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Adobe, pressed-earth, and rammed-earth industries in New Mexico (revised edition)

by Edward W. Smith[1] and George S. Austin[2]

[1]P.O. Box 537, Tesuque, NM 87574
[2]New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801-4796

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Contents

Tables

Figures

Preface

Mud is the oldest building material mastered by man. Since the birth of civilization, people have used mud to construct homes. Today, soil remains the primary building material for over 50% of the world's population. In the United States, one third of the nation's adobe dwellings is in New Mexico.

This study attempts to document the current adobe industry in New Mexico and to update the *Adobe bricks in New Mexico* (Smith, 1982) and the first edition of *Adobe, pressed-earth, and rammed-earth industries in New Mexico* (Smith and Austin, 1989). Since 1980, new findings have emerged concerning the history and characteristics of adobe, the geology and mineralogy of adobe soil, the physical properties of adobe bricks, and the production techniques and market trends of the adobe industry. This report surveys and discusses recent developments in the adobe-brick, pressed-earth-block, and rammed-earth industries.

Current (1996) commercial adobe-brick producers as well as manufacturers of pressed-earth-block machines, producers of pressed-earth blocks, and builders of rammed-earth walls are included in the survey. Soil samples were collected from the majority of producers and analyzed for particle sizes and clay-size minerals. Some samples of adobe bricks and pressed-earth blocks from selected producers were tested for durability, strength, and moisture content by Dr. Kalman I. Oravecz at the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

We are indebted to Charles Chapin, Director of the New Mexico Bureau of Mines and Mineral Resources, and to staff members who have provided technical assistance for this project, in particular for the help and patience of Jennifer Boryta who edited the first edition manuscript and Jiri Zidek and Nancy Gilson, editors of the second edition. Grateful acknowledgment is made to Dr. Kalman I. Oravecz, Professor of Mining Engineering, for his excellent testing of adobe bricks and pressed-earth blocks. Appreciation is also extended to Paul Domski, graduate student, and Tanya Brickell and Matt Goolsby, undergraduate students, all at New Mexico Institute of Mining and Technology, who under the direction of George S. Austin, Senior Industrial Minerals Geologist, analyzed particle sizes and identified clay-size minerals.

Special thanks are due to architects William Lumpkins, P. G. McHenry, Jr., and Dale Zinn, and to Michael Taylor, Museum of New Mexico, for their assistance in reviewing the first edition manuscript.

Edward W. Smith
Consulting Geologist (retired)
Tesuque, New Mexico

George S. Austin Senior
Industrial Minerals Geologist
New Mexico Bureau of Mines
and Mineral Resources
Socorro, New Mexico

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Abstract—New Mexico continues to be the largest producer and user of adobe bricks and pressed-earth blocks in the nation. Thirteen commercial adobe-brick producers, one company manufacturing pressed-earth-block machines, and two rammed-earth contractors were located during field investigation and sampling in New Mexico in 1995. A variety of pressed-earth-block machines were available; the gasoline- and diesel-powered machines were being made by New Mexico manufacturers. Approximately 2,625,000 adobe bricks and 380,000 pressed-earth blocks were produced in 1995. A breakdown on the types of adobe bricks produced in 1995 shows that five producers made 168,000 traditional (untreated) adobe bricks that sold for 35-45¢ per brick, 2,245,000 semistabilized adobe bricks that sold for 35-55¢ per brick, and four producers made stabilized adobe bricks that sold for 50-65¢ per brick. The 395,000 pressed-earth blocks from three producers, most made without stabilizers, sold for about 50¢ per block.

New Mexico has two construction firms that produce earthen buildings with the rammed-earth contruction technique that does not form individual mud bricks. In 1995 these companies produced a total of 17 homes.

During sampling in 1987-1988, various tests were conducted on all types of adobe bricks, pressed-earth blocks, and rammed-earth materials. Mineralogy and particle-size analyses of the clays and soils, performed at the New Mexico Bureau of Mines and Mineral Resources show that soil materials used by the commercial earth materials industries contain more sand+-size particles than previously reported. Physical-property tests on selected adobe bricks and pressed-earth blocks, performed at the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology, show that the adobe bricks and particularly the pressed-earth blocks have high physical strength and in all cases meet or surpass the specifications and requirements of the New Mexico Building Code.

The characteristics of the soils, the techniques of production, and the examples of earth-constructed buildings that are detailed in this report show that adobe bricks, pressed-earth blocks, and rammed-earth walls make energy-efficient, durable, attractive dwellings. If problems in radon-prone and seismically active areas are properly recognized and controlled, then earth-constructed buildings are no more dangerous than homes constructed with other materials.

Introduction

The study, *Adobe bricks in New Mexico* (Smith, 1982), located 48 commercial adobe-brick producers, who in 1980 produced and sold 4,133,000 adobe bricks valued at $1,174,598. The history of adobe use, the geology and mineralogy of adobe soil, the physical properties of adobe bricks, and various production methods and market trends in the adobe-brick industry were described.

The *Adobe, pressed-earth, and rammed-earth industries in New Mexico* (Smith and Austin, 1989) updated and expanded the original report. In addition to 29 adobe-brick producers, this study located five manufacturers of pressedearth-block machines, the 16 producers in New Mexico who used the machines, and two builders of rammed-earth walls (Fig. 1). Recent developments in the production techniques for pressed-earth blocks and rammed-earth walls were described and new data on the geology and mineralogy of adobe soil were documented.

The 1987-88 field investigations show that since 1980 labor-saving, power-driven pressed-earth-block machines had been introduced to add a greater efficiently and flexibility to pressed-earth-block production. Twenty-seven machines were found in operation. Not all, whether producing or on standby, were engaged in commercial production; some were used by owners for individual, noncommercial building projects. Many New Mexico manufacturers were producing and selling pressed-earth-block machines to markets beyond the state and even overseas.

The rammed-earth industry in New Mexico was also investigated. Although several contractors had been active in the past, in 1988 only two contractors were found building rammed-earth walls.

Production data for adobe bricks, pressed-earth blocks, and rammed-earth construction in 1987 indicate that the overall production volume was about 3,766,000 adobe bricks, pressed-earth blocks, and four rammed-earth houses were produced. A total of 29 adobe brick producers made 3,124,000 adobe bricks and 16 pressed-earth-blocks producers made 642,000 pressed-earth blocks (Table 1). Most adobe bricks used in construction in New Mexico in 1987 were produced by eight major adobe-brick manufacturers who made and sold 2,110,000 semistabilized bricks for 30-35¢ each (Table 1). Approximately 849,000 traditional (untreated) adobe bricks were made and sold for 21-40¢ each. Only one company extensively produced fully stabilized adobe bricks, of which 165,000 were made and sold for 59¢ each. Several other producers indicated that they could produce stabilized adobe bricks on special order at the average price of 50¢ each.

Extensive sampling of adobe bricks and pressed-earth blocks in 1987-88 shows that commercial producers use adobe soils with far less clay-size material than expected. Most adobe soils contain about the same amount of silt, but the average adobe soil is sandier than expected. The sampling shows that the clay-size (less-than-2-micrometers, <2 μm, or <0.002 mm) fraction contains a variety of clay-mineral groups consisting of kaolinite, illite, smectite, mixed-layer illite/smectite (I/S), and rarely chlorite. As found in the previous study (Smith, 1982), expandable clay minerals (smectite and I/S) tend to present in more or less

TABLE 1—Total production, price range, and number of producers of New Mexico adobe bricks and pressed-earth blocks in 1987 and 1995. **NA**, not available.

Type of adobe	Number of producers 1987	Number of producers 1995	Price per adobe/block 1987	Price per adobe/block 1995	Total production 1987	Total production 1995
Adobe brick						
Traditional	20	5	21–40¢	35–45¢	849,000	168,000
Semistabilized	8	8	30–35¢	35–55¢	2,110,000	2,245,000
Stabilized	1	5	59¢	50–65¢	165,000	212,000
Pressed-earth block						
Traditional	16	3	25–35¢	~ 50¢	642,000	395,000
Stabilized	special order		45–55¢	**NA**	NA	NA

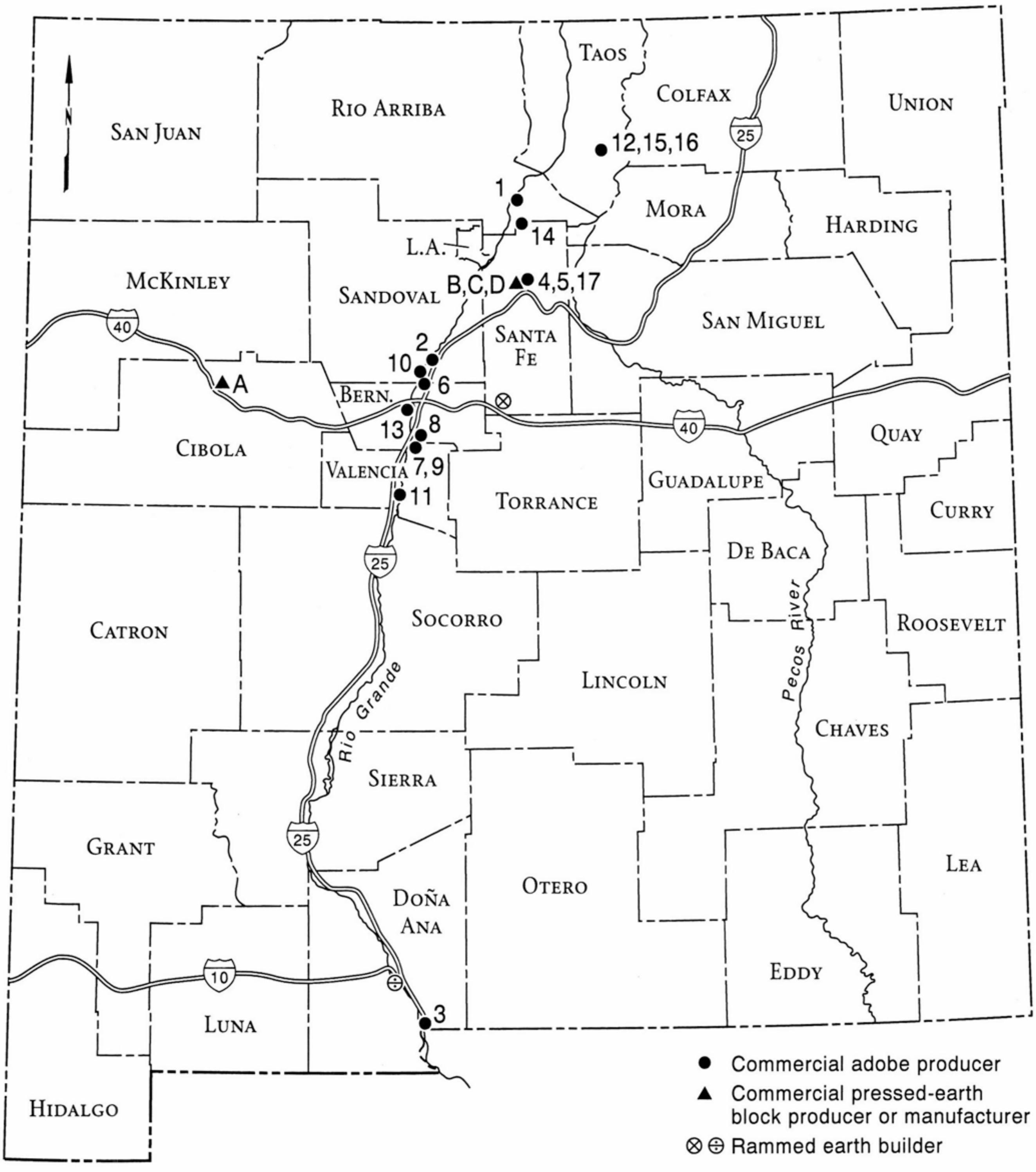


FIGURE 1—Locations of commercial adobe-brick, pressed-earth-block, and rammed-earth producers active in New Mexico in 1995.

equal proportions to nonexpandable (kaolinite, illite, and chlorite); however, no clay-mineral group dominates the mix and individual samples contain from trace amounts to about 60% of the groups.

The <2 gm fraction also contains significant amounts of nonclay minerals. Clay-size calcite ($CaCO_3$) and quartz (SiO_2) are nearly ubiquitous along with less common dolomite ($CaMg(CO_3)_2$), feldspar (sodium, calcium, and potassium aluminosilicates), and gypsum ($CaSO_4 \cdot 2H_20$), in decreasing order of abundance.

The apparent small percentage of <2 p.m particles indicates that clay minerals are not the only binding agent in adobe soils. The presence of calcite in both the clay-size and coarser fractions strongly suggests that it be the other chief

FIGURE 2—Puddled-adobe walls near White Rock on Pajarito Plateau. Archaelogy site excavated by C. Steen and Staff.

FIGURE 4—Old adobe and field-stone structure, San Jose.

binding agent in adobe soils from arid climates. After adobe blocks are produced in commercial yards, they are allowed to dry slowly (10 days to two weeks). During this time adobes become increasingly resistant to the erosion by rainfall. We believe that relatively insoluble, microscopic calcite crystals form from evaporating water binding sand- and silt-size grains together. Further tests are required for a definitive conclusion.

History

The word "adobe has its roots in an Egyptian hieroglyph denoting brick. The etymological chain of events ultimately yielded the Arabic "at-tob" or "al-tob" (sun-dried brick), which then spread to Spain in the form of the verb "adobar," meaning to daub or to plaster (Lumpkins, 1977). Through Spanish conquests of the New World, the word adobe was brought to the Americas.

Today, adobe is generally used to describe various earth-building materials and techniques and the structures built from them. Most often the term has come to refer to the sun-dried adobe brick, the earth-building material now most widely used in the United States, but adobe can also be applied to puddled structures, adobe-plastered logs or branches, and even to rammed-earth (pise) construction. Generally, any building that employs soil or mud as a primary material can be considered adobe.

FIGURE 3—Old house near Abiquiu. Jacal construction using cedar poles and adobe.

Outlining a clear-cut chronology of the development and spread of the use of adobe in ancient times is difficult because such use probably emerged in many forms. Given the relative abundance of the material, understanding why experimentation with mud buildings was attempted by many ancient peoples is not difficult. The Neolithic Period (10,000-3000 B.C.) marks the gradual replacement of nomadic hunting and foraging with primitive agriculture and the domestication of animals. With this stable, nonmigratory existence came the first efforts to build relatively permanent adobe structures.

Among the earliest remains of adobe structures are those discovered in the ruins of Neolithic farming villages in Mesopotamia, dating as far back as 7000 B.C. (Steen, 1972). Hand- and form-molded bricks from this era are also seen in the ruins of structures throughout Mesopotamia, Crete, Egypt, and India. The use of mud construction spread rapidly eastward through Asia and westward through northern Africa and the Mediterranean Basin and, as the glaciers of the ice age receded, throughout Europe. Meanwhile, the New World was undergoing a similar development. Although not used as early as in the great civilizations of the eastern hemisphere, adobe construction has been dated at 3000 B.C. in the Chicama Valley in Peru (Steen, 1972).

The first adobe structure in what is now the United States, however, probably does not predate A.D. 900. Since that time the region that now includes the state of New Mexico has undergone much development in adobe architectural styles, incorporating contributions from Indian, Spanish, and Anglo residents to produce a distinct native New Mexican architectural landscape. The evolution of architectural styles in New Mexico can be roughly broken down into four periods (Bunting, 1976): Indian (A.D. 700-1598), Spanish and Mexican Colonial (A.D. 1598-1848), Territorial (A.D. 1848-1880), and later American (A.D.

FIGURE 5—Taos Pueblo originally built of puddled adobe. Note mud plastering that is carried out each year to maintain the structure.

FIGURE 6—Puddled Adobe Structure at old Picuris Pueblo, ca 1900. Note size of puddled adobes that were patted into place by hand. Photo by A. C. Broman.

1880-present). Regardless of period or style, until recently construction of buildings in New Mexico has always revolved around adobe as the primary building material.

What is known as the Indian period actually includes all architecture predating the arrival of Spanish settlers in 1598 and can be broken down along archaeological lines into several distinct periods: Pueblo I (A.D. 700-900), Pueblo II (A.D. 900-1050), Pueblo III (A.D. 1050-1300), and Pueblo IV (A.D. 1300-1598). During Pueblo I, the early Pueblo Indians lived in below-ground earth-walled pithouses, some of which had mud-plastered wood partitions and roofs. The floors of the pithouses were often below the depth at which the ground froze so that the temperature of the homes would not drop below freezing. By A.D. 900 (Pueblo II) most of the Anasazi had moved into above-ground rooms often facing south, the walls of which were made of stone masonry and mud mortar. The walls of stone and mud retained the thermal properties of the older pithouses. For interior walls, jacal—a framework of vertical poles and branches covered with mud—was sometimes constructed (Bunting, 1976; Jones and Cordell, 1985).

The architecture of the Great or Classic period of Indian culture (Pueblo HI) can be seen at many famous archaeological ruins in the southwestern United States, including Pueblo Bonito at Chaco Canyon, old Picuris Pueblo, the site of Sapawe near El Rito, and the Pajarito Plateau sites (Steen, 1977; Bunting, 1976; Fig. 2) in the state of New Mexico. Jacal and stone masonry combined with adobe were the techniques generally employed during this era (Figs. 3,4).

The rammed-earth technique was used extensively also during Pueblo III, and is represented by such famous structures as the puddled-adobe multi-storied Taos housing complex (Fig. 5). With limited primitive wood and stone tools, the Pueblo Indians probably mixed adobe soil with water and carried the mud mixture to building sites, where the mud was shaped and patted by hand to form walls. The puddled-adobe and turtle-back methods are similar to rammed-earth construction except that the mud mixture is laid without the aid of wooden forms. Structures built with puddled-adobe and turtle-back methods have been identified at the excavation site of Sapawe near El Rito, various Pajarito Plateau sites near Bandelier National Monument (Steen, 1977), and at the old Picuris Pueblo (Bunting, 1976). Examples of old puddled-adobe structures made by patting mud into a wall shape can be seen at the modern pueblos of Picuris and Taos (Fig. 6).

The Pueblo IV period marks the migration of large numbers of Pueblo Indians into the Rio Grande valley. Pueblo IV culture was markedly less advanced than that of Pueblo III, as evidenced in the less sophisticated building technology and the smaller and less complex community organization. Ruins dating from this time can be seen at the ancestral villages of Tyounyi (Bandelier National Monument), Hawikuh (Zuni), Kuaua (Coronado State Monument), and Pecos (Bunting, 1976). Adobe structures dating from before Pueblo IV times have been continuously occupied only at Taos and Acoma Pueblos.

The Pueblo V period began after the 1598 arrival of the Spanish colonists and continues to the present day. Pueblo V overlaps, meshes with, and is overshadowed by the Spanish and Mexican Colonial, Territorial, and later American architectural styles. This period is marked by many rapid architectural changes and a general disintegration of pure Indian style as the influence of Spanish and later American newcomers encroached upon the pueblo communities.

Upon the arrival of the Spanish colonists in 1598, new building techniques and forms of architecture were introduced in New Mexico. Yet, because of the isolation of the region and the severe survival conditions imposed on the new settlers, the colonial era was characterized by little technical or cultural advancement. In fact, most buildings of this era may have been reduced to the barest essentials, and techniques and materials remained virtually unchanged from what the Indians had used before. A major contribution of the Spanish, however, was the introduction of the formed standard adobe brick (Bunting, 1976). In addition, the classic Spanish single-file linear room plan also began to appear and sometimes homes were constructed around a central plaza area for defense, with fortified round, two-story towers (torreónes) built nearby (Bunting et al., 1964; Bunting, 1976; Fig. 7). Another notable architectural feature of the Spanish and Mexican Colonial period was the "fortress church"—solid, rectangular adobe churches that resemble fortresses in their imposing size and lack of fenestration.

FIGURE 7—Reconstructed Spanish and Mexican Colonial fortress-like structure at el Rancho de las Golondrinas near La Cienega. Note tower (torréon) on right used for defense.

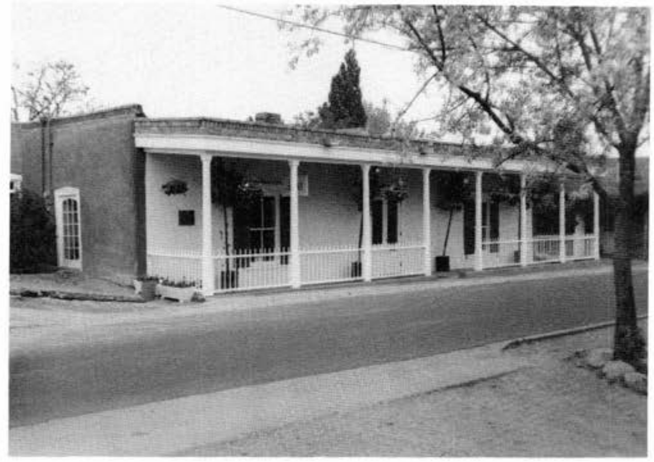


FIGURE 8—Territorial-style adobe building on Canyon Road, Santa Fe. Note neo-classic (vaguely Doric) columns and portal, exterior woodwork painted white, and burnt bricks on top of adobe walls.

With the opening of the Santa Fe Trail in 1821, influences from the eastern and midwestern states began to trickle slowly westward, and upon annexation of the territory of New Mexico in 1848 the flow of new materials and ideas increased. The Territorial period was one of rapid economic and cultural development that contrasted markedly with the preceding centuries of cultural isolation and preoccupation with warfare and survival. This change is reflected clearly in the architecture of the period, which went through several phases. However, the new architectural style was in essence nothing more than a transported version of the Greek Revival style was popular in the East in the 1820s. The Territorial style is probably best known for its elaborate neo-Classic and Gothic wood trim on windows and doors, the symmetrical floor plan based around a center hall, two-story construction, and columned verandas (Bunting, 1976; Fig. 8). The influx of new technology and materials, such as milled lumber, window glass, burnt brick (used to trim the tops of

TABLE 2—Estimated numbers and percentages of adobe dwellings in New Mexico from 1850 to 1980 (from Gerbrandt and May, 1986). "Population" and "total dwellings" figures without superscripts are taken from the U.S. Bureau of Census. *, dwellings occupied by "white and free colored" populace (U.S. Bureau of Census); †, estimated from 1870 census; —, net reduction.

