ¼ to ½	
	½	1	None	
N	1	None	Over ½ to 1	
	None	1	None	
O	1	None	Over 1 to 2	

* For the purpose of these specifications, the weight of one cubic foot of the respective materials used shall be considered to be as follows:

Portland Cement .... 94 pounds
Masonry Cement .... weight printed on bag
Hydrated Lime .... 40 pounds
Lime Putty (Quicklime) .... 80 pounds
Sand, damp and loose .... 80 pounds of dry sand

TABLE 3 — TYPES OF MORTAR REQUIRED

Type of Masonry	Types of Mortar Permitted
Foundations: (below grade masonry)	
Footings	M or S
Walls of Solid Units	M, S or N
Walls of Hollow Units	M or S
Hollow Walls	M or S
Masonry Other Than Foundation Masonry	
Piers of Solid Masonry	M, S or N
Piers of Hollow Units	M or S
Walls of Solid Masonry	M, S, N or O
Walls of Hollow Masonry	M, S or N
Hollow Walls and Cavity Walls	
(a) Design Wind Pressure Exceeds 20 psf.	M or S
(b) Design Wind Pressure 20 psf or less.	M, S or N
Glass Block Masonry	M, S or N
Non-Bearing Partition and Fireproofing	M, S, N, O or Gypsum
Gypsum Partition Tile or Block	Gypsum
Fire Brick	Refractory Air Setting Mortar
Masonry Other Than Above	M, S or N

1402.13 — CERAMIC TILE

(a) Ceramic tile units shall be as defined in "Definition of Terms Relating to Ceramic Whitewares and Related Products, ASTM C242-60," and shall be of a quality at least equal to that required by "Federal Specification SS-T-308b," and shall be graded and marked in conformance with "United States Department of Commerce Simplified Practice Recommendation R61-61."

(b) Ceramic Tile set in cement mortar shall be installed in accordance with "Glazed Ceramic Wall Tile Installed in Portland Cement Mortar, USASI A108.1-1967"; "Ceramic Mosaic Tile Installed in Portland Cement Mortar, USASI A108.2-1967"; "Quarry and Pavers Tile Installed in Portland Cement Mortar, USASI A108.3-1967," with mortar mixes as specified therein for particular uses.

(c) Organic adhesives to be used in installing ceramic tile shall conform to requirements of "Water Resistant Organic Adhesives for Installation of Clay Tile, U. S. Department of Commerce, Commercial Standard 181-52."

(d) Ceramic tile set in dry-set mortar shall be installed in accordance with "Ceramic Tile Installed in Dry-Set Portland Cement Mortar, USASI A108.5-1967," and the dry-set mortar shall conform with requirements of "Dry-Set Portland Cement Mortar, USASI A118.1-1967."

SECTION 1403 — WORKING STRESSES

1403.1 — GENERAL REQUIREMENTS

(a) In determining the stresses in masonry, the effects of all loads and conditions of loading and the influence of all forces affecting the design and strength of the several parts shall be taken into account.

(b) The thickness of masonry walls shall be sufficient at all points to withstand all vertical and horizontal loads as specified in Chapter XII, Minimum Design Loads.

(c) Stresses shall be calculated on actual rather than nominal dimensions.

(d) The maximum allowable stresses in masonry shall not exceed those set out in this chapter, unless it can be determined by accepted engineering analysis that the design meets all safety requirements; see Sections 1403.3, 1403.7 and 1411.1.

1403.2 — WORKING STRESSES IN UNREINFORCED MASONRY

Except as permitted in other sections of this Code, the compressive stresses in unreinforced masonry shall not exceed the values given in Table 4.

fire-resistance requirements of Chapter X and are so anchored to the structural frame as to insure adequate lateral support and resistance to wind or other lateral forces (See Section 608.3).

1404.4 — FOUNDATION WALLS

See Section 1302.5.

SECTION 1405 — LATERAL SUPPORT

1405.1 — EXTERIOR WALLS

Exterior masonry walls, whether they be bearing or non-bearing shall be supported either horizontally or vertically (whichever distance is the lesser) at right angles to the face of the wall at intervals not exceeding those shown in Table 5 except that an additional 6 feet will be permitted for gables in residential structures and private garages that do not exceed one story in height. (See Section 1403.7.)

TABLE 5 — LATERAL SUPPORT-EXTERIOR WALLS

Type of Masonry	Maximum Ratio of Unsupported Height or Length to Thickness			
Mortar Type	M	S	N	O
Grouted Brick Masonry	22	22	22	—
Plain Solid Masonry	20	20	20	16
Hollow Unit Masonry	18	18	18	12
Masonry Bonded Hollow Walls	18	18	18	—
Cavity Walls*	18	18	18	—

*In computing the ratio for cavity walls the value for thickness shall be the sum of the nominal thickness of the inner and outer wythes.

1405.2 — BEARING PARTITIONS

Masonry bearing partitions shall be supported either vertically or horizontally (whichever distance is the lesser) at right angles to the face of the wall at intervals not exceeding 24 times the wall thickness for solid masonry units, and 20 times the wall thickness for hollow masonry units when laid in Type M, S or N mortar. Gypsum partition tile or block shall not be used in bearing walls. (See Section 1403.7.)

1405.3 — NON-BEARING PARTITIONS

(a) Non-bearing partitions shall be supported either vertically or horizontally (whichever distance is the lesser) at right angles to the face of the wall at intervals not exceeding 45 times the nominal wall thickness exclusive of plaster. (See Section 1403.7.)

(b) Gypsum partition tile shall not be used for partitions to receive portland cement plaster, ceramic tile, marble or structural glass, unless self-furring metal lath is placed over the gypsum tile. Gypsum partition tile or block shall not be used where they will be subjected to continuous dampness.