	Population	Total dwellings	Percentage of dwellings that were adobe	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of dwellings built per year during decade that were adobe
1850	61,546	13,453*	97	13,050	690	91
1860	93,516	21,000†	95	19,950	—	—
1870	91,874	21,052	94	19,800	360	70
1880	119,565	26,311	89	23,400	600	72
1890	160,282	34,671	85	29,500	650	63
1900	195,310	44,903	80	35,900	1,800	58
1910	327,301	75,888	71	53,900	—	—
1920	360,350	78,024	63	49,000	—	—
1930	423,317	92,530	50	46,300	270	5
1940	531,818	145,642	34	48,900	—	—
1950	681,187	199,706	26	51,100	210	4
1960	951,023	281,976	19	52,500	170	2
1970	1,019,060	326,762	16	53,600	620	3
1980	1,299,968	503,676	12	59,000		

FIGURE 9—Santa Fe-style (Pueblo Revival-style) architecture, Santa Fe.

adobe walls), and corrugated iron, contributed to the new modern American look of New Mexican architecture. Many people felt traditional adobe architecture was jeopardized during the Territorial period. An attempt was even made to disguise adobe-building material completely with a lime, sand, or cement coating that was scored or painted to resemble ashlar masonry.

The later American period began with the arrival of the railroad in New Mexico cities in 1880, yet this style did not reach some of the more remote mountain villages until after World War H. During this period, diverse architectural trends from California and the east coast were introduced in New Mexico, as the state rushed to catch up with the rest of the country. The availability of iron, improved tools and fittings, and other manufactured items hastened New Mexico's arrival in the 20th century. In addition, pueblo-like architecture was experiencing a rebirth in what became known as the Santa Fe style (Pueblo Revival style), which is now associated in the minds of many people with the soft, earth-tone, curvilinear adobe architecture of the Southwest (Fig. 9).

Also during this time, because of the advent of railroads and the influx of Anglo settlers mainly from the east coast, who constructed homes made with other materials, the extent of adobe use decreased in New Mexico. Gerbrandt and May (1986) calculated from U.S. Bureau of Census reports that in 1850 as much as 97% of the homes in New Mexico were adobe. Whereas in 1980 only 12% of the homes were adobe (Table 2). Over a period of 130 years, the number of adobe dwellings increased from 13,050 to an estimated 59,000, but during **the** same period the population increased from 61,546 to 1,299,968.

In Albuquerque during the 1970s, approximately 100 construction permits per year were issued for adobe homes (Gerbrandt and May, 1986). Based on this number, Gerbrandt and May (1986) estimated that 3% of new homes built in New Mexico during that decade were adobe. In 1980, an estimated 7.1% of new homes built in Albuquerque were adobe. Although adobe bricks continue to be produced in Indian and Spanish-American communities, much of today's commercial production is used to construct large-scale, expensive homes and commercial buildings throughout the state.

In order to appreciate modern adobe buildings, it is necessary to understand how they are constructed. Architectural drawings of adobe walls and structures, first published by the senior author in 1982 in *Adobe bricks in New Mexico,* (New Mexico Bureau of Mines and Mineral Resources Circular 188), are reproduced here as Figures 10-25. These drawings are provided only as guides to assure that the basic rules of adobe construction are understood. Many local variations different from the ones shown exist, but they do not affect the energy efficiency and simplicity of adobe. All drawings and specifications made for specific homes should be the responsibility of the person who prepares them, the owner, the designer, the architect, or the engineer. These drawings were prepared for publication by us by architect Dale Zinn of Santa Fe and reviewed by Architects William Lumpkins, Santa Fe, and Allen McNown, Nambé.

The developments in the use of adobe over hundreds of years have formed the backbone of New Mexico's architectural heritage. The unique and eclectic architectural landscape continues to distinguish the state from the rest of the **nation.**

Terminology and characteristics

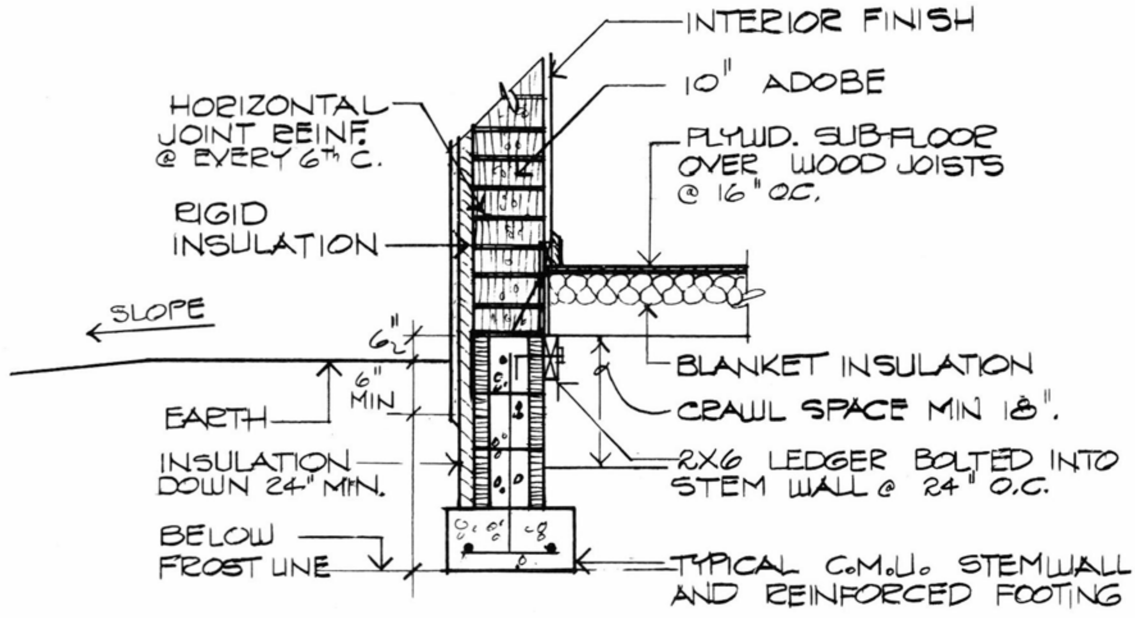
Adobe bricks

Adobe or sun-dried mud brick has a long history of widespread use by the Indians, Spanish Americans, and Anglo-Americans in the southwestern United States, where annual precipitation is low. However, the use of adobe need not be restricted to arid and semiarid climates if buildings are properly protected or certain soil stabilizers used (Hubbell, 1943). In fact, examples of earth-wall construction can be found from New England to South Carolina in climates that are far from arid or semiarid. Modern residences of earth-wall construction have been built since 1920 in Washington, D.C., Illinois, Michigan, Arkansas, Colorado, North Dakota, Wyoming, Idaho, and in all the southwestern states (Long and Neubauer, 1946).

The wooden form introduced by the Spanish colonists in the late 1600s permitted the adobero (adobe maker) to control the size and weight of the bricks, which in turn allowed a greater construction flexibility. Many sizes of adobe bricks with considerable variation in weight have been produced in the Southwest. Long and Neubauer (1946) noted bricks from early California and New Mexico adobe structures that varied in size and weight as follows:

Dimensions (inches)	Weight (lbs)
4x 8 x 16	30
4x 9 x 18	38
4 x 12 x 18	50
5x 9 **x 18**	48
5 x 12 x 18	60
6 x 12 x 24	100

The adobe bricks produced today in New Mexico vary from the 3 x 5 x 10-inch mosque-type Egyptian brick of size that weighs 8 lbs and is used in the construction of domes



10" STEM WALL-JOIST FLOOR

NOTE: ALL FOOTINGS AND FOUNDATION WALLS ARE SHOWN FOR AVERAGE SOIL AND LOADING CONDITIONS. ALL FOOTINGS SHOULD BE DESIGNED FOR THE SPECIFIC CONDITIONS OF EACH PROJECT.

THE THICKNESS OF INSULATION REQUIRED BY ENERGY CODES VARIES WITH PROJECT, SITE, CLIMATE AND THE R-VALUE OF THE INSULATION TO BE USED.

FIGURE 10—Typical foundation for 10-inch adobe wall.

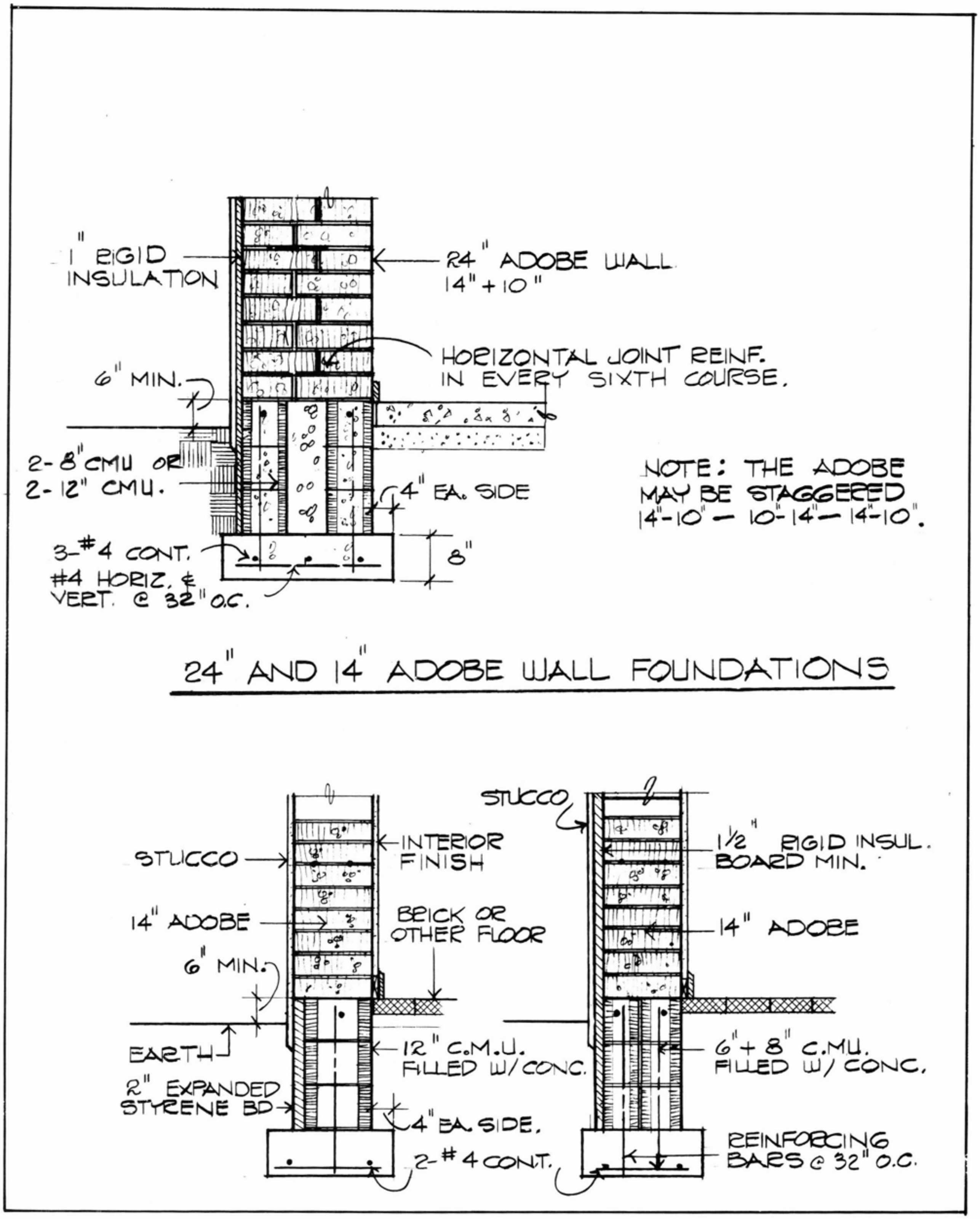


FIGURE 11—Typical foundation for 14-inch and 24-inch walls.

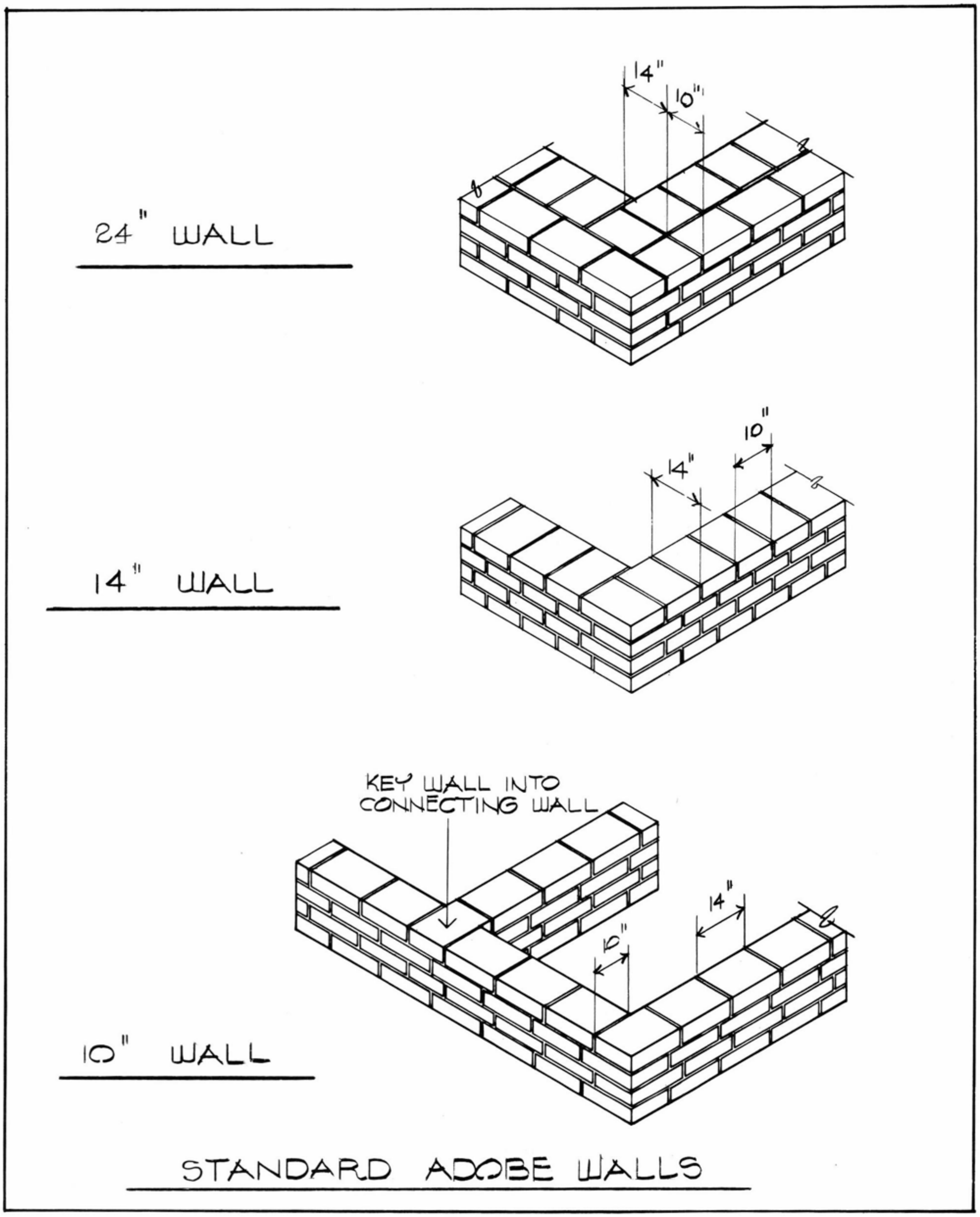


FIGURE 12—Standard adobe-wall thickness.

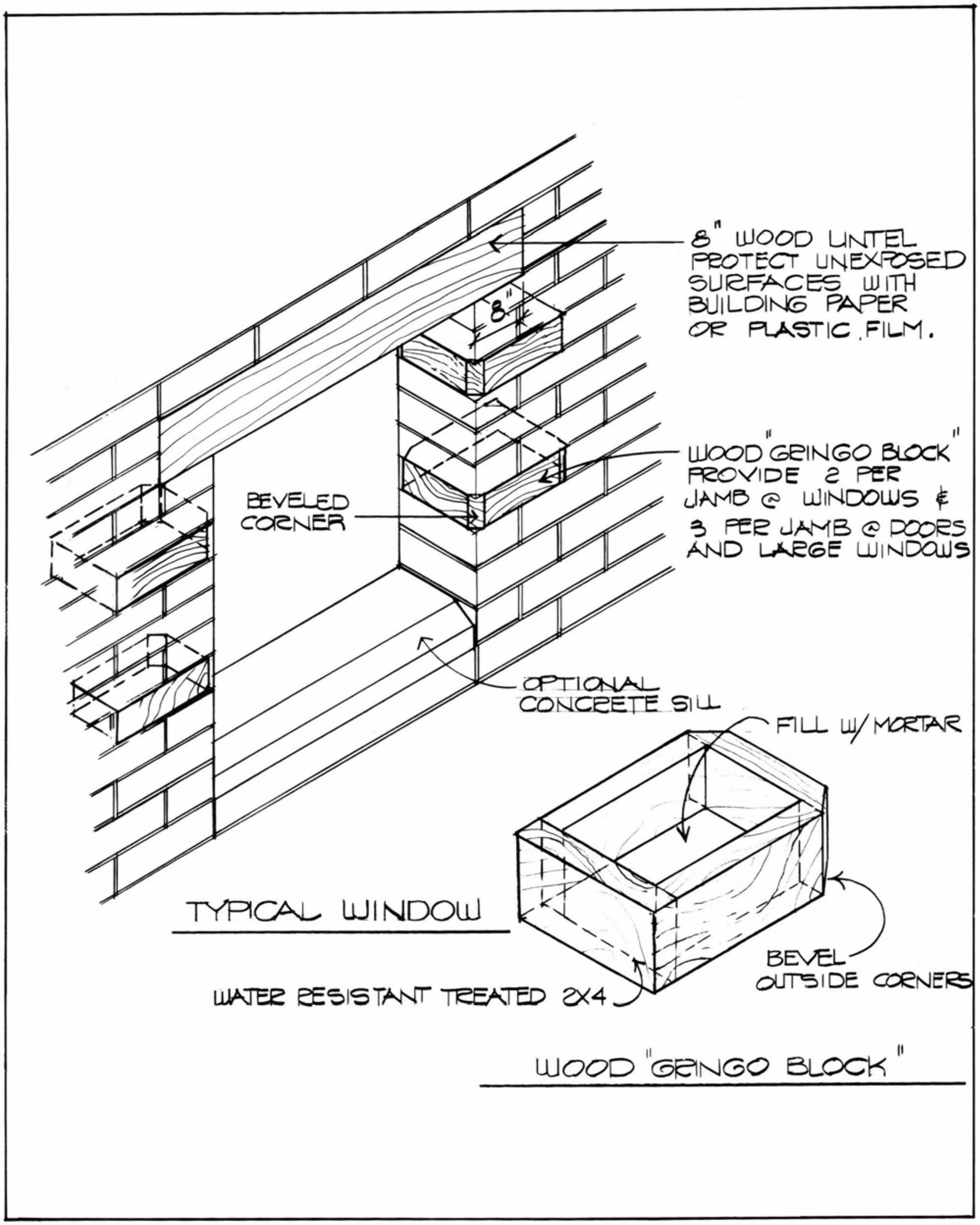


FIGURE 13—Wood "Gringo" blocking detail.

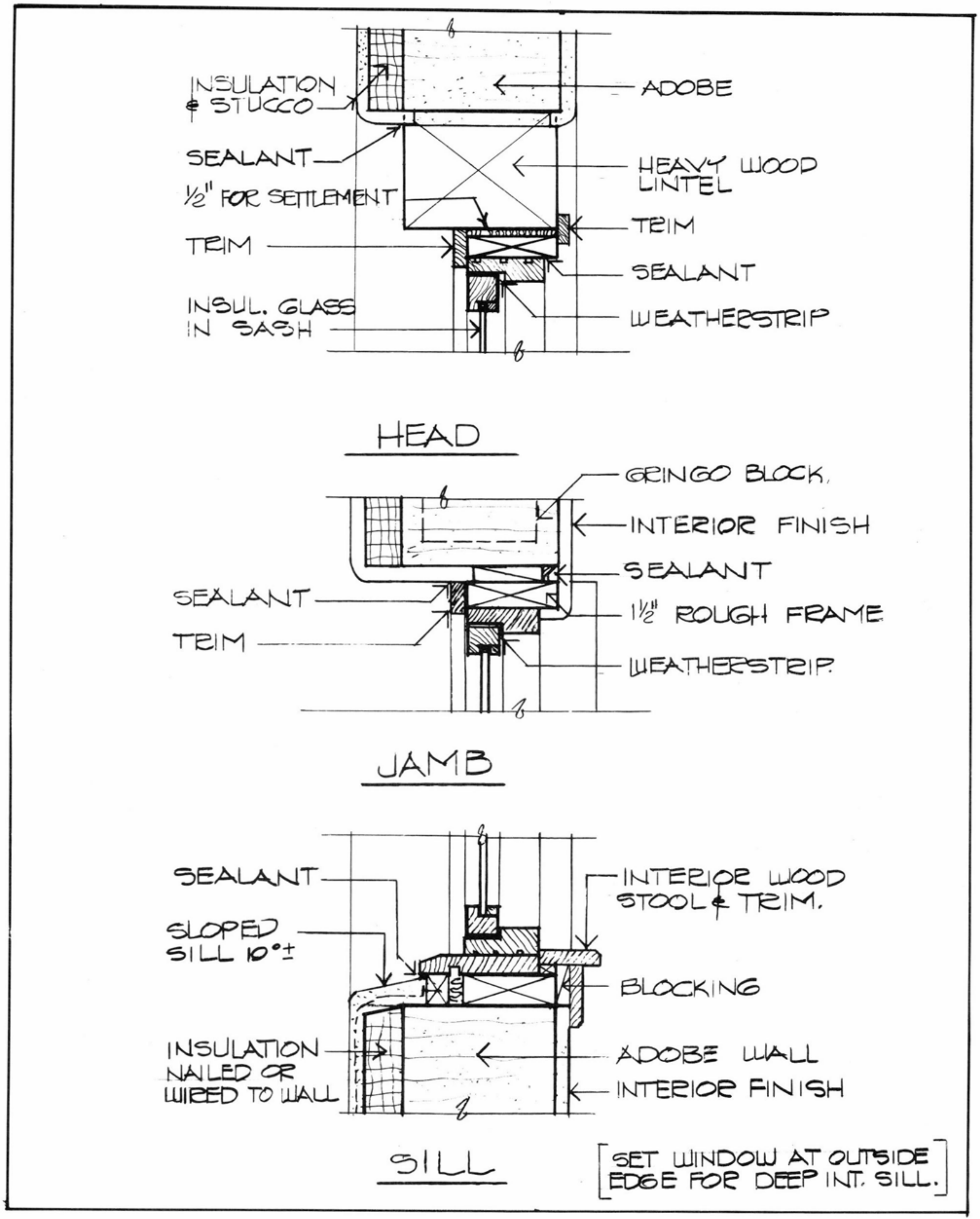


FIGURE 14—Typical wood window.

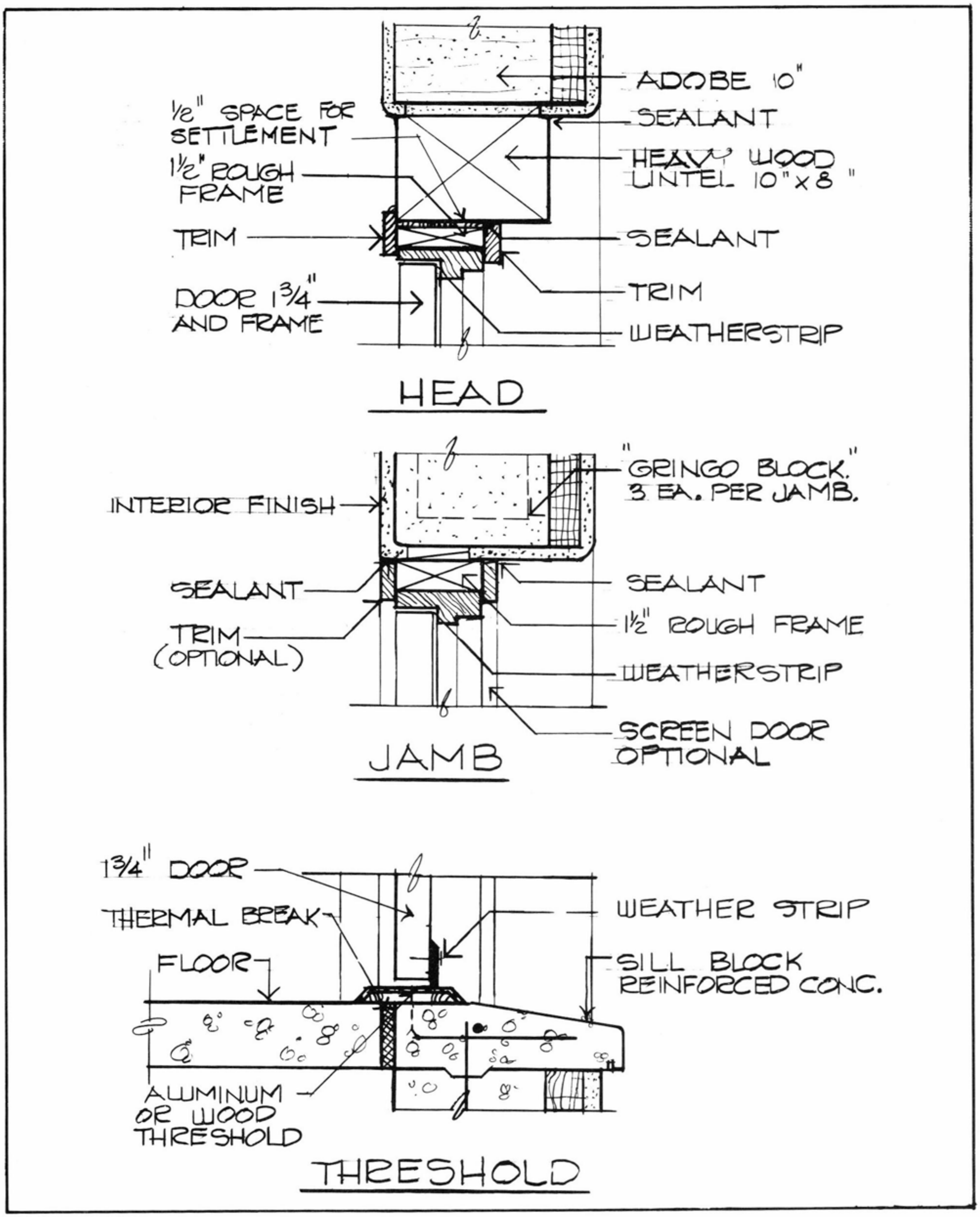


FIGURE 15—Typical exterior wood door details.

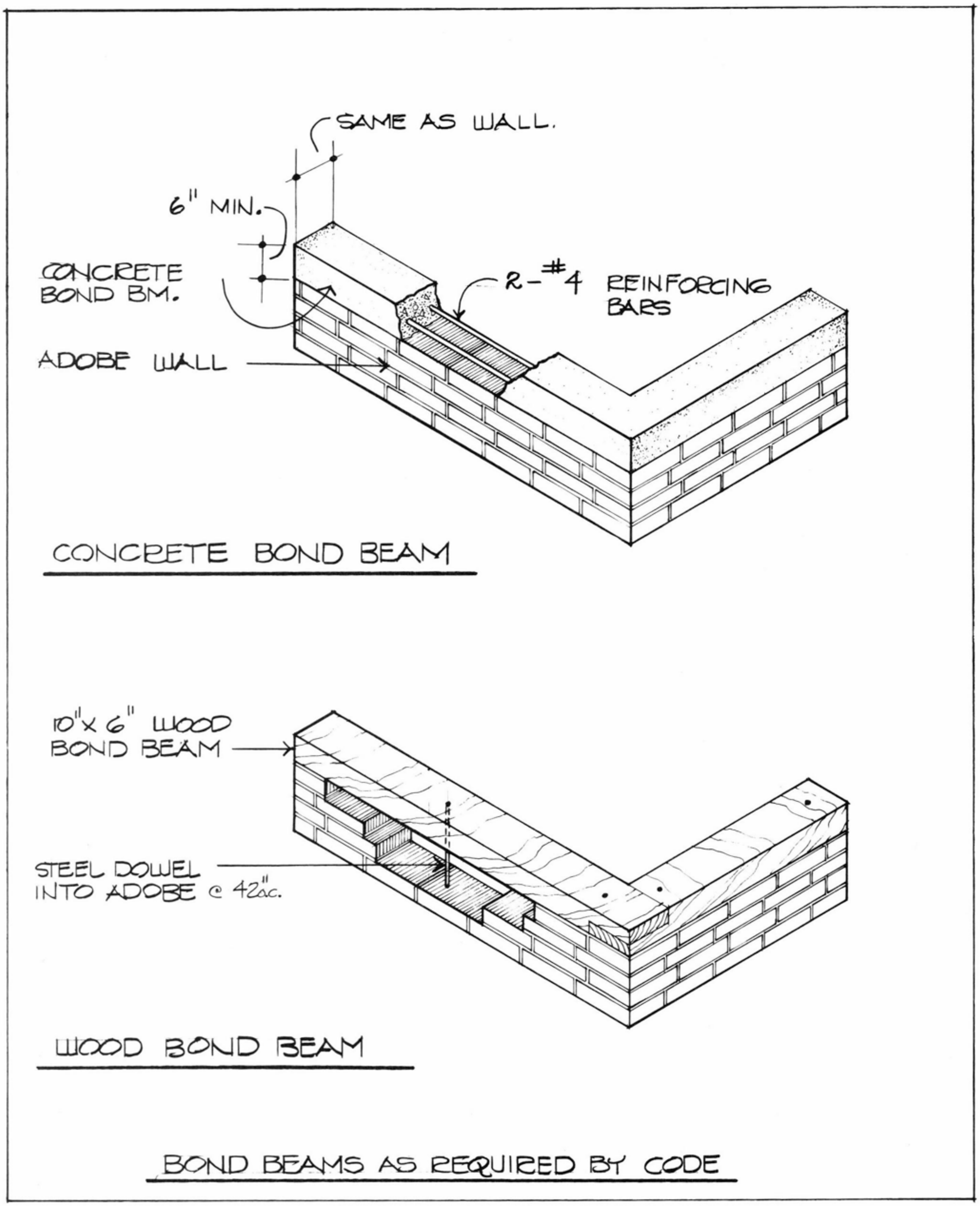


FIGURE 16—Bond beams as required by code—wood timber and concrete.

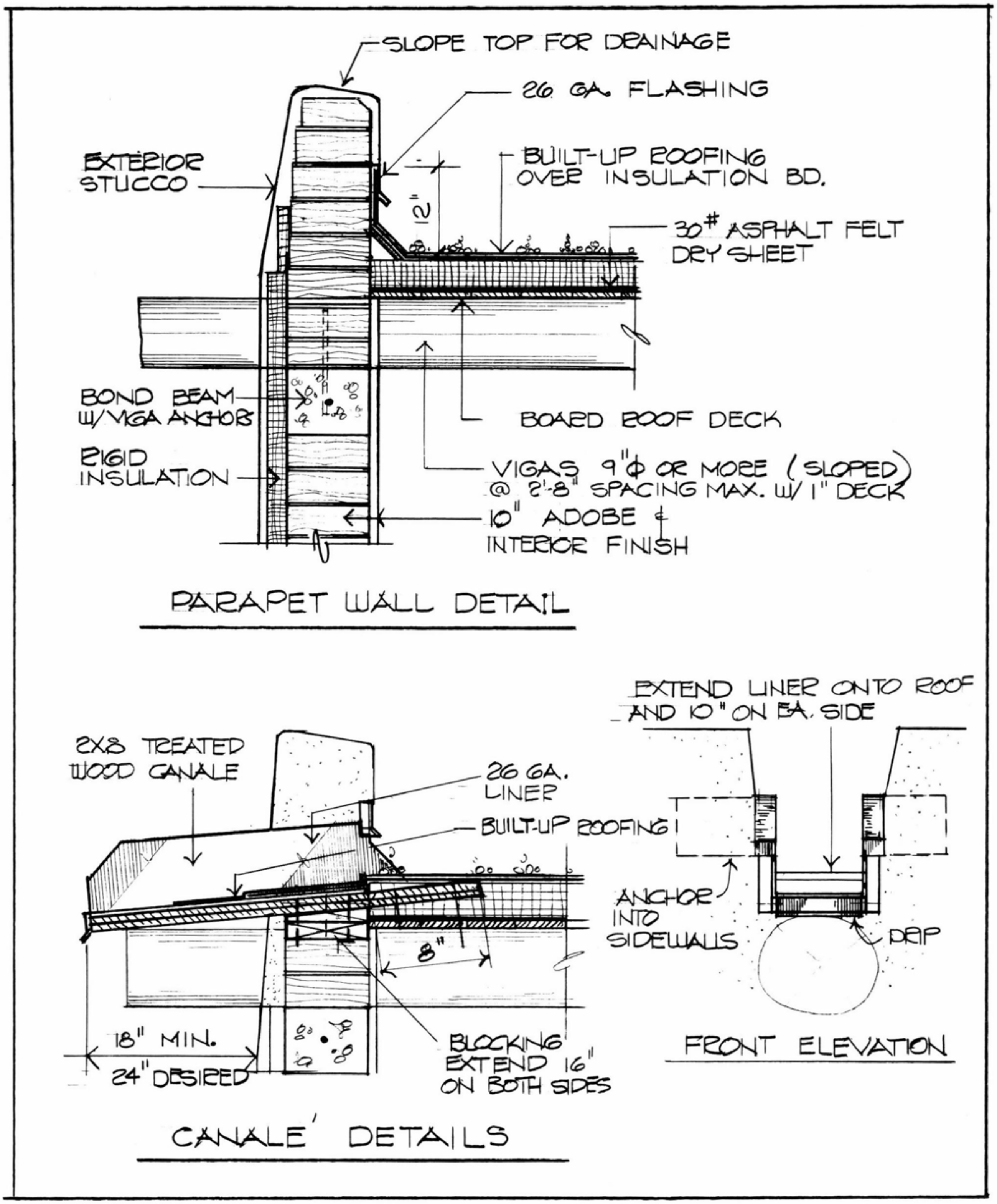


FIGURE 17—Roof parapet and canalé detail.

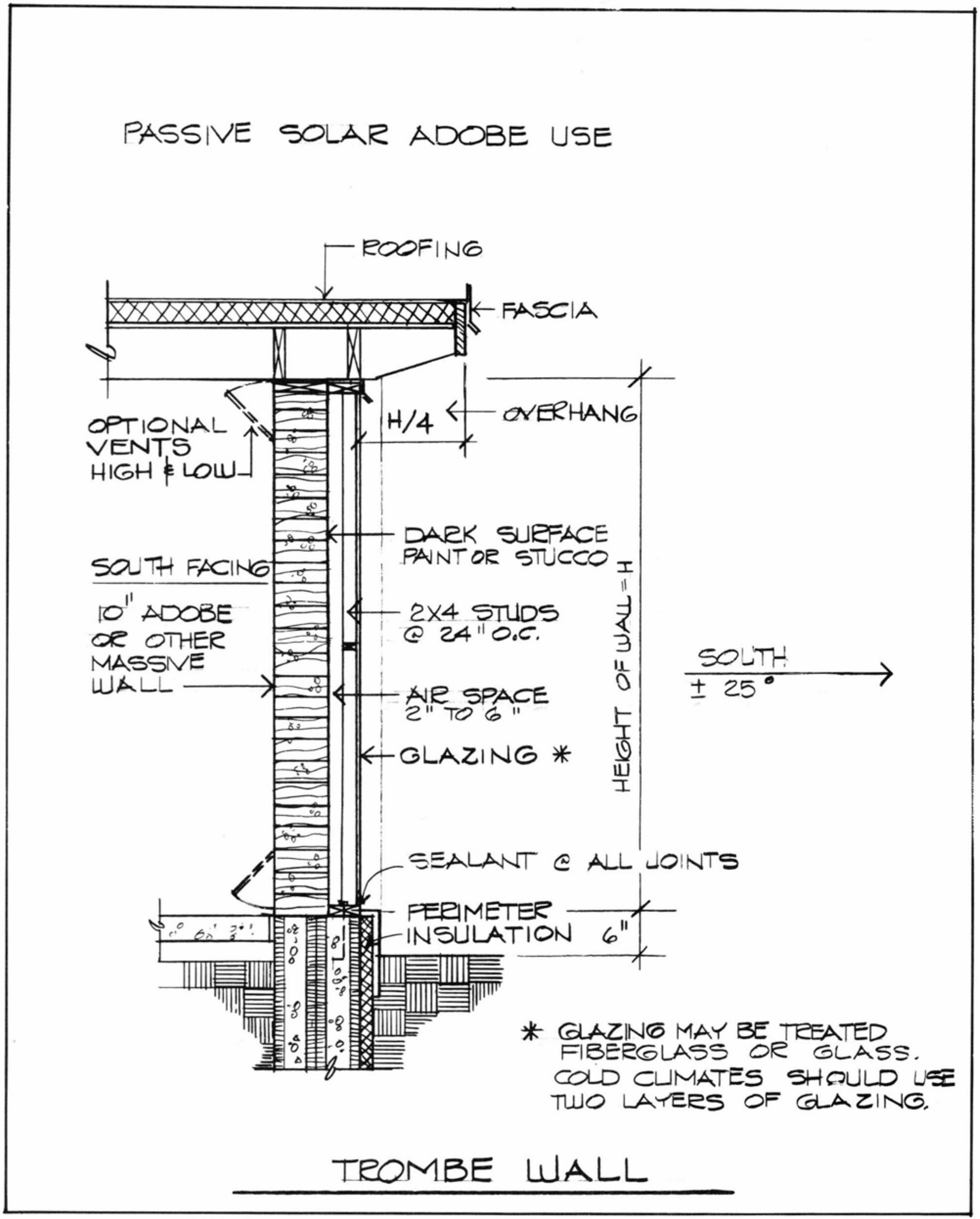


FIGURE 18—Passive solar trombe-wall detail.

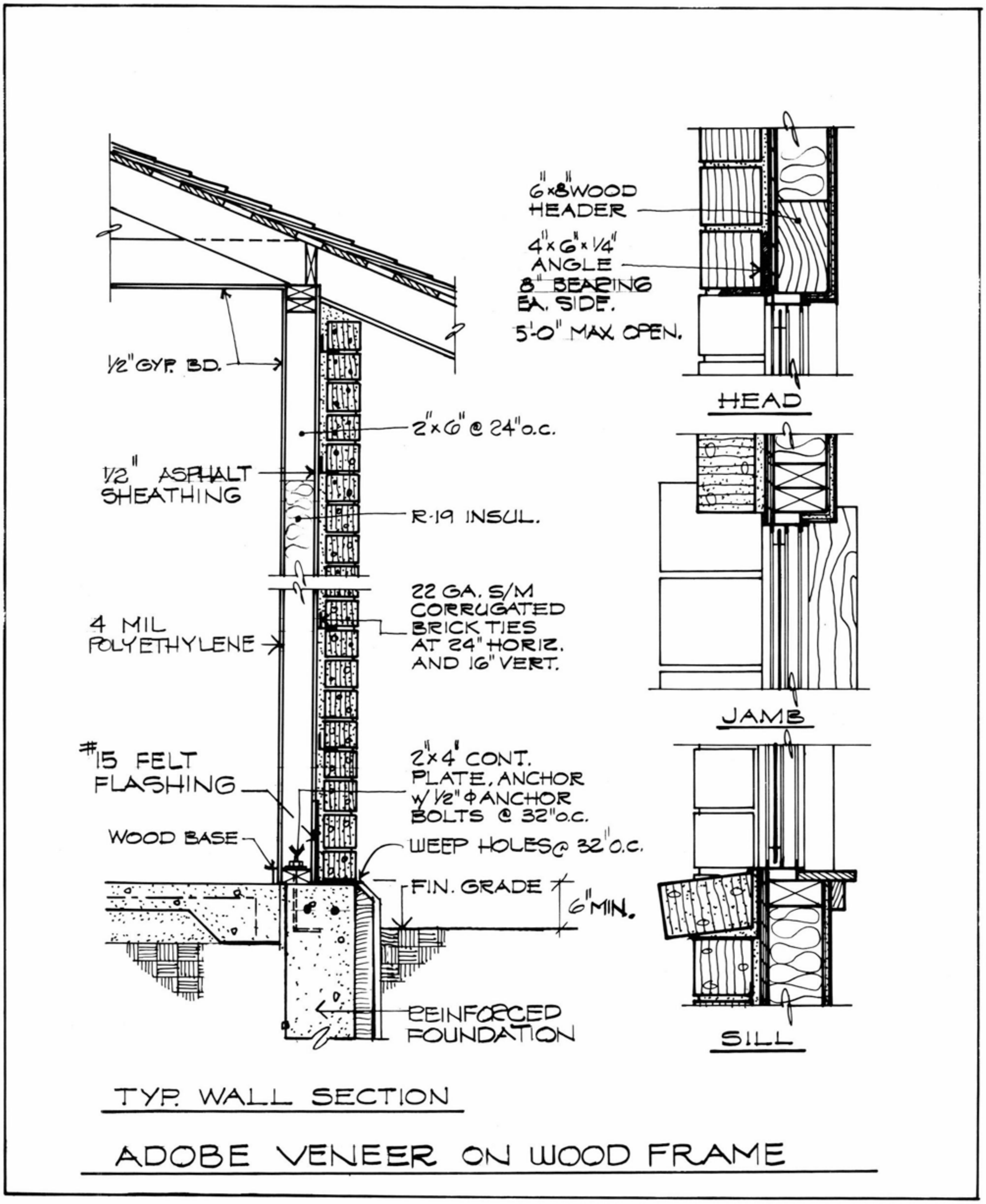


FIGURE 19—Adobe veneer over stud wall section.