(c) Only gypsum cement mortar shall be used in the erection of gypsum partition tile or block.

1405.4 — METHOD OF SUPPORT

(a) Lateral support shall be provided by intersecting walls, pilasters, columns, or other vertical members of sufficient strength to provide the required support when the distance is measured horizontally; or by floors, roofs, or other horizontal structural elements which are of sufficient strength to provide the required support when the distance is measured vertically.

(b) Sufficient bonding or anchorage shall be provided between the walls and its supports to resist the assumed wind or other horizontal forces acting either inward or outward. All structural elements relied upon for lateral support shall have sufficient strength and stability to transfer the horizontal force acting in either direction to adjacent structural members or to the ground. When floors or roofs are depended upon for receiving horizontal forces, provisions shall be made in the buildings to transfer the lateral forces to the ground.

(c) When horizontal structural elements of a building (such as floors, roof, spandrel beams) are depended upon for lateral support, vertical bracing of bearing or non-bearing walls shall also be provided at intervals of not more than 75 times the wall thickness. Such vertical bracing may be provided by cross-walls, pilasters, buttresses or other equivalent structural members.

1405.5 — PILASTERS

When relied upon to provide the required lateral support, the width of pilasters shall be not less than one-tenth (1/10) the spaces between such pilasters. All pilasters shall be not less than four (4) inches thicker than the wall supported. In no case shall the distance between such pilasters exceed the lateral support provisions of Table 5.

1405.6 — PIERS

The unsupported height of masonry piers shall not exceed 10 times their least dimension. When structural clay tile or hollow concrete masonry units are used for isolated piers to support beams and girders, the cellular spaces shall be filled solidly with concrete or Type M or S mortar, except that unfilled hollow piers may be used if their unsupported height is not more than 4 times their least dimension. When hollow masonry units are solidly filled with concrete or Type M, S or N mortar, the allowable compressive stress may be increased as provided for in Table 4.

(b) All stumps and roots shall be removed from the soil to a depth of at least twelve (12) inches.

1701.2 — REMOVAL OF DEBRIS

After all work is completed, loose wood and debris shall be completely removed from all spaces under the building. All wood forms and supports shall be completey removed. Loose or casual wood shall not be stored in contact with the ground under any building.

1701.3 — FOUNDATIONS

Foundations shall be designed and constructed in accordance with the provisions of Section 1302. Where spot piers are used, unless properly designed, spacing of such piers shall not exceed eight (8) feet center to center.

1701.4 — MUD SILLS

A one-story building, except a dwelling, which does not exceed 800 square feet in area may be constructed without masonry or reinforced concrete foundation, provided such building is placed on a sill of approved wood of natural decay resistance or pressure treated wood. No mud sills shall be less than nominal two by six inches (2x6) or three by four inches (3x4) in cross-section.

SECTION 1702 — PROTECTION AGAINST DECAY AND TERMITES

1702.1 — WOOD SUPPORTS EMBEDDED IN GROUND

Where wood is embedded in the ground for support of permanent structures, it shall have an approved pressure preservative treatment, except where continuously below the ground-water line or continuously submerged in fresh water.

1702.2 — UNEXCAVATED SPACES

When wood joists or the bottom of wood structural floors without joists are closer than 18 inches, or wood girders are closer than 12 inches to exposed ground located within the periphery of the building over crawl space or unexcavated areas, they shall be approved wood of natural decay resistance, or pressure treated wood.

1702.3 — SILLS ON EXTERIOR WALLS

All sills which rest on concrete or masonry exterior walls and are less than 8 inches from exposed earth shall be of approved wood of natural decay resistance or pressure treated wood.

1702.4 — SLEEPERS AND SILLS ON CONCRETE SLAB

Sleepers and sills on concrete or masonry slabs which are in direct contact with the earth shall be of approved wood of natural decay resistance or pressure treated wood.

1702.5 — BASEMENT POSTS

Wood posts or columns in basements shall be supported by piers projecting at least two inches above the finish floor and separated therefrom by an approved impervious barrier except when approved wood of natural decay resistance or pressure treated wood is used. Posts or columns used in damp locations below grade shall be of approved wood of natural decay resistance or pressure treated wood.

1702.6 — GIRDERS ENTERING MASONRY WALLS

Ends of wood girders entering masonry or concrete walls shall be provided with a ½-inch air space on tops, sides and ends unless approved wood of natural decay resistance or pressure treated wood is used.

1702.7 — CLEARANCE BETWEEN SIDING AND EARTH

Clearance between wood siding and earth on the exterior of a building shall be not less than six (6) inches.

1702.8 — CRAWL SPACE VENTILATION

Crawl spaces under buildings without basements shall be ventilated in accordance with Section 1302.5(d).

1702.9 — APPROVED WOOD OF NATURAL RESISTANCE

(a) Approved wood for natural resistance to decay shall be all heartwood of bald cypress, black locust, black walnut, catalpa, and cedars, chestnut, osage orange, red mulberry, redwood and white oak.

(b) Approved wood for natural resistance to termites shall be all heartwood of bald cypress, redwood or Eastern red cedar.

1702.10 — APPROVED PRESSURE PRESERVATIVE TREATMENT

The Standards of the American Wood Preservers Association and the American Wood Preservers Institute shall be deemed as approved in respect to pressure treated lumber.

1702.11 — APPROVED PRE-CONSTRUCTION SOIL TREATMENT

The Standards of the National Pest Control Association shall be deemed as approved in respect to pre-construction soil treatment for protection against termites.

1702.12 — SPECIAL TERMITE PROTECTION

In territories where hazard of termite damage is known to be very heavy the building official may require floor framing of termite resistant wood, pressure treated wood, soil treatment or other approved methods of termite protection.