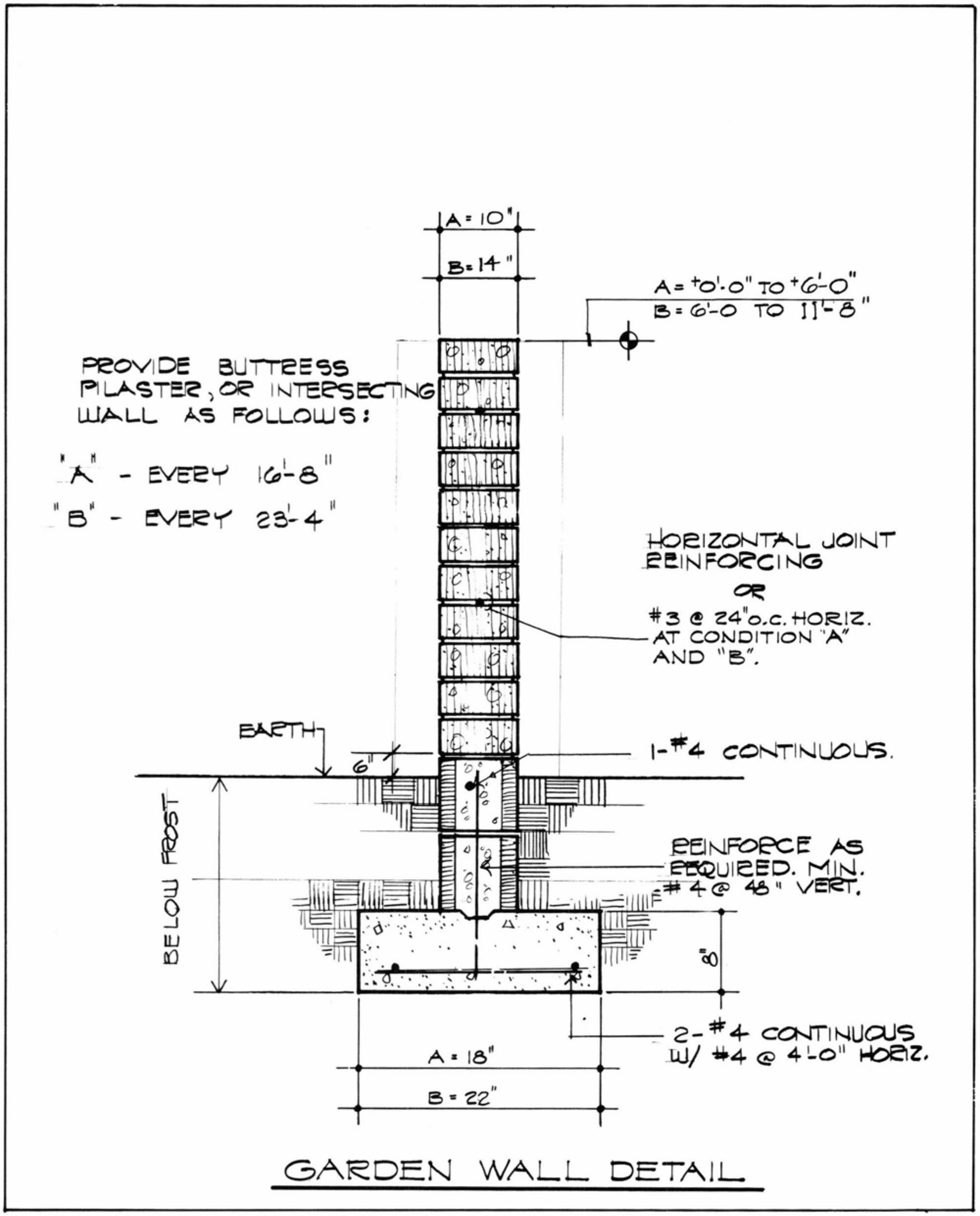


FIGURE 20—Garden-wall detail.

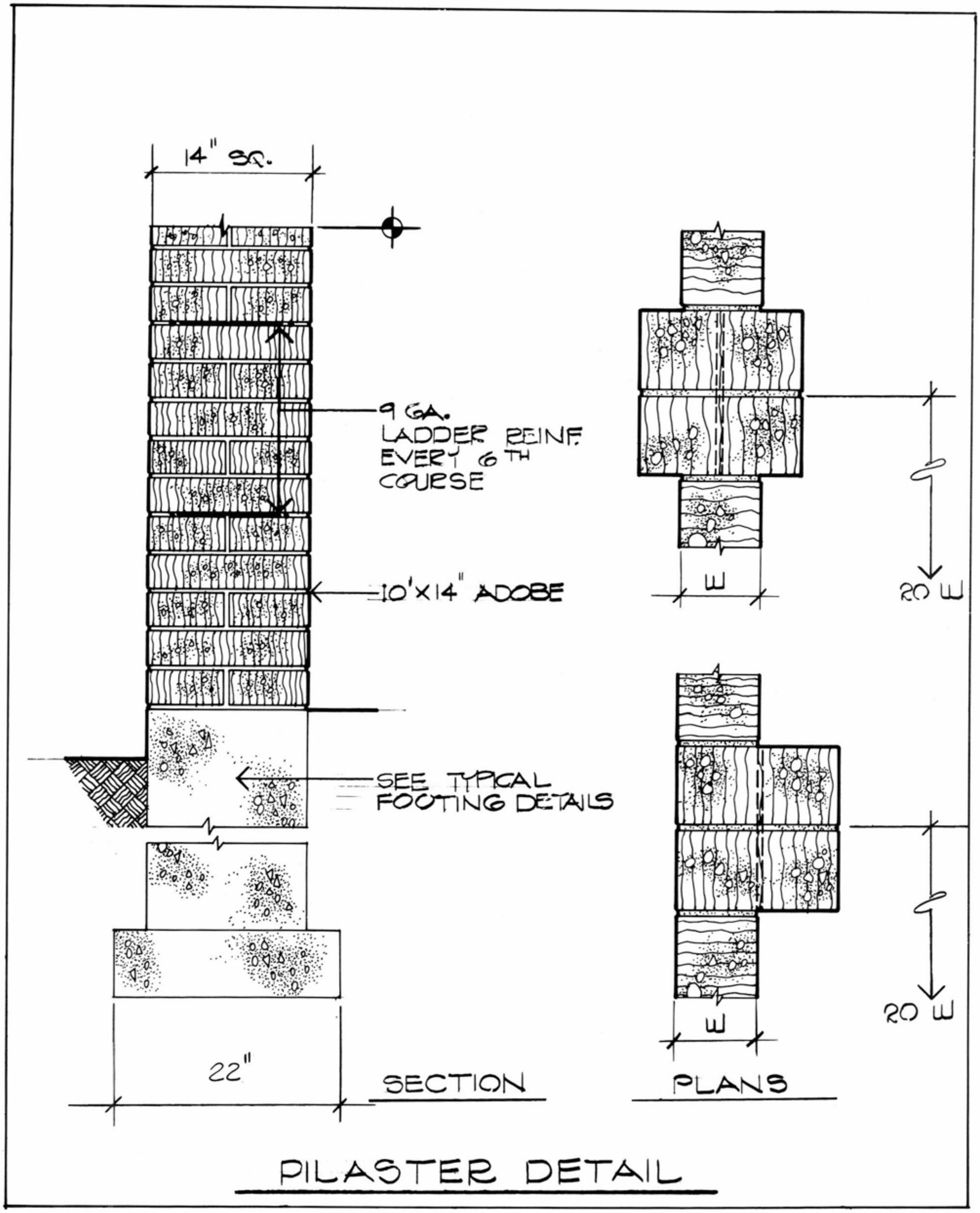


FIGURE 21—Adobe post or pilaster detail.

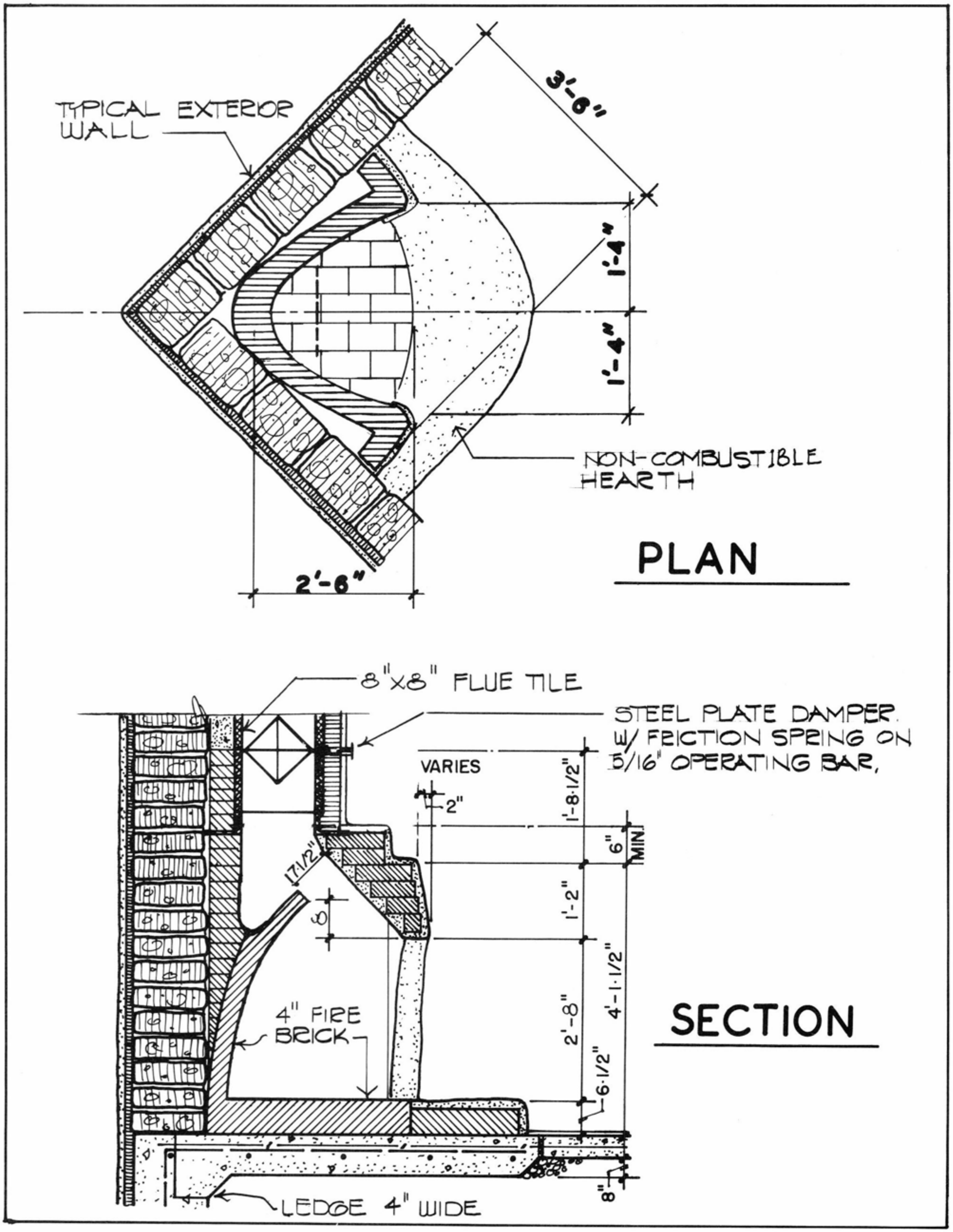


FIGURE 22—Adobe corner fireplace.

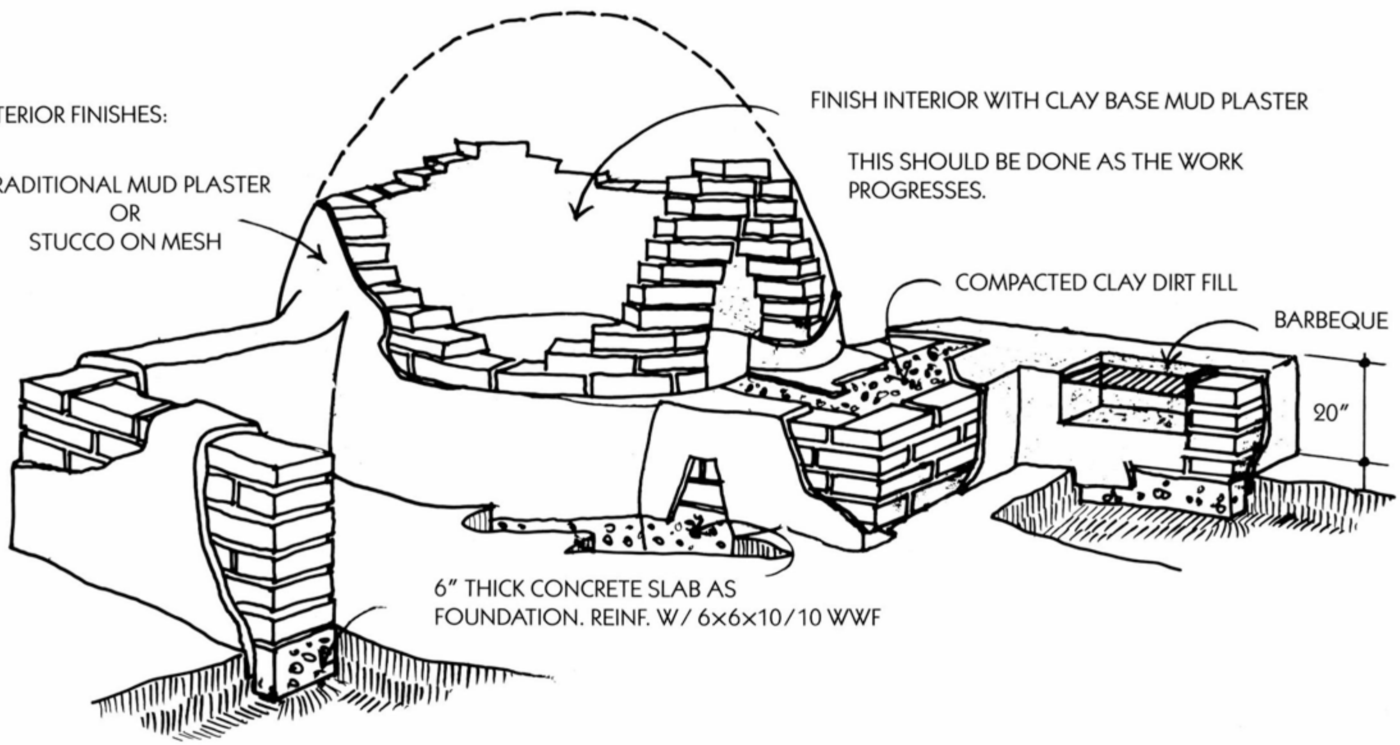


FIGURE 23—Adobe horno or Indian oven.

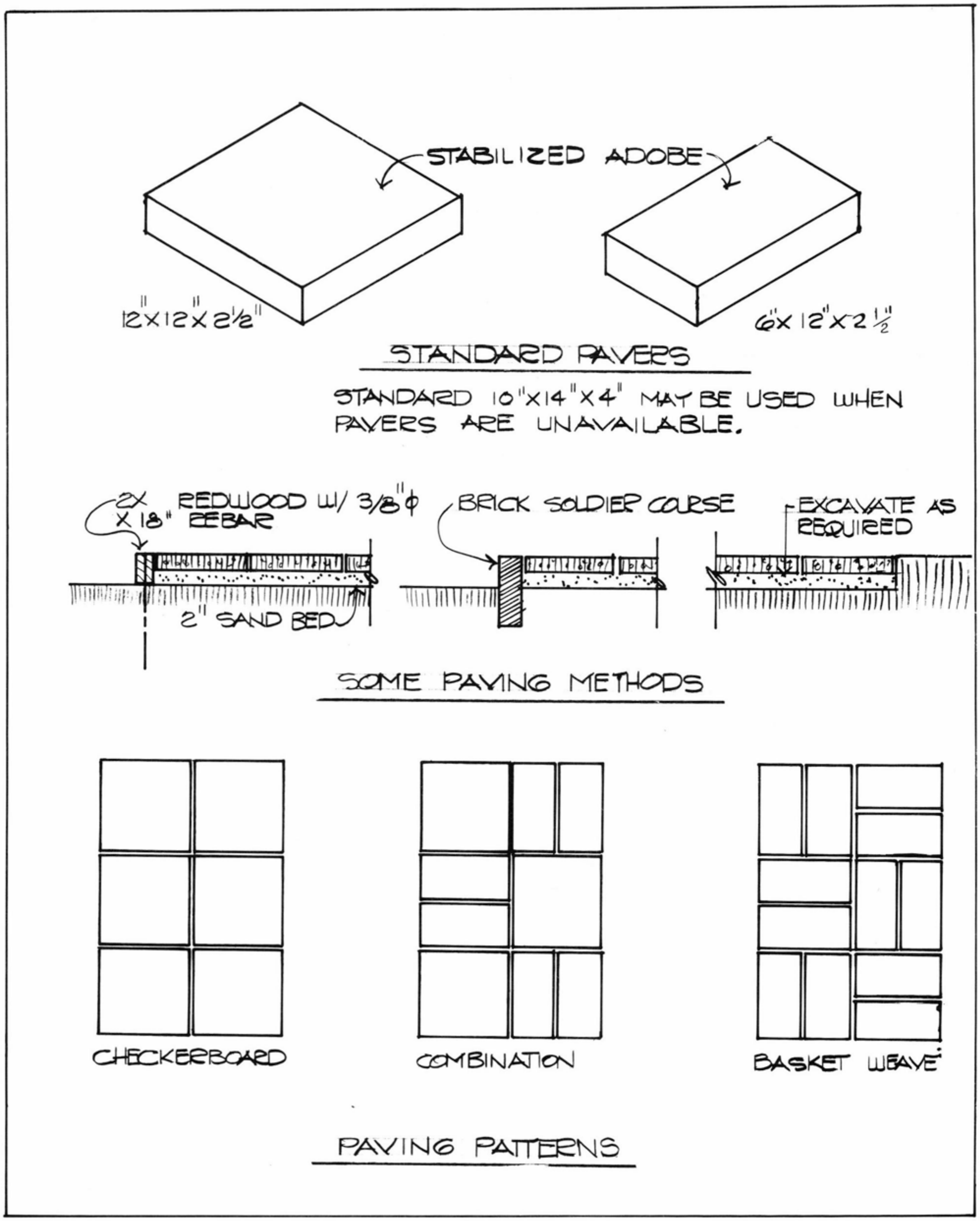
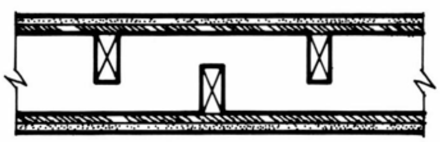
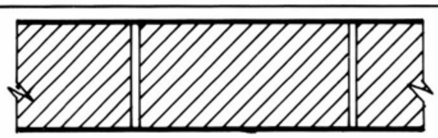


FIGURE 24—Adobe-brick paving for walkways and patios.

TEST NO.	CONSTRUCTION	WEIGHT LBS./S.F.	TRANSMISSION DB.	CLASS
1x	 ½" INSULATING ON 2×4 STUD BOARD @ 16" OC	3.8	32.2	FAIR
2x	 2×4 STUDS @ 16" OC 3/8" GYP. ½" PLASTER LATH	15.0	34.9	FAIR TO GOOD
3x	 2×4 STUDS @ 16 " OC ½" INS. ON 2×6 PLATE BD. LOOSE W/ ¾" INSUL BD.	6.2	42.8	VERY GOOD
4x	 2×4 STUDS STAGGERED - ½" 16" OC 2×6 PLT. PLAST. & LATH	13.1	53.7	EXCELLENT
5	 10" ADOBE BRICK	109	63	EXCELLENT

x : TESTS SHOWN WITH (✤) ARE RESULTS OF TESTS SPONSORED BY THE INSULATION BOARD INSTITUTE.
FROM A REPORT DATED SEPT. 14, 1956. EXAMINATION 308691
AFTER HANS STUMPF COMPANY, INC.

FIGURE 25—Sound-transmssion test results.

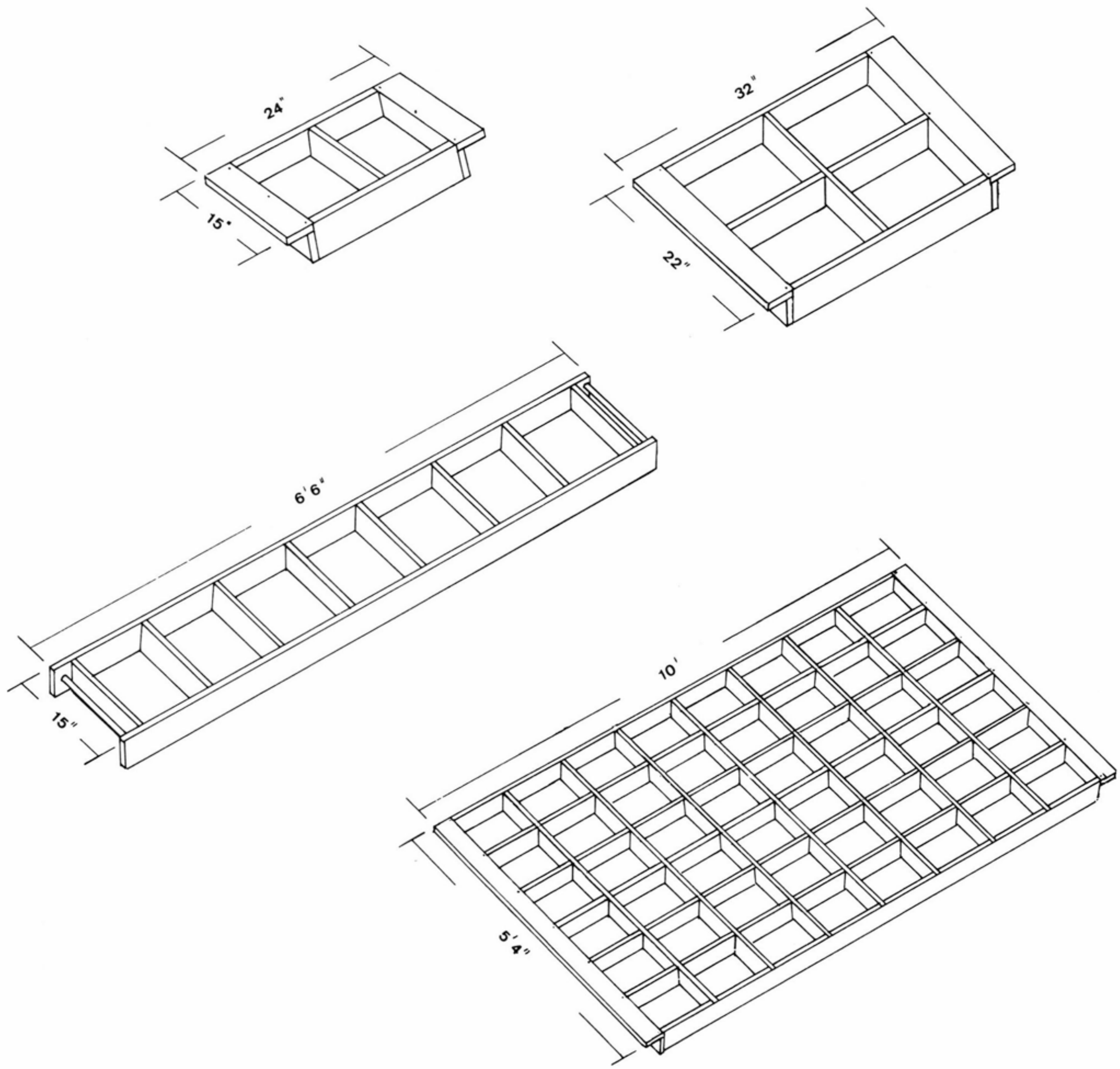


FIGURE 26—Diagrams of typical New Mexico wooden molding forms with approxmiate overall dimensions.

and arches, to the 7 x 7 x 14-inch Isleta Pueblo terrón brick that weighs 35 lbs. The principal brick (97%) manufactured today by the majority of adobe producers in New Mexico is 4 x 10 x 14-inches and approximately 30 lbs in weight. Other sizes are usually produced only in limited quantities or as ordered (Table 3).

Adobe soils

Adobe bricks can be made from a variety of local soils, but the most suitable soil found in the Rio Grande valley is a sandy loam composed of approximately 55-85% sand and 15-45% finer material (generally more silt than clay), and usually containing caliche (pedogenic or formed-in-the-soil calcium carbonate). A balance of particle sizes is essential to obtain a quality adobe. Clay gives strength but in excessive amounts causes shrinkage; sand or straw is added to decrease shrinkage and prevent cracking (California Research Corporation, 1963).

Adobe mortars

Adobe bricks and pressed-earth blocks are joined together in an adobe wall with a water-adobe-soil mortar that hardens and becomes firm upon drying. The New Mexico Building Code allows the use of earth mortar if it is composed of the same materials as the bricks. Most adobe-brick and pressed-earth-block producers can furnish this screened adobe soil.

Stabilizers

Moisture re-entering an adobe brick causes clays to swell and release their bonds so that the entire mass disintegrates.

TABLE 3—Sizes and weights of adobe bricks and pressed-earth blocks made in New Mexico.

Type of earth block	Dimensions (inches)	Weight (lbs)
Adobe brick		
Egyptian brick	3×5×10	8
Veneer brick	4×4×16	26
Half adobe	4×4×8	23
Quemado (burnt adobe)	3½×8×16	30
New Mexico standard adobe	4×10×14	30
Adobe (old style)	4×5½×16	28
Adobe (old style)	4×12×18	50
Taos standard adobe	4×8×12	26
Terrón	7×7×14	35
Dome brick (mosque)	2×10×6	8
Mexico standard adobe	3½×10×16	35
Salazar adobe	4×10×15½	37
Acoma Mission adobe	3×9×18	30
Pressed-earth block		
CINVA-Ram pressed block	3½×5½×11½	20
Standard pressed-earth block	4×10×14	40
Medium pressed-earth block	4×10×12	30
Small pressed-earth block	4×8×12	25
California/Arizona pressed-earth block	4×10×16	50

To prevent disintegration, various soil stabilizers are added to the basic soil mix to waterproof the brick or to increase its resistance to weathering. As many as 20 different stabilizing materials have been found in use (Wolfskill et al., 1970), the most common being sand, straw, portland cement, lime, and bituminous and asphalt emulsions (Clifton, 1977). In New Mexico, asphalt emulsions (Clifton, 1977), are widely used by the large-scale commercial producers to protect bricks drying in open yards during intense rains.

Molding forms

The construction and design of the metal and wooden molding forms used to make adobe bricks are as numerous and varied as the makers of adobes themselves. Typical types of molding forms used in the state are illustrated in Figure 26. Most of them are made of wood with the sides, ends, and dividers usually 4 inches wide to produce the standard 4-inch-thick adobe brick. The common use of 2 x 4s produces a 31/2-inch-thick, lighter adobe averaging 27-30 lbs.

Small-scale producers who make traditional (untreated) adobe bricks generally use a two- or four-mold wooden form, which can be handled by a single worker. Large-scale producers typically have several hundred wooden molding forms resembling ladders that may vary from seven to ten up to 48 molds per form. Usually two or more workers are required to lift these large molding forms to free the drying bricks.

Traditional (untreated) adobe bricks

Often referred to as untreated or standard sun-dried adobe brick, the traditional adobe brick is made with soil composed of a homogeneous mixture of clay, sand, and silt. Straw is sometimes added to prevent the brick from cracking when curing. Examples of traditional adobe bricks can be found in the majority of cities, villages, and pueblos of New Mexico.

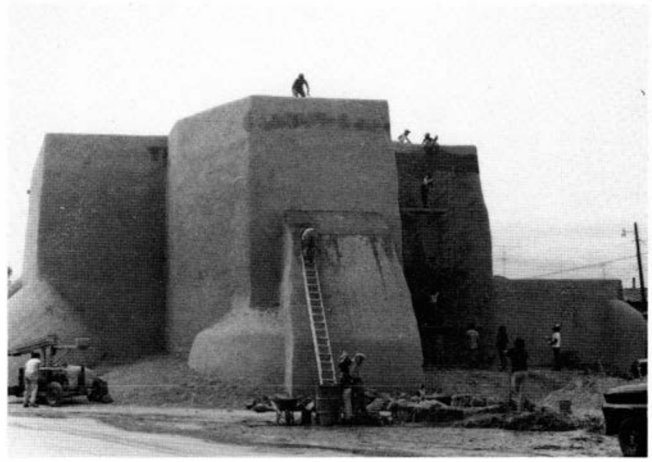


FIGURE 27—Plastering adobe mud on walls of church, Ranchos de Taos.

To protect structures made of traditional (untreated) adobe, two methods have been used. Owners have plastered on a simple adobe-mud mixture, which usually requires periodic reapplication (Fig. 27), or have applied a longer lasting wire mesh and cement stucco. In many areas of the state, the owners of adobe structures have added a pitched tin or corrugated iron roof with an overhang to protect the adobe roof and walls from excessive erosion (Fig. 28).

The durability of untreated adobe structures that are carefully maintained is well illustrated by the multistoried Taos and Acoma Pueblos, which have been continuously occupied for more than 900 years. Many other examples of historic, traditional (untreated) adobe architecture can be seen in the numerous mountain villages of New Mexico, where some adobe structures are more than 300 years old.

Semistabilized adobe bricks

Developed by the large-scale producers to be somewhat water-resistant, the semistabilized adobe brick is the most widely produced brick in New Mexico. Its name is derived from the practice of adding a small amount of stabilizer to adobe mud to make water-resistant bricks. The primary purpose of the stabilizer is to protect the several thousand bricks that may be drying in an adobe yard from the damage of a

FIGURE 28—Old adobe home, San Jose. The owner has added a corrugated iron roof to protect the adobe structure.

FIGURE 29—Mudpit at the Rio Abajo Adobe Works adobe yard, Belen. Asphalt emulsion from tank on the right and water are added to soil in the center. Mixing is done by the front-end loader.

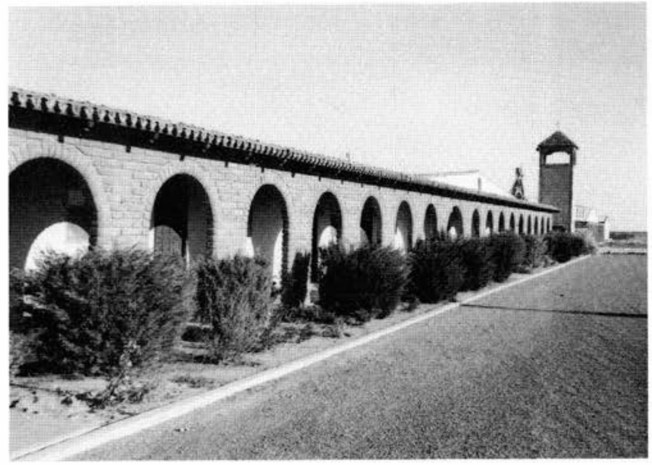


FIGURE 31—Portal made with quemados, airport near Columbus.

heavy rain. The semistabilized brick is made essentially the same way as the traditional adobe brick except that 3-5 wt% asphalt emulsion is added to the adobe soil as the soil is mixed in a pugmill or mudpit (Fig. 29).

Stabilized adobe bricks

The fully stabilized adobe brick, referred to by the New Mexico Building Code (Appendix 3) as a treated adobe, is defined by the addition of a sufficient amount of stabilizer to limit the brick's seven-day water absorption to less than 4 wt%. The fully stabilized adobe brick is usually manufactured with 6-12 wt% asphalt emulsion, which produces a waterproof building material that resists water penetration without a protective coating. The addition of portland cement (5-10 wt%), although not in use as a stabilizer in adobe bricks in 1995, can also produce a good water-resistant brick.

Terrónes

The Spanish word *terrón* meaning *a flat clod of earth,* refers to the type of adobe brick made of cut sod or turf material found in boggy river-bottom locations, particularly in the Rio Grande floodplain areas (McHenry, 1985). The tenón is cut from sod in 7 x 7 x 14-inch block using a flat spade and then is stacked in a dry area to sun-dry and cure (Fig. 30). Probably because of the sod-root structure and the high clay content of the soil, the terrón has a high compressive strength and modulus of rupture, but also a measurable shrinkage during drying.

Quemados

The quemado or burnt adobe is a traditional sun-dried adobe brick that has undergone a modified low-temperature firing process. Combustible materials are burned in a stacked-brick oven that is built to allow air circulation within the kiln. Usually firewood is fed through small doors at each end of the kiln with smoke escaping through holes at the top. The firing process usually takes two to four days and approximately 300-500 quemados are produced per firing (Fig. 31).

Pressed-earth blocks

Usually manufactured with traditional (untreated) soil, the pressed-earth block is a type of adobe brick that does not require much curing time. The soil, placed in a steel mold

FIGURE 30—Cutting terrónes from Rio Grande sod, Isleta Pueblo.

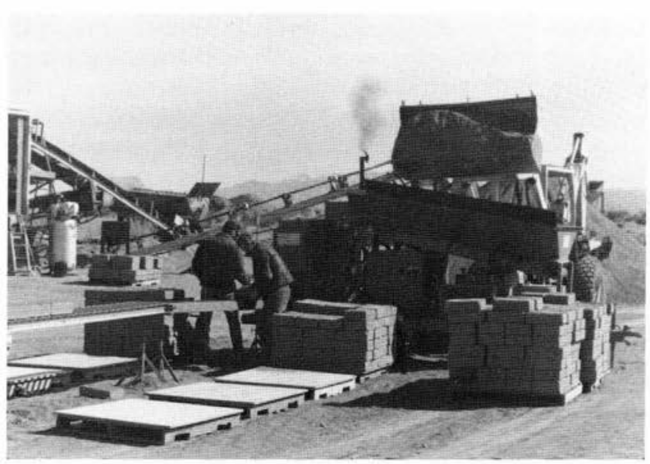


FIGURE 32—Goldbrick "5000" pressed-earth-block machine in operation at the Ridge Adobe production yard, Santa Fe.

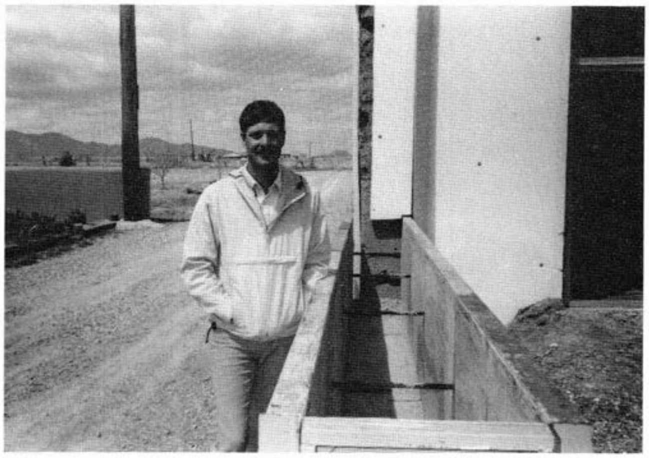


FIGURE 33—Stan Huston of Huston Construction Company standing by rammed-earth forms, Edgewood.

usually of 4 x 10 x 14-inch size, is pressed into a dense block by a hand-operated press referred to as a *CINVA-Ram,* or a gasoline- or diesel-powered hydraulically operated machine. The powered machines are capable of producing several thousand blocks per day (Fig. 32). Because of the high pressure applied by the hydraulic press, the pressed-earth block usually tests very high in compressive strength and modulus of rupture.

Rammed-earth walls

The rammed-earth (pise) wall is built by thoroughly-tamping layers of moist soil between wooden, steel, or aluminum forms (Fig. 33). Hand-operated or pneumatic tampers ram the soil until it becomes dense and firm. When a section of the wall is done, the forms are moved upwards or sideways and the process is repeated until the entire wall is completed. The density of the wall depends on the soil type and the length of tamping time.

According to Santa Fe architect William Lumpkins (pers. comm. 1988), several puddled-earth houses were built north of Santa Fe in the late 1970s. The contractor used a cement mixer to blend soil with a small amount of portland-cement binder and an overload of pea-size gravel, which prevented "gumming up" in the mixer. The mix was moved to the future site of a wall and patted into place. Lumpkins observed that one house was built in seven or eight days by four laborers. Both exterior and interior partition walls were made with the puddled earth.

Geology

Usable adobe soils are found in much of the Southwest and constitute a virtually inexhaustible supply in New Mexico. The adobe materials are principally from stream deposits, particularly Holocene (Recent) terraces and older, loosely compacted deposits, such as in the Santa Fe Group (Tertiary), present throughout the Rio Grande valley. More than 95% of the adobe producers are located between Belen and Taos, New Mexico, and most of them use a sandy loam (50% clay and silt) associated with or derived from the Santa Fe Group.

Although soils suited for adobe structures are found in almost all areas of New Mexico, a satisfactory soil deposit may not be at or near the proposed manufacturing site. The best method to determine the quality of a soil is to make a series of experimental adobe bricks or pressed-earth blocks that can be tested for strength, modulus of rupture, and moisture content. To obtain the best adobe material, soils from more than one deposit may be blended.

In many areas, the best sources of adobe material are the local sand and gravel operations where overlying soil or undersized material are sold at $2-7/cubic yard. Many adobe soils used by large-scale adobe producers are obtained from state, federal, and Indian lands, where most of the sand and gravel pits are presently located. However, most small-scale adobe producers haul their adobe soil to the adobe yard from nearby land-leveling operations and from private land sites.

The development and extensive use of pressed-earth-block machines have made the locations of commercial adobe operations less important. Many of the machines are now operating at remote mountain sites and Indian reservations. The soil requirements for pressed-earth blocks are similar to those for adobe bricks but the soil mixture commonly contains less moisture.

The locations of the main sources of adobe soil used by most commercial adobe producers have been adapted from the report by Carter (1965) on sand and gravel in New Mexico and are shown in Figure 34. For detailed geologic data on the major adobe-soil locations, see the reports on and maps of the Albuquerque and Espanola Basins (Kelley, 1977,1978). Brief descriptions of the major sources of adobe soil in the state follow.

Channel deposits

Various stream or arroyo deposits, which consist of intermixed sand, silt, clay, and gravel, are usually a major source of adobe soil. The deposits are accessible during the dry season and the soil can be easily removed by front-end loaders (Fig. 35), loaded into trucks, and hauled to the adobe yard. To remove soil from public lands, a permit or lease can be obtained at a relatively low cost.

Terrace deposits

Extensive terrace deposits that offer excellent sources of sand, gravel, and adobe soil are particularly widespread in the Albuquerque and Espanola Basins. These deposits border streams but are above the level of the present floodplains; they are remnants of older several floodplains through which the present channel has cut. The terrace deposits, especially the lower terrace deposits above the floodplain, are widely mined by sand and gravel operators and by adobe producers. Through most of the Rio Grande valley, the upper 15-30 ft of overburden covering the terrace deposits are composed of a sandy loam that contains the proper percentage of sand, silt, and clay to produce a quality adobe brick (Fig. 36).

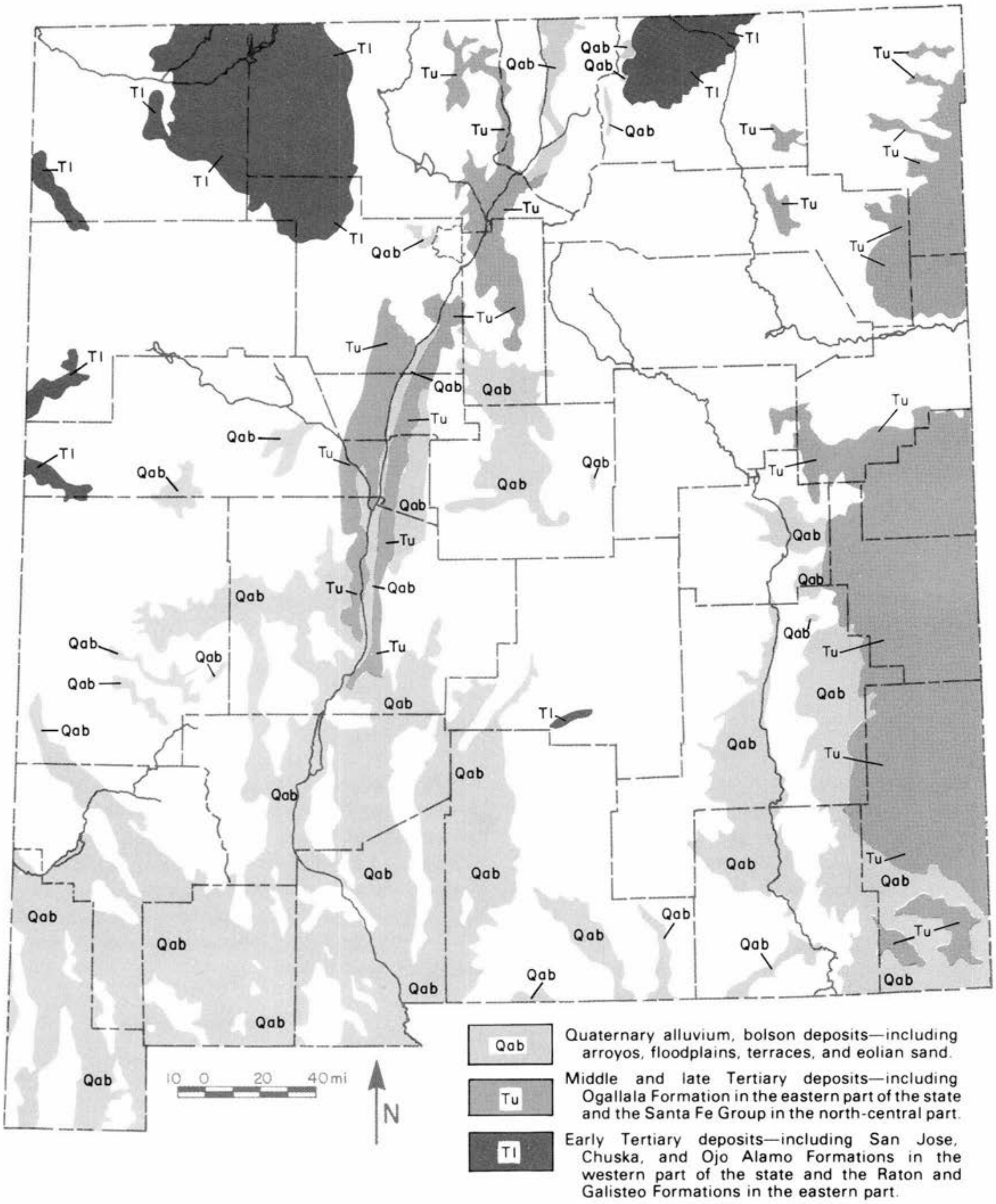


FIGURE 34—Major sources of adobe soil in New Mexico (modified from Carter, 1965).

Alluvial fans—piedmont plains

Gently sloping alluvial fans are found throughout New Mexico at the mouths of canyons where streams from mountains enter larger valleys or the plains. The flattening slope at the base of the mountains causes cobbles and boulders to be deposited at the apex of the fan-shaped mass and finer particles toward the sides and toes (Fig. 37). These fans coalesce to form alluvial piedmont plains in large areas of the state, and represent a continuous supply of adobe and gravel material. The alluvial fans and piedmont plains are mostly located on public lands and are mined by many sand and gravel operators. In the Alamogordo area, the Alamo Canyon alluvial deposit is a major source of sand, gravel, and adobe soil that was used for many years by The Adobe Patch in La Luz, New Mexico. Using the fine fraction of the alluvial deposit, The Adobe Patch produced a quality stabilized adobe brick.

Also found in the piedmont plains are gravel, sand, silt, and clay that were initially cemented by porous caliche. Caliche, a whitish calcium carbonate deposit, forms in the soil from a buildup of the mineral calcite ($CaCO3$). Subsequent buildup may entirely fill soil voids resulting in an impervious limestone layer. In the dry Southwest where materials erode much slower, a buildup of calcite (calichification) often accompanies weathering.

FIGURE 35—Stream or arroyo deposit being mined for production of adobes, San Juan Pueblo.

FIGURE 37—Cross section of the alluvial Tesuque Formation (Tertiary), composed of sand and gravel, dipping west toward the Rio Grande. Photo taken near Tesuque River.

Older geologic formations

Many older geologic formations throughout the state contain sources of sand, gravel, **and adobe** soil. Early Tertiary deposits include the Raton and Galisteo Formations in the eastern part of the state and the San Jose, Chuska, and Ojo Alamo Formations in the northwestern part. The middle and late Tertiary deposits are composed of partially consolidated beds of sandstone, mudstone, arkose, conglomerate, and fanglomerate and include the Ogallala Formation in the eastern part of New Mexico and the Santa Fe Group in the north-central part.

Ditch and aggregate by-products

The extensive irrigation systems throughout the Rio Grande valley require cleaning and removal of soil each year. The fine soils, usually high in clay and silt, are stockpiled adjacent to ditches and can be mixed with other material to make an adobe soil. Permits to remove the soils can usually be obtained from the conservancy districts (Fig. 38).

Most sand and gravel operations with large screening and crusher plants produce large quantities of fine soil (crusher fines). Upper layers of soil are also removed during excavations for gravel and are stockpiled for use as fill. These aggregate by-products (Fig. 39) are sold and can be tested for clay content and for use in adobe production. The fine soils can be blended with other material or can be used directly by large-scale producers to make adobes.

Mineralogy

Adobe soils contain particles of clay, silt, and sand-and-larger (sand+) sizes. Clay-size particles are <2 pm in diameter, as fine as face powder; they contain no grit and are smooth when ground between teeth. Particles of this size consist chiefly of clay minerals. Silt-size particles are larger than 2 micrometers (>2 pm), but smaller than/ 1,16 mm (<0.0625 mm), whereas sand-size particles are larger **than 1/16** mm (>0.0625 mm), but smaller than 2 mm (<2 mm). Silt-size particles feel gritty between teeth and coarse grains can be seen with the naked eye. Sand-size particles are easily visible with the naked eye. The silt—sand dividing line in terms of U.S. Standard Sieve Mesh Numbers is mesh 230.

Silt- and sand-size particles can be thought of as bits of pre-existing rock. Although many different minerals make up these particles, the most common are quartz (Si02) and

FIGURE 36—Old terrace deposit east of the Rio Grande, San Juan Pueblo. The upper 10–15 ft of fine sandy loam are underlain by coarse gravel.

FIGURE 38—Stockpile of fine silt and clay removed from a Middle Rio Grande Conservancy District ditch, Corrales.

FIGURE 39—Crusher fines that are suitable for the construction of rammed-earth walls on property owned by Huston Construction Comapny, Edgewood.

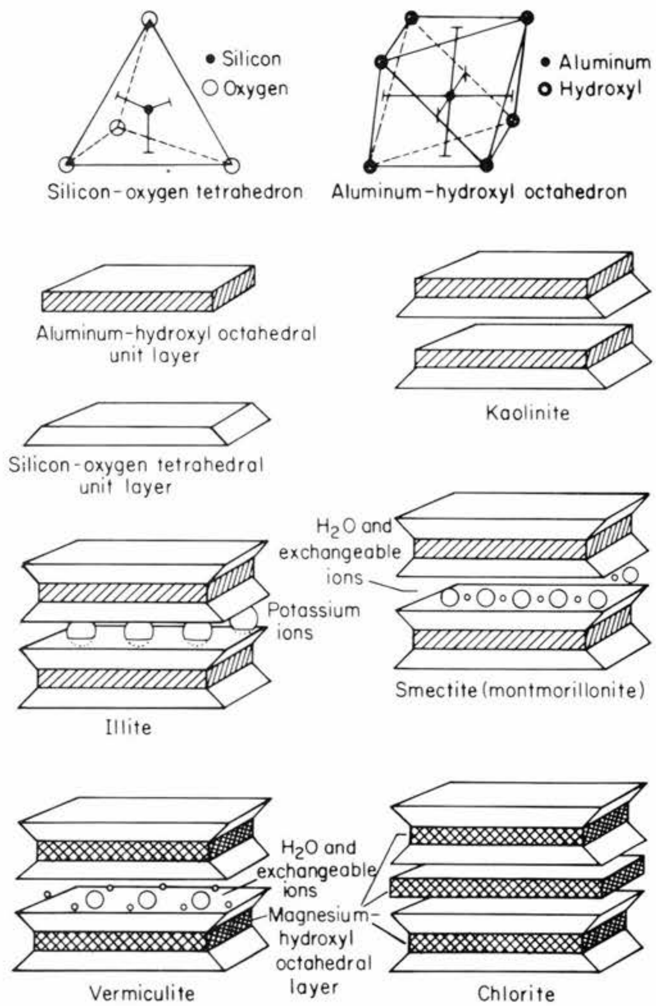


FIGURE 40—Diagrams of major clay-mineral groups. The silicon-oxygen tetrahedron and the aluminum-hydroxyl octahedron are the fundamental building blocks of most clay minerals (modified from Harrison and Murry, 1964; Austin 1975.)

feldspars (calcium, sodium, and potassium aluminosili cates). Quartz and feldspars are major constituents of rock and are hard and chemically resistant. Clay minerals an also present in silt and sand, but in small amounts as the finest silt-size fragments or as indurated (hardened) aggre gates of shale or mudstone, which have properties mon akin to fragments of rock than to clay minerals or clay-size particles. The "sharpness" of aggregates and sand-size par tides may increase the strength and reduce the require(amount of binder material necessary to produce an accept able adobe. Architect P. G. McHenry, Jr. (pers. comm. 1988) says that the shape of sand-size particles in adobe soils significant and that rounded particles, as found in "blow sand," need more clay—silt binder than other soils.

During this project, particle-size analyses of adobe soils unearthed several new findings. First, all samples testa contained far more sand+-size particles than previously re ported (Smith, 1982). Typical adobe materials are 60-80% and as high as 89%, sand+-size particles; 40%, but as low as 8% and as high as 68%, silt-size particles; and 4-15%, but a: low as 1%, clay-size particles. Second, the particle-size analyses indicate that clay minerals cannot be the only, a perhaps even the chief, binding agent.

Smith (1982) discussed the presence of calcite in the majority of adobe soils tested in 1980. The present inves ligation shows that calcite is present in the clay-size fraction in 99% of the samples tested; furthermore, it is not limited to clay size but is present in the silt- and sand+-size fractions as well. The presence of calcite thus is more extensive than expected, and its predominantly clay-particle size indicate: that it undoubtedly is of pedogenic (formed-in-the-soil) origin.

Inorganic calcite as layers or sheets in the soils of the Southwest is identified as caliche. Caliche can make or breal the quality of an adobe soil. If the calichification has pro ceeded to the point where all or most of the voids are filled the soil is too hard and will not break down as it is work& in an adobe yard. A small amount of finely divided calcite can aid in the cementation of grains in adobes. Recently deposited sediments have relatively dispersed, fibrous to powdery calcite as a common constituent. When these soils are wetted, the calcium carbonate is partly mobilized. Wher dried, the dissolved calcium carbonate deposited in pores binds particles together. Ground water in the Southwest is generally high in dissolved solids. When this water evapo- rates, as from drying adobes, calcium carbonate and calcium sulfate (gypsum) is precipitated as very fine-grained cementing agents.

Processing adobe soils into a form with a hydraulic rani or a pressed-earth-block machine further binds particles together. Indeed, pressed-earth-block producers, particularly users of pressed-earth-block machines, state that caliche soils make the best pressed-earth block. However, caliche builds an impermeable barrier over relatively long time intervals. If the calichification process has proceeded to the point that the caliche is very hard and massive, then caliche acts as an aggregate, making particle mobilization and recrystallization difficult and binding insufficient for adobe soils.

Clay mineralogy

The clay-size (<2 pm) fraction of soil is made up of different minerals in varying proportions, the most abundant being clay minerals. Kaolinite, illite, smectite, chlorite, vermiculite, and mixed-layer illite/smectite (I/S) are the principal clay-mineral groups or types, each with their own chemical and physical properties. Nonclay minerals such as quartz, feldspar, and calcite may also be present.

Appendix 1 shows that the amount of clay minerals in adobe soils varies greatly and is less than previously thought (Smith, 1982). Although the proportion of clay minerals is relatively low (1-15% in the adobe soils sampled), the amount of the clay-size fraction and the presence or absence of a particular clay-mineral group affect the physical properties of an adobe product. To understand the effect of one clay-mineral group relative to another in an adobe soil, it is necessary to understand the structures of clay minerals. Diagrams of the silicon-oxygen tetrahedron and aluminum-hydroxyl octahedron—the fundamental building blocks of most clay minerals—and the of crystal structures of major clay-mineral types are shown in Figure 40 (after Grim, 1968; Austin, 1975).

Four clay-mineral groups are commonly represented in the <2 gm fraction of adobe soils in New Mexico: kaolinite, illite, smectite, and I/S (Appendix 1; Fig. 40). The high-aluminum kaolinite and high-potassium illite generally make up about 50% of the clay minerals in the 41 samples tested. Both groups are nonexpandable; they will expand only slightly in the presence of water. The calcium- or sodium-rich smectite and I/S also make up about 50% of the clay minerals in the adobe soils analyzed. They are expandable and will swell in the presence of water. I/S is generally represented by interstratification of both illite and smectite layers. I/S will expand somewhat, but not as much as pure smectite. Chlorite was found in only two samples and vermiculite in none.

The proportions of expandable/nonexpandable clay minerals and the amount of the clay-size fraction in adobe soils help to control the quality of adobe bricks, pressed-earth blocks, and rammed-earth walls. Clay-size fractions high in expandable clay minerals relative to nonexpandable clay minerals increase the compressive strengths of adobe materials. That is, a soil with a small clay-size fraction high in smectite will make an adobe product as high in compressive strength as a soil with a larger clay-size fraction low in smectite. Generally, inclusion of expandable clay minerals (especially smectite and I/S groups) in an adobe soil results in a greater compressive strength than would inclusion of nonexpandable minerals; however, too much smectite in the soil may make a poor adobe product. In such soils, depending on the presence or absence of water, expansion and contraction of the smectite-rich clay may cause excessive cracks in the adobe product. More silt, sand, or straw can be added to the soil to lessen the effect of the expandable clay minerals.

Quemados (burnt adobe bricks) are similarly affected by the mineralogy of adobe soils. Moderate heat applied to a brick increases compressive strength. Although temperature is not closely controlled in quemado kilns, it is clear that clay minerals are responsible for the increased strength. A standard brick is normally heated to approximately 1,800°F (1,000°C) before incipient vitrification (melting) of the clay minerals occurs, binding more resistant aggregates together. However, if calcite is present in the brick, the calcium ion acts as a flux, lowering the incipient vitrification temperature by as much as several hundred degrees (Fahrenheit).

Preservation of adobe structure

The deterioration of adobe walls at historical sites in New Mexico has spurred interest in improving conservation techniques. Presently the best maintenance and repair strategy is to replaster weathering and crumbling ruins with like material, to cap walls with mud, and to build basal supports of untreated adobe bricks and mortar for unstable walls that have wasted at the base. However, these efforts are certainly costly and may be impractical for abandoned structures. The Getty Conservation Institute (GCI), in collaboration with the New Mexico State Monuments (a unit of the Museum of New Mexico) has designed and tested chemical and nonchemical treatments of deteriorating adobe structures to determine which preservation methods are most effective in the Southwest and throughout the world. The field testing was carried out at Fort Selden State Monument, an abandoned mid-19th-century adobe fort north of Las Cruces, New Mexico.

As part of the project, adobe test walls were constructed by the staff of the New Mexico State Monuments near the Fort Selden State Monument. Various mixtures of mud plasters and preservatives, including commercial sprays, that have been used at other monuments in New Mexico, throughout the Southwest, or universally to protect adobe structures were applied to the test walls (Fig. 41). Some of these materials covered the surface while others penetrated an inch or more into the adobes. Other test walls were built and capped with cement, adobe brick, or fired brick, with and without drip edges. The bases of some test walls were constructed with different materials to determine the best type of foundation. Included in the experiments are historic and modern preservation techniques, some of which may actually accelerate the erosion of adobe structures (Taylor, 1987a, b).

Other conservation techniques designed to alter the historic fabric of a site, some more obvious others less so, are being tested by GCI. Simulated reburial under "nonwoven geotextiles" and the use of "aerotextile" shelters and "geotextile drains are some of the tests that are being conducted to assess the protective effects of reburying archaeological sites (Agnew et al., 1987; Taylor, 1987a).

For these experimental purposes, more than 50 adobe test walls were constructed about 450 ft from Fort Selden State Monument. Some of the walls were allowed to cure and undergo weathering for several months before preservative plasters and sprays were applied (Fig. 42). To achieve rapid results and to facilitate comparisons of the various techniques together with the effects of natural exposure, a spray system to artificially accelerate weathering of the GCI adobe test walls was used.

The project, begun in 1985 and concluded in 1995, gives conservationists the best preservation methods to use for adobe structures in the Southwest. Preliminary results were

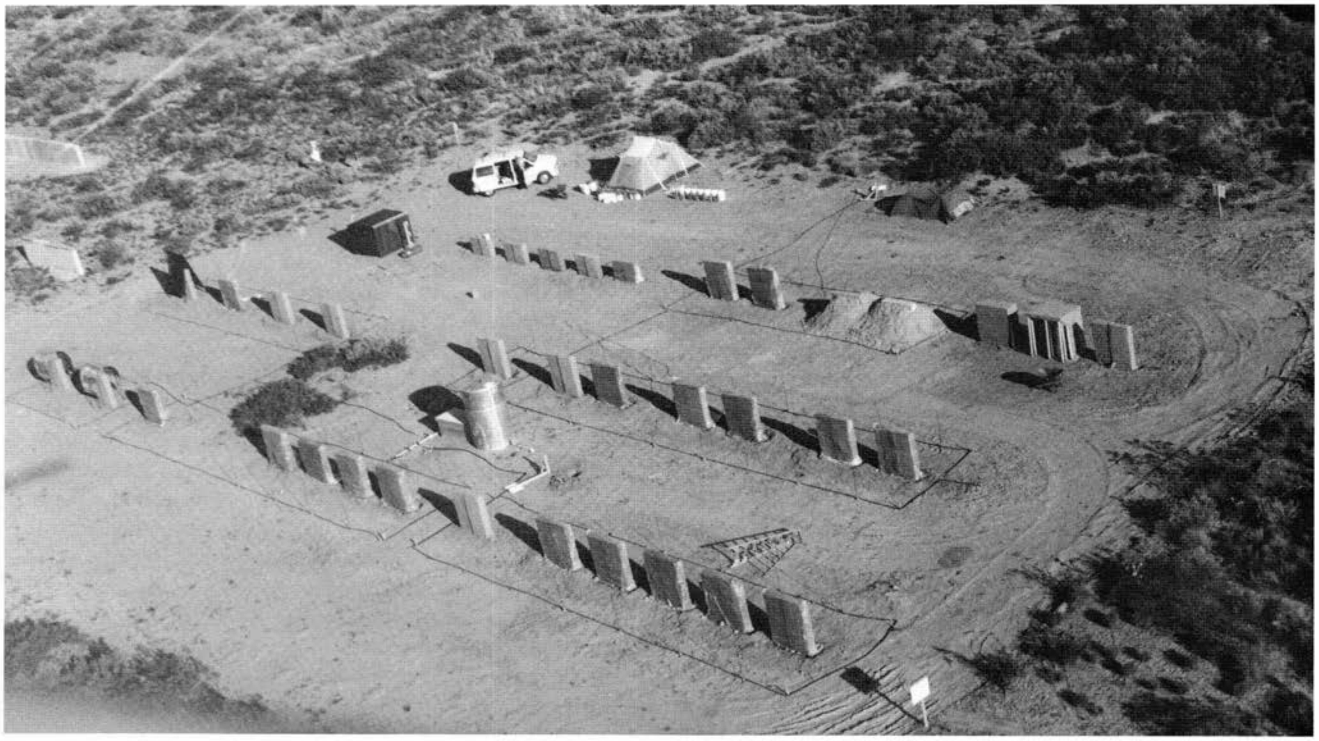


FIGURE 41—Adobe test walls, Fort Selden State Monument, May 1988.

presented in detail in Las Cruces, New Mexico, in October 1990 at the 6th International Meeting of Experts on the Conservation of Earthen Architecture (Getty Conservation Institute, 1990). The final reports and status reports are available from the New Mexico State Monuments, Museum of New Mexico. However, the testing did not include occupied dwellings and the effect of the various preservation techniques on the inhabitants.

FIGURE 42—Neville Agnew of the Queensland Museum, Austrailia, working in cooperation with the Getty Conservation Institute, is applying chemicals to adobe test walls at Fort Selden State Monument, May 1988.

Radon

The identification of radon gas as a potential health hazard in homes has prompted adobe homeowners to wonder whether they are exposed to a greater danger than other homeowners. Concern about elevated indoor concentrations of radon first arose in the late 1960s when homes that had been built with aggregate from uranium tailings were found high in radon. Studies by the U.S. Environmental Protection Agency and the State of New Mexico Environmental Improvement Division showed that low concentrations of radon gas are naturally present in the atmosphere. High indoor levels of radon may be caused by natural concentrations of uranium in the soil beneath houses as well as in adobe bricks. Although concentrations are known to exist in certain soils and rock types, no area is free from the possible accumulation of radon.

Radon is a colorless, odorless, heavier-than-air radioactive gas that is derived directly from the breakdown of an isotope of radium, ^{226}Ra, one in a chain of radioactive daughter elements produced from the radioactive decay of the most abundant isotope of uranium, ^{238}U. The most stable of radon isotopes, ^{222}Rn, has a half-life of 3.8 days (Wilkening, 1980). The half-life is the time it takes for one-half of the parent isotope to change to daughter products; the less stable the isotope, the shorter the half-life. Radon is extremely unstable, so it decays to daughter products in a relatively short amount of time. Each time a radioactive element decays to daughter products, radiation in the form of particles is emitted. Whereas most radioactive elements are relatively immobile solids, radon is a mobile gas that can find its way into homes. If gaseous radon decays in air that is breathed, the fine solid particles that are emitted can cause lung cancer. It is the combination of mobility, decay, and emission of fine solid particles, which can become trapped in the respiratory tract, that makes radon hazardous.

Few adobe homes have basements where radon can easily enter, and they may thus have less of a radon problem than other homes. Most radon enters homes from soils through cracks in basements or slabs, drains, and other openings (Fig. 43). Devices such as clothes dryers, fireplaces, and furnaces that reduce air pressure within a home increase the amount of air (and radon) moving into the home by pulling the soil gas from beneath the house through openings into areas of lower air pressure.

Remedial actions to prevent the accumulation of radon in a home are relatively inexpensive (Green, 1988). The simplest way is to keep the home well ventilated. Positive air pressure in the home prevents entry of radon from outside soils. In the summertime, positive air pressure is relatively easy to maintain because evaporative (swamp) coolers are in use; homes using refrigerated air require other methods. One involves cooling some of the hot outside air along with the already cooled inside air to create the positive pressure. In the winter positive air pressure is more difficult to achieve in all dwellings because heat is kept in and the cold out. However, external sources of air for furnaces, fireplaces, and clothes dryers can diminish the entry of radon into a home during winter. Finally, keeping the adobe home in good repair by filling cracks and openings in concrete slabs, repairing cracks in walls, and sealing adobe blocks with plaster and paint, especially inside the house, greatly decreases the chances of radon accumulation.

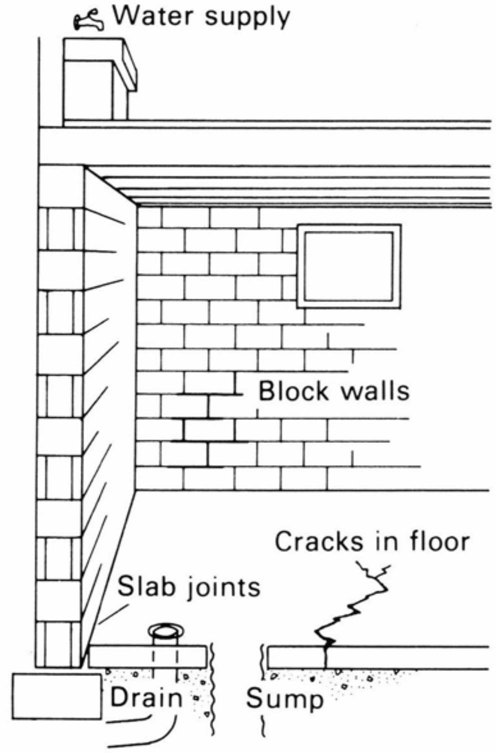


FIGURE 43—Common radon entry points.

The U.S. Environmental Protection Agency and the State of New Mexico Environmental Improvement Division can provide information about radon concentrations in homes. Although tests of most homes in New Mexico have located only a few problem areas, the State of New Mexico Environmental Department, Hazardous and Radioactive Materials Bureau, continues testing upon request. Test canisters are also available from many drugstores.

Adobe construction in seismically active areas

Adobe structures may be hazardous in seismically active areas because of the low-strength materials used; with heavy earthen roofs supported by low-strength walls, adobe structures can collapse during earthquakes. However, studies conducted at the Richmond Field Station of the University of California, Berkeley, on nearly full-size adobe structures (Scawthorn, 1986) showed that they can be strengthened quite inexpensively to a point where adobe structures are no more hazardous in earthquakes than buildings constructed with other commonly used materials.

Tests were performed on structures with walls of 4 x 12 x 16-inch unstabilized adobe blocks and mud mortar built on a 20 x 20-ft Earthquake Simulator Laboratory shaking table. The first test structure contained a window opening, a door with lintel beams, and 4 x 6-inch wooden roof beams bolted into the top three adobe courses, which carried the weight of a simulated earthen roof. The second test structure was installed with a wooden bond beam (Fig. 44). Subsequent test structures also had with a bond beam and walls reinforced inside and out with welded wire mesh and stucco

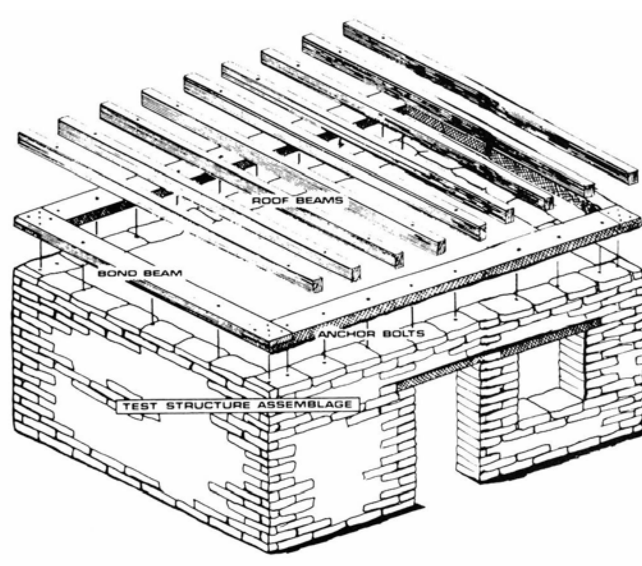


FIGURE 44—Nearly full-size adobe structure that was tested for strength during a simulated earthquake (from Tibbets, 1986).

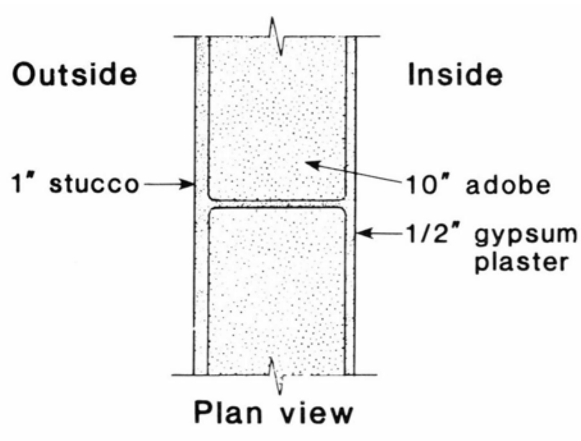
netting. Based on the test results, structural improvements of adobe structures to reduce hazards related to earthquakes have been suggested (Tibbets 1986):

(1) A simple inside-and-out wire enclosure of an adobe structure, can be used to greatly strengthen adobe walls.
(2) Inexpensive stucco netting or chicken wire is equal, or nearly so, to more expensive welded wire mesh.
(3) New adobe structures commonly use stucco netting or chicken wire as a stucco attachment system nailed to outside walls at little additional cost. (The wire enclosure system used in the tests had wire anchored with 7/8-inch staples both inside and outside the home.)
(4) If wire mesh is not desired, overlapping steel rebar bent to curve around wall corners can be used for internal reinforcement.
(5) Wooden or concrete bond beams (tie beams) are important in strengthening adobe structures and are required by the New Mexico Building Code to be at least 6 inches thick. Thinner, well-reinforced bond beams perform better than massive, less well reinforced ones because of the need for horizontal and
(6) vertical flex. Buttresses at certain points on walls can add additional strength. Although not required by the New Mexico Building Code for adobe and pressed-earth construction, such strengthened structures will nonetheless provide increased safety and peace of mind which can be translated into financial benefit at resale time.

Thermal properties

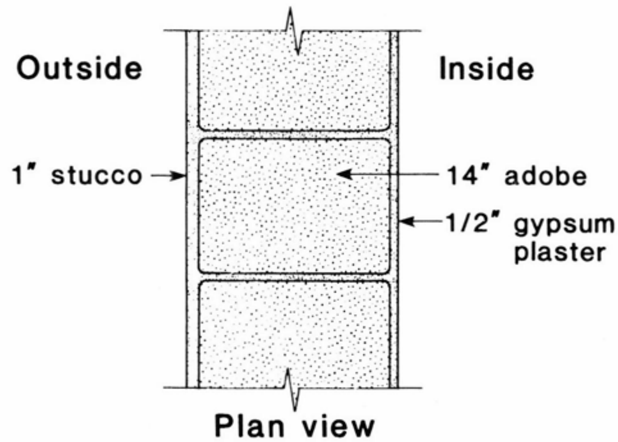
In New Mexico, thermal specifications for building materials are covered in the 1993 New Mexico Energy Conservation Code as adopted from the Uniform Building Code and the New Mexico Building Code. Portions of the New Mexico Building Code relating to adobe appear in Appendix 3.

Traditionally, materials are evaluated for thermal performance based on measurements known as R- and U-values. The R-value is an indicator of the ability of a wall to insulate effectively. Insulation is nothing more than the resistance of a material to the transfer of heat, and naturally the higher that resistance (R-value), the more the material insulates. The R-value is calculated by dividing the thickness of the wall by the wall's thermal conductivity, the amount of heat per ft^2/hr flowing from the warmer to the cooler side of the wall. The U-value, sometimes referred to as the value of conductance, is the reciprocal of the R-value and reflects the rate at which heat is conducted through a material. Total R-value may be calculated for a given wall by adding up the values of all individual components of the wall structure; for example, all insulation, interior sheathing, framing, air-space resistance, or masonry must be taken into consideration.



Wall type 1	ASHRAE steady-state U-value: 0.240		BTU/(ft²·hr·°F)		
Heating effective U-value					
Wall orientation	Wall color	Climatic region 1	2	3	4
East	light	0.226	0.217	0.222	0.211
	medium	0.194	0.176	0.178	0.158
	dark	0.161	0.135	0.133	0.106
South	light	0.218	0.208	0.206	0.197
	medium	0.174	0.152	0.136	0.123
	dark	0.131	0.096	0.067	0.050
West	light	0.232	0.224	0.229	0.218
	medium	0.208	0.193	0.194	0.178
	dark	0.185	0.162	0.160	0.137
North	light	0.238	0.234	0.241	0.231
	medium	0.223	0.217	0.224	0.210
	dark	0.208	0.201	0.207	0.188

FIGURE 45A—Effective U-values for different orientations and colors of a 10-inch adobe wall in the four climactic regions of New Mexico (from Robertson, 1981). Climatic regions determined by solar radiation, dry-bulb temperature, and wind velocity. Low-number climatic regions (regions 1 and 2) tend to be rugged areas of high elevation, whereas high-number climatic regions (regions 3 and 4) tend to be desert areas of low elevation. Note generally higher ASHRAE steady-state U-value of 0.240.



Wall type 2	ASHRAE steady-state U-value: 0.189		BTU/(ft²·hr·°F)		
Heating effective U-value					
Wall orientation	Wall color	Climatic region 1	2	3	4
East	light	0.181	0.174	0.178	0.168
	medium	0.155	0.141	0.142	0.126
	dark	0.129	0.108	0.106	0.084
South	light	0.175	0.166	0.165	0.157
	medium	0.140	0.122	0.109	0.098
	dark	0.105	0.077	0.053	0.040
West	light	0.186	0.179	0.183	0.174
	medium	0.167	0.155	0.155	0.142
	dark	0.148	0.130	0.128	0.109
North	light	0.191	0.187	0.193	0.185
	medium	0.179	0.174	0.179	0.167
	dark	0.167	0.161	0.165	0.150

FIGURE 45B—Effective U-values for different orientations and colors of a 10-inch adobe wall in the four climactic regions of New Mexico (from Robertson, 1981). Climatic regions determined by solar radiation, dry-bulb temperature, and wind velocity. Low-number climatic regions (regions 1 and 2) tend to be rugged areas of high elevation, whereas high-number climatic regions (regions 3 and 4) tend to be desert areas of low elevation. Note generally higher ASHRAE steady-state U-value of 0.189.

R- and U-values do not, however, tell the full story in determining what constitutes a high-quality, thermally efficient wall (Fine, 1976). Both of these values reflect the rate at which heat passes through a wall only after the steady state of heat flow (the state when heat energy is passing uninterrupted from one side of the wall to the other at a constant rate) has been achieved. What is not taken into consideration, and what is of critical importance in the case of masonry-mass walls such as adobe, is the heat-storage capacity of the wall, which determines the length of time that passes before a steady state of heat flow is achieved. The higher the heat-storage capacity of the wall, the longer it will take for heat flow to reach a steady state. In real situations, external and internal temperatures change constantly and a true steady-state condition thus is rarely achieved. What does occur, in the case of a wall with a high heat-storage capacity such as adobe, is outlined below.

In the morning, when the sun rises, heat from the warmer exterior side of the wall begins to move through the adobe mass. Depending not only on the resistance (R-value) of adobe, but also on the heat-storage capacity of the wall (a factor of both the specific heat capacity of adobe and the thickness of the wall), the heat takes a certain length of time to reach the cooler interior side of the wall where it is released into the atmosphere. In adobe walls of sufficient thickness and sufficient R-values (perhaps supplemented by other insulation), the normal daily fluctuations of temperature are not large enough to cause much heat to pass through the wall at a steady state. At night, when the warmer side of the wall cools off, heat already absorbed into the adobe wall flows to both sides of the wall until a temperature equilibrium is reached. This cycle is repeated in what is known as the flywheel effect, and it is responsible for the comfort of properly designed adobe homes.

Thermal properties of masonry materials in general, and adobe in particular, have often been unjustly maligned because only R-values and steady-state U-values were considered when evaluating thermal performance. For mass materials such as adobe, a more accurate representation of average thermal performance is obtained by what is known as the effective U-value (Figs. 45A, B), which is determined by both the resistance of a wall to the transfer of heat and of its capacity to hold heat. The inside wall temperature approximates the average of the high/low ambient exterior temperatures and the time delay affected by the thickness of the wall. Therefore, in actual home use, optimal comfort may be achieved by a massive wall with a moderate R-value and high heat-storage capacity (adobe with a small amount of insulation), or by a highly resistant wall with little or no heat-storage capacity (traditionally a highly insulated frame wall).

The New Mexico Energy Research and Development Institute has determined effective U-values for many different wall types (including adobe), which have been incorporated into the New Mexico Energy Conservation Code for building materials. The effective U-values may be used in lieu of traditional R-values and steady-state U-values when a design relying primarily on passive solar gain and masonry-mass materials would not normally pass the code (Robertson, 1981). The State of New Mexico has prepared information that details the method of calculating effective U-values for the climatic zones in the state (Scheuch and Busch, 1988).

Adobe-brick production

Adobe-brick production varies from a labor-intensive traditional technique to a mechanized large-scale operation capable of producing 5,000-20,000 bricks per day. The production is seasonal and is usually limited by the number of available frost-free days. In general, the production season lasts from five to nine months, depending on climate and weather conditions.

The bricks are made in various sizes according to their intended use. The principal standard-size adobe brick used in the state measures 4 x 10 x 14 inches. An average of 1 cubic yard of adobe soil is used to produce approximately 70-80 standard-size bricks. In 1995, 13 manufacturers produced 2,625,000 adobe bricks (Table 4), 168,000 traditional (untreated) 2,245,000 semistabilized, and 212,000 stabilized bricks. The bricks were produced by three techniques, the handcrafted (traditional), semimechanized, and mechanized. The procedures used by producers representative of each technique are described below.

Handcrafted (traditional) technique

The handcrafted technique was used by six adobe-brick producers contacted in 1996, who produced 78,500 traditional untreated bricks, 105,000 semistabilized, and 1,800 stabilized bricks in 1995. This figure does not represent the total production of handcrafted adobe bricks in the state; bricks handcrafted for noncommercial use by individuals for their own construction projects were not included in the survey. Daily production rates of handcrafted bricks varied considerably. One-person commercial adobe yards produced 100-300 bricks per day, whereas commercial adobe yards utilizing two or three adobe makers produced 300-500

TABLE 4—Commercial adobe-brick and pressed-earth-block producers and rammed-earth construction companies active in New Mexico in 1995.

ADOBES

Map no. (Fig. 1)	Name and mailing address	Telephone	County	Production
1	Adobe Factory P.O. Box 519 Alcade, NM 87511 Mel Medina, Owner	505-852-4131	Rio Arriba	1,000,000
2	Big "M" Sand and Cinder Box 33 Bernalillo, NM 87004 Randy Montoya, Owner	505-867-5498	Sandoval	50,000
3	DeLaO Adobe Brick P.O. Box 1283 Anthony, NM 88021 Antonio DeLaO, Owner	505-882-5278	Doña Ana	40,000
4	Eloy Montano Sand & Gravel 14 Calle Chuparosa Santa Fe, NM 87505 Eloy Montano, Owner	505-471-4747	Santa Fe	45,000
5	Gilbert Montano 503 Barela Lane Santa Fe, NM 87501 Gilbert Montano, Owner	505-983-2838	Santa Fe	15,000
6	New Mexico Earth P.O. Box 10506 Alameda, NM 87184 Richard Levine, Owner	505-898-1271	Bernalillo	600,000
7	Leroy Otero 2725 Highway 47 Los Lunas, NM 87031 Leroy Otero, Owner	505-864-4054	Valencia	45,000
8	Philip Otero 2055 Winchester Bosque Farms, NM 87068 Philip Otero, Owner	505-869-0934	Valencia	50,000
9	Simon Otero 224 El Cerro Loop Los Lunas, NM 87031 Simon Otero, Owner	505-865-7133	Valencia	10,000

TABLE 4—continued.

Map no. (Fig. 1)	Name and mailing address	Telephone	County	Production
10	Sol Systems Adobe Box 104 Corrales, NM 87048 Manuel Ruiz, Owner	505-898-2218	Sandoval	300,000
11	Rio Abajo Adobe 07 Industrial Park Belen, NM 87002 Jerry Sanchez, Owner	505-864-6191	Valencia	300,000
12	Trini Velarde Box 726 Rancho de Taos, NM 87557 Trini Velarde, Owner	505-758-4185	Taos	20,000
13	Western Adobe 7800 Tower Road SW Albuquerque, NM 87121 Dean Leach, Owner	505-836-1839	Bernalillo	150,000
			TOTAL	2,625,000
No production in 1995				
14	Adobe Bricks of New Mexico Box 733 Santa Cruz, NM 87467 Dennis Duran, Owner	505-753-6189	Santa Fe	0
15	Aguires Services P.O. Box 475 Rancho de Taos, NM 87557 Ismael Aguires, Owner	505-758-9181	Taos	0
16	Ralph Mondragon Box 199 Rancho de Taos, NM 87557 Ralph Mondragon, Owner	505-758-3644	Taos	0
17	Rodrigues Brothers Rt. 6, Box 22 Santa Fe, NM 87502 George and Jim Rodriguez, Owners	505-471-3375	Santa Fe	0

PRESSED-EARTH BLOCKS

Map letter (Fig. 1)	Name and mailing address	Telephone	County	Production
A	Adobe International Box 1284 Grants, NM 87020 Henry Elkins, Owner	505-287-3961	Cibola	250,000 (made about 100 machines)
B	Habitat for Humanity P.O. Box 2844 Santa Fe, NM 87501 David DePolo, President	505-986-5880	Santa Fe	15,000
C	Santa Fe Adobe P.O. Box 4841 Santa Fe, NM 87502 Chris Jaquez and M. Hunter, owners	505-471-3401	Santa Fe	130,000
			TOTAL	395,000 and about 100 machines
No production in 1995				
D	Coyote Adobe Inc. 247-F Rosario Boulevard Santa Fe, NM 87501 Robert W. Higginson and Paul Romero, Owners	505-983-5376	Santa Fe	0

TABLE 4—continued.

Map symbol (Fig. 1)	Name and mailing address	Telephone	County	Production
	RAMMED-EARTH BUILDERS			
⊗	Huston Construction Box 99 Edgewood, NM 87015 Stan Huston, Owner	505-281-9534	Santa Fe	11 houses
⊕	Soledad Canyon Earth Builders P.O. Box 274 Mesilla, NM 88046 Mario Bellestri, Owner	505-521-9350	Doña Ana	6 houses
			TOTAL	17 houses

bricks per day. Prices at the adobe yards varied from 21 to 40t per brick.

Eloy Montano Sand & Gravel (Santa Fe)

Eloy Montano Sand & Gravel, located by Airport Road in the southwest (Aqua Fria) section of Santa Fe, is a typical adobe yard that uses the traditional (handcrafted) method of production. It produced 45,000 traditional untreated adobe bricks in 1995. Workers at the adobe yard excavate soil from nearby private lands and stockpile the material adjacent to a mudpit. With two or three employees, Eloy Montano Sand & Gravel makes adobe bricks as follows:

(1) The adobe sod from the stockpile is used to build a mudpit into which is placed the adobe soil and water. The soil and water are mixed by hoe and shovel until the proper adobe-mud mixture is achieved. Depending on the type of soil used, straw is usually added to prevent excessive cracking the adobe bricks.

(2) The prepared adobe mud is shoveled into a wheelbarrow and is delivered to several four-mold wooden forms laid out on a leveled ground. The mud is then dumped into the molding forms, tamped by hand into the corners, and brushed clean of excess material (Fig. 46).

(3) The molding forms are removed by hand, with care taken to retain the shape of the four adobe bricks, and the excess mud is washed off the forms before reusing them (Fig. 47).

(4) After two or three days of drying the bricks are turned on edge and trimmed of excess material and any rough edges. They are then allowed to sun-cure for three to four weeks before stacking for delivery.

Semimechanized technique

Semimechanized adobe-brick production is similar to the traditional handcrafted technique except that front-end loaders and mixing equipment—pugmills, plaster mixers, and cement mixers—are used. This technique is the lowest capital-investment (equipment) type of operation capable of large-scale production. Adobe-brick producers using the semimechanized technique can make 1,000,000 or more bricks per year.

In 1995, 13 adobe-brick producers manufactured 2,625,000 adobe bricks (untreated, semistabilized, and stabilized) using the semimechanized and mechanized methods. Their annual totals varied from 10,000 to 1,000,000 adobe bricks, most of which were of the standard 4 x 10 x 14-inch size and were semistabilized. Prices for semistabilized bricks varied from 35 to 55¢ per brick at the adobe yard. Three different and representative examples of the semimechanized technique are described below.

New Mexico Earth (Alameda)

The largest producer of adobe bricks in the Albuquerque area is the New Mexico Earth, a company established in 1972 and managed by Richard Levine of Alameda, New

FIGURE 46—Packing the adobe mud into a four-mold wooden form. Eloy Montano Sand & Gravel adobe yard, Santa Fe.

FIGURE 47—Lifting the four-mold wooden form to permit the adobe bricks to dry for two or three days before they are turned on edge. Eloy Montano Sand & Gravel adobe yard, Santa Fe.

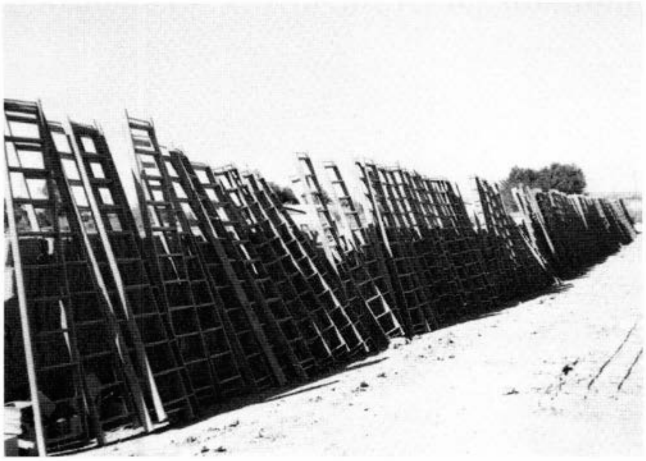


FIGURE 48—Stacked adobe bricks and ladder molding forms. New Mexico Earth adobe yard, Alameda

FIGURE 50—Front-end loader working the mudpit. Note conveyer system from pugmill on the right. New Mexico Earth adobe yard, Alameda.

Mexico. The operation is located on four acres in Alameda on the north side of Albuquerque, where over 600,000 adobe bricks were produced in 1995. The site has an average elevation of 4,800 ft and a semiarid climate. The average annual rainfall is 10-14 inches and the mean annual temperature is 57°F. The adobe season usually extends from March through November and normally has a frost-free period of 203 days.

Equipment at the adobe yard includes two front-end loaders, a pugmill, a storage and conveyer system, and 700-800 ten-mold wooden ladder forms (Fig. 48). The adobe soil is obtained from a local sand and gravel operation, where the overburden (15-30 ft) of the alluvial piedmont plain and Quaternary terrace deposits of the Albuquerque Basin are mined. The sandy loam is typical of the material used by a majority of the Rio Grande valley adobe producers.

The technique used by the company is as follows:

(1) The soil, and perhaps sand as well, is delivered to the adobe yard and stockpiled adjacent to the hopper. The material is moved from the stockpile by a front-end loader (1-cubic-yard capacity) and placed into the 8 x 8-ft pugmill hopper (Fig. 49).

(2) The soil mixture, water, and asphalt emulsion are added simultaneously in the pugmill. Two shafts studded with paddles rotate in the trough of the pugmill and continuously mix the adobe material as the mud works its way to the open end of the trough. The mud drops into a large mudpit (30 x 80 ft), and a front-end loader removes and carries it to the adobe-laying yard (Fig. 50).

(3) Located in the leveled adobe yard are usually 500-600 ten-mold wooden forms. The adobe mud is dumped into the forms and then raked and leveled (Fig. 51). The newly laid bricks are allowed to dry for several hours or until they start to shrink and part from the form walls. The molding forms are then lifted and moved to a new area.

(4) The adobe bricks are allowed to sun-dry for two or three days, turned on edge, trimmed, and finally stacked to cure or left in place until delivery. With a crew of 8-10 employees, this operation produces an average of 5,000-6,000 adobe bricks per day, and with available yard space, the daily production can double.

(5) The delivery system at New Mexico Earth consists of several 21/2-ton flatbed trucks with a local delivery capability of approximately 5,000 adobe bricks per day. The number of trucks requires a shop mechanic and a dispatcher to coordinate the schedules. An efficient delivery system is essential to maintain the company's production goals because the four-acre adobe yard can hold only 65,000 bricks.

FIGURE 49—Front-end loader placing soil mixture into pugmill, where the adobe mud is mixed and then dumped into the mudpit by the conveyer system. New Mexico Earth adobe yard, Alameda

FIGURE 51—Front-end loader dumping the adobe mud into the ladder molding forms. New Mexico Earth adobe yard, Alameda.

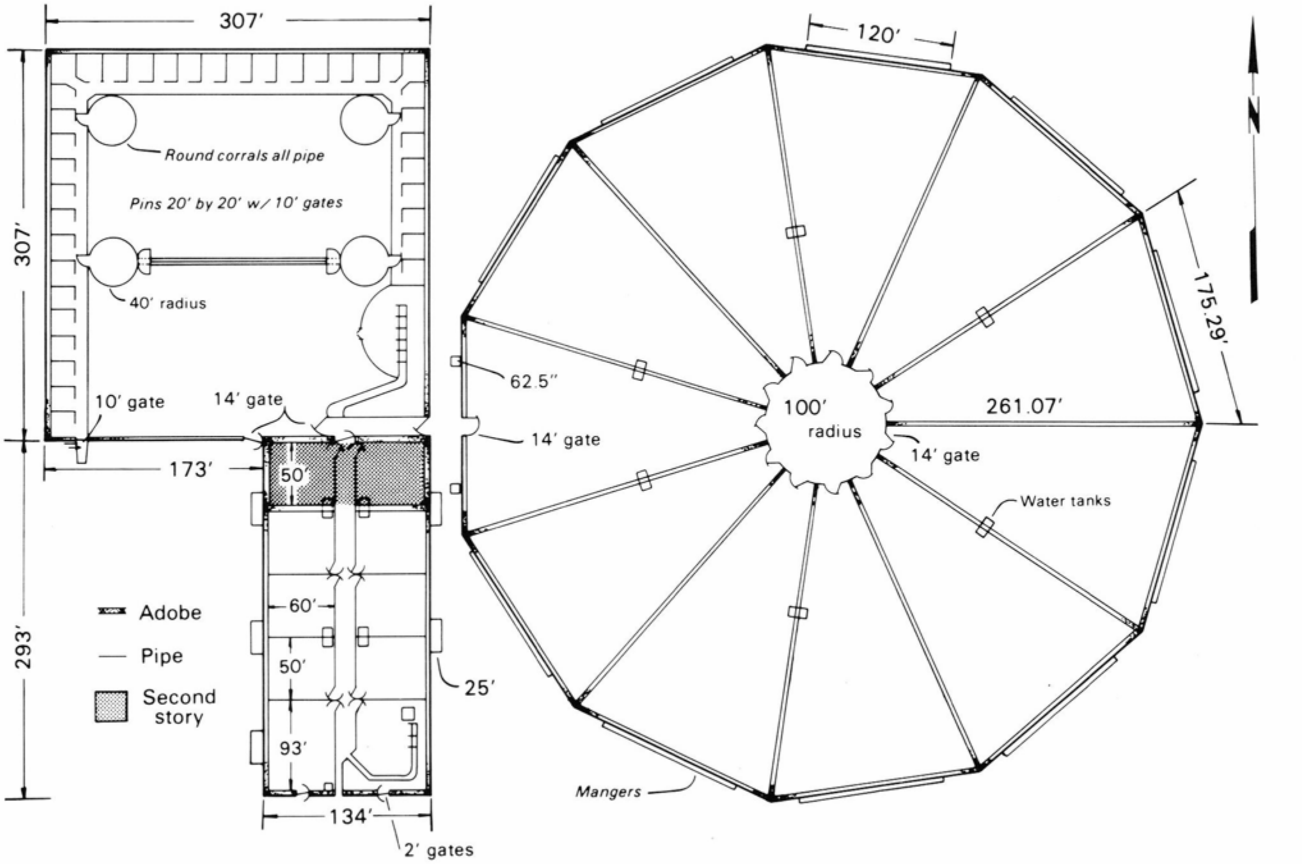


FIGURE 52—Drawing of the wild-horse corrals on NM–14 near Santa Fe. Adobe Corrals Project, Corrections Industries, Santa Fe.

Adobe Corrals Project, Corrections Industries (Santa Fe)

A unique adobe operation, the Adobe Corrals Project, was initiated in July 1987 by the State of New Mexico Corrections Industries. The project manufactures and uses adobe bricks to construct stables for wild horses. At the medium-security correctional facility near Los Lunas, New Mexico, nine corrals and holding pens were built by 60 inmates in 1987. Approximately 180,000 adobe bricks were produced and used. In the summer of 1988 stables also were completed at the Las Cruces and Santa Fe correctional facilities.

In 1987-1988 ten corrals were under construction at the Santa Fe site 12 miles south of Santa Fe on the west side of NM-14 (Fig. 52), with adobe walls 7 ft high, 261 ft long, and 16 inches thick (Fig. 53). Lloyd McClendon (production manager), Don Timberman, and David Falance of the Corrections Industries supervised eight crews of four inmates each, that worked on assigned sections of the corrals and pens.

Mechanized equipment at the site included two front-end loaders and a combination dump-and-water truck. The soil used to make the adobe bricks was obtained from the building site by land leveling. The native vegetation was scraped from the surface and 2-10 inches of soil were removed and stockpiled. In general, the following production procedure was used:

(1) Sand (used as a stabilizer to prevent cracking of the adobes) was delivered to the building site and stockpiled by each corral wall under construction. Initially, adobe soil was moved by a front-end loader from its stockpile to a mudpit, where the front-end loader mixed the soil and then delivered it to a mixing hod located adjacent to the walls under construction. Later, crews used hoes and shovels to mix the sand and soil (at a ratio of one shovel of sand to eight shovels of soil) directly into the mixing hod, where water and a drying/hardening agent, XLR-8, were added (Fig. 54).

(2) The adobe-mud mixture was shoveled from the mixing hod into a five-mold wooden form that had been set on a wall. The five-mold wooden form measures 4 x 18 x 57¹/2 inches and produces five 4 x 10 x 15¹/2-inch bricks. Usually two wooden forms were assigned to each crew

FIGURE 53—View of the wild-horse corrals under construction during the summer of 1988. The walls are 7 ft high, 261 ft long, and 16 inches thick. Adobe Corrals Project, Corrections Industries, Santa Fe.

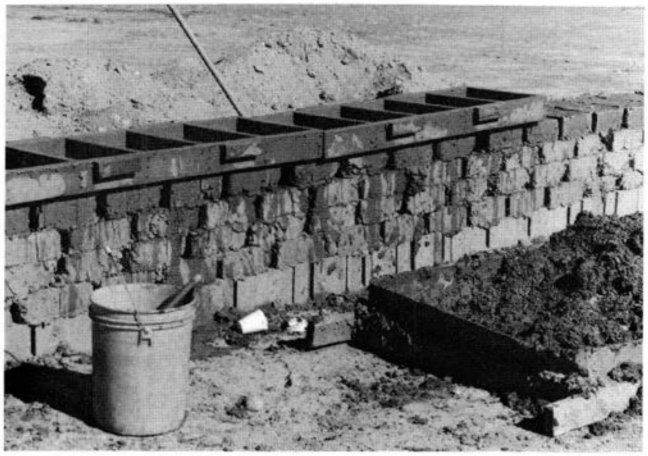


FIGURE 54—Close-up of an adobe corral wall under construction. Adobe Corrals Project, Corrections Industries, Santa Fe.

FIGURE 56—Packing adobe mud into the five-mold wooden forms to produce bricks directly on the wall. Adobe Corrals Project, Corrections Industries, Santa Fe.

so that 10 adobe bricks were made before the forms were lifted and moved further along the wall (Fig. 55). No mud mortar was used because the placement of the wooden forms and the moisture content of the adobe material allowed the bricks to bond and interlock with the lower bricks, which had been drying for several hours (Fig. 56).

(3) After removal from the wall, the forms were brushed by wet brooms and reset for the next set of adobe bricks. This process continued until three wall courses were completed and permitted to dry

(4) After allowing the finished two to three courses of adobe bricks to dry for several hours, the next series of courses was ready for construction. Upon completion of each wall to its full length and height, the crews wired the walls with commercial stucco netting and added a cement and stucco coat for final finish and protection.

According to the Corrections Industries officials, David Salazar of Santa Fe developed the technique of adobe-brick production and wall construction used at the corral sites. The formula that quickly dries and hardens the adobes (identified as XLR-8) was developed by chemist Kenneth Salazar. The system permits the adobe bricks to be produced directly on the wall and eliminates the need for traditional sun-drying in an adobe yard. The technique can be corn-

FIGURE 55—Two five-mold wooden forms set on corral wall under construction and ready for filling. Adobe Corrals Project, Corrections Industries, Santa Fe.

FIGURE 57—Close-up of adobe bricks after removal of five-mold wooden form. Note interlocking of bricks and lack of mortar (unlike normal sun-dried adobe-brick construction). Adobe Corrals Project, Corrections Industries, Santa Fe.

pared with that used to make rammed-earth buildings except that the adobe soil is not mechanically tamped in the corral-wall forms (Fig. 57).

Bricks produced by David Salazar were delivered in March and April 1988 to the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology. Test results have shown the soil to consist of 5% clay-, 36% silt-, and 59% sand+-size particles. The mineralogy of the clay-size fraction was three parts I/S, three parts illite, two parts kaolinite, and two parts calcium smectite, plus minor calcite and quartz. The traditional (untreated) adobe bricks, which were dried and hardened with the XLR-8 formula, had a compressive strength of 499-621 psi for a mean of 525 psi. The modulus of rupture was 55-76 psi for a mean of 61 psi.

Rio Abajo Adobe (Belen)

This is a well-organized semi-mechanized operation owned by Jerry Sanchez of Belen, New Mexico. The operation is on two sites of several acres each where a total of over 300,000 semistabilized adobe bricks were produced in 1995. The company also produces fully stabilized adobe bricks on special order. All adobe bricks are 31/2 x 10 x 14 inches. The

FIGURE 58—Ladder molding forms ready for filling. Rio Abajo Adobe Works adobe yard, Belen.

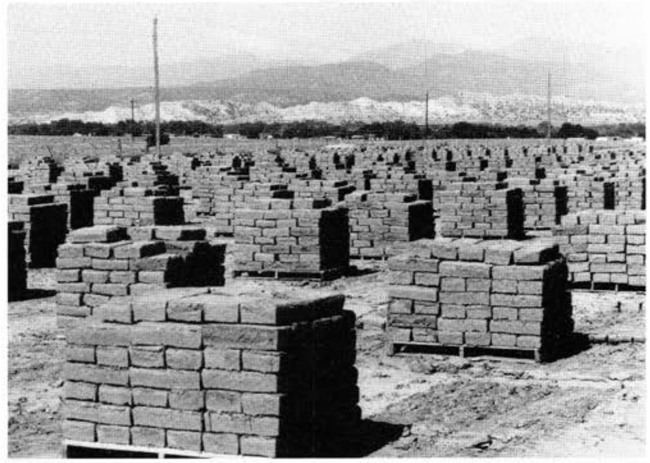


FIGURE 60—Dried and stacked adobe bricks. Adobe Factory adobe yard, Acalde.

newer adobe-yard near the north Belen 1-25 interchange has an average elevation of 4,870 ft and a semiarid climate. The average annual rainfall is 10 inches and the average annual temperature is 57°F. The adobe season usually extends from March through November and normally has a frost-free period of 200 days.

Equipment available in 1988 included a 2-cubic-yard-capacity Michigan Model 75 front-end loader, 200 eight-mold wooden forms (Fig. 58), a portable mud vat, a portable oil tank, and a 21/2-ton flatbed truck. The adobe soil is taken from nearby Quaternary terrace deposits and Santa Fe Group (Tertiary) sediments and is hauled to the adobe yard, where it is stockpiled adjacent to the mudpit. The sandy loam and clay soil are typical of the adobe material used by most Rio Grande valley producers.

The method used by Sanchez and a crew of two or three employees for the large-scale production of adobe bricks is as follows:

(1) The sandy loam and clay are removed by the front-end loader from the soil stockpile and are blended in a large mudpit that measures approximately 30 x 65 ft and slopes to a maximum 3-ft depth at one end. Water from an adjacent irrigation ditch is added to the adobe soil (8 cubic yards), which is then allowed to soak overnight in order to break down the clay mixture. A measured amount of asphalt emulsion (33 gal) is added to the adobe mud, which is worked by the front-end loader in the pit until a uniform mixture is achieved.

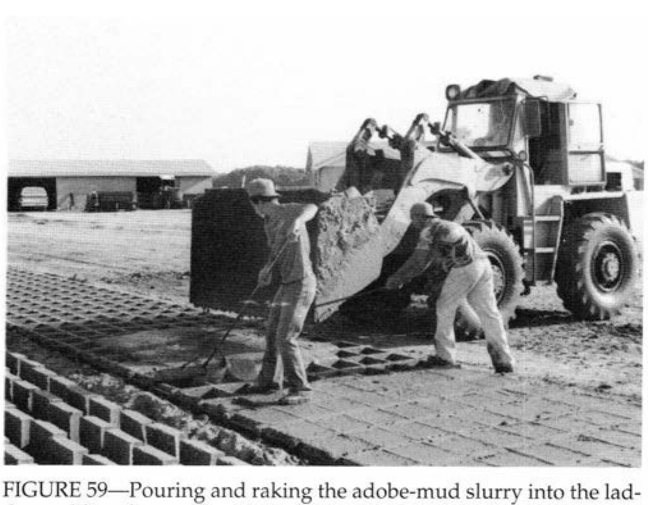


FIGURE 59—Pouring and raking the adobe-mud slurry into the ladder molding forms. Rio Abajo Adobe Works adobe yard, Belen.

(2) The adobe mud is removed from the pit by the front-end loader and is delivered to the adobe-laying yard where oil-sprayed wooden molding forms have been placed next to each other. The mud is poured into the molding forms and the excess material is raked and leveled (Fig. 59). The adobe bricks are allowed to dry in the molding forms for several hours, depending on the weather. When the bricks have shrunk from the form walls, the forms are lifted and moved to an adjacent location for the next pouring of adobe mud.

(3) The bricks are allowed to dry for two or three days, turned on edge, trimmed, and later (after drying for two to three weeks) stacked ready for delivery. This method of production with a crew of two or three employees is capable of producing 1,500-3,000 adobe bricks per day.

(4) Sanchez has designed and constructed a portable mud vat that is mounted on the 21/2-ton flatbed delivery truck. The adobe mud mixed in the yard is transferred by the front-end loader to the mud vat which is then delivered to the construction site. Once at the site, a valve on the mud vat is opened and the mud is poured into a wheelbarrow. The mud mortar is then transported to the workers laying the bricks for adobe walls or other structures.

Mechanized technique

Mechanized production is usually employed in large-scale manufacturing of adobe bricks. Three mechanized operations located in New Mexico in 1995-96 were using front-end loaders, pugmills or ready-mix cement trucks, and machine-powered mechanical adobe layers.

Mechanized operations use several thousand cubic yards of adobe soil per year and can produce over 2,000,000 bricks annually. The soil is usually obtained from the adobe yards or is purchased from local sand and gravel operations. The size of the adobe yards varies from one to eight acres, and the yards are capable of producing 5,000-7,000 adobe bricks per day. 2,100,000 semistabilized and stabilized adobe bricks of the standard 4 x 10 x 14-inch size were produced by the three fully mechanized New Mexico manufacturers.

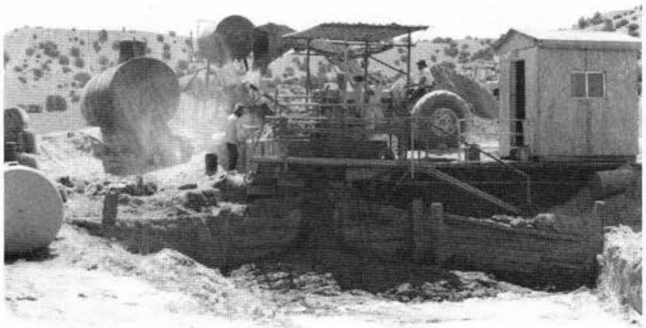


FIGURE 61—Dumping soil into the pugmill. Note mud accumulating in the mudpin. Adobe Factory adobe yard, Acalde.

FIGURE 63—Hans Sumpf-type adobe layer that produces 25 standard-size adobe bricks per laydown. Adobe Factory adobe yard, Alcalde.

Adobe Factory (Alcalde)

The largest producer of adobe bricks in northern New Mexico is the Adobe Factory, owned and managed by Mel Medina of Alcalde, New Mexico (Fig. 60). In 1995 the company produced 1,000,000 semistabilized adobe bricks primarily of the 4 x 10 x 14-inch size using the following procedures:

(1) Local sandy loam is obtained by land leveling nearby alluvial or pediment deposits. The sandy loam is hauled to the adobe yard and stockpiled adjacent to the pugmill mixer. The soil is removed from the stockpile by a 1.5-cubic-yard front-end loader and is dumped onto a 1-inch screen placed over the pugmill (Fig. 61).

(2) Approximately 3 cubic yards of adobe soil are screened and placed in the pugmill, where water and asphalt emulsion are added to the mixing process. The two pug-mill shafts, studded with paddles, rotate in the trough of the 4 x 6-ft pugmill and mix the adobe mud for 15-20 minutes (Fig. 62). The mud is then dumped into a large 33 x 75 x 74-ft mudpit. The production crew mix and dump a sizable amount of adobe mud throughout the morning.

(3) In the afternoon, a front-end loader moves the adobe mud from the mudpit to the mud hopper on the Hans Sumpf-type adobe-layer machine (Fig. 63). The machine, called a self-propelled adobe layer, is operated by one person who maneuvers it across the leveled yard depositing 25 standard 4 x 10 x 14-inch bricks at a time. The steel adobe form is then hydraulically lifted by the machine operator and the adobe layer is moved ahead for the next batch. A continuous straight line of adobe bricks ready for drying is produced in the yard.

(4) The newly laid bricks, which may total several thousands, and cover a large area of the adobe yard, are then allowed to dry for two or three days, depending on the weather. They are then hand-turned on edge, trimmed of any excess material, and allowed to dry for at least three weeks under normal conditions.

(5) When the bricks have cured sufficiently, they are either stacked directly on flatbed trucks and trailers for delivery or are placed on wooden pallets that hold 70 bricks each. The stacked pallets are lifted onto a truck by a forklift that is also hauled to the purchaser's building site, permitting placement of the stacked adobe bricks adjacent to the construction project (Fig. 64).

The Adobe Factory has several sizes of adobe molds, which can be mounted on the mechanical adobe layer to produce bricks of different shapes and dimensions. With good weather conditions and a minimum of mechanical breakdowns, the operation can produce 5,000-7,000 adobe

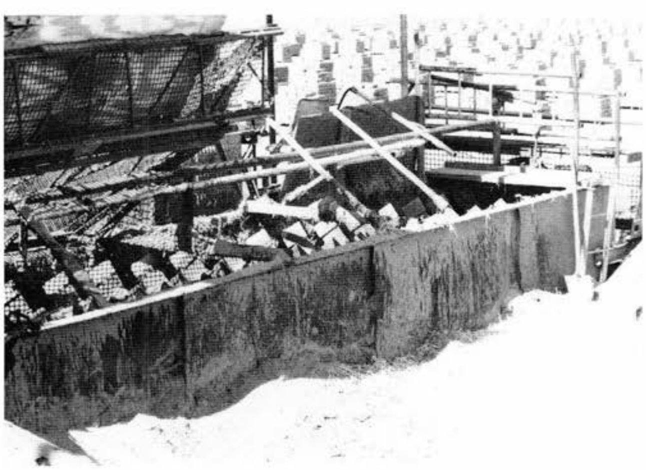


FIGURE 62—Close-up of the large 4 × 6-ft pugmill. Adobe Factory adobe yard, Alcalde.

FIGURE 64—Fladbed truck and trailer load of adobe bricks ready for delivery. Adobe Factory adobe yard, Alcalde.

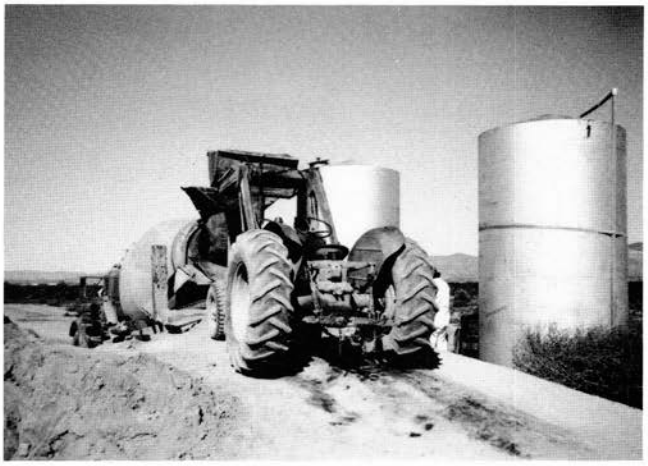


FIGURE 65—Loading adobe soul into the hopper of the ready-mix truck. The Adobe Patch adobe yard, La Luz.

FIGURE 67—Spyder forklift loading adobe bricks onto fladtbed truck. The Adobe Patch adobe yard, La Luz.

bricks per eight-hour day with a crew of three employees.

In July 1988, 15 semistabilized adobe bricks were tested by the Professional Services Industries, Inc., in Albuquerque. The tests have shown the bricks had a compressive strength of 390-450 psi for an average of 430 psi. The modulus of nip-ture was 70-150 psi for an average of 80 psi, and the moisture content varied from 1.2 to 7.0 wt% for an average of 3.78 wt%. A seven-day water absorption test has shown only 1.3 wt% absorption.

The Adobe Patch (La Luz)

In 1988, the Adobe Patch was located approximately one mile north of Alamogordo and was owned by Robert and Christina Duran Godby of La Luz, New Mexico. It was the only large-scale producer of stabilized adobe bricks in the eastern part of New Mexico, with more than 165,000 bricks made during the 1987 season. Operation ceased in 1990, but a description is nevertheless included below because of a unique production technique.

The geographic location of The Adobe Patch permitted production season of approximately 300 frost-free days. Adobe soil (crusher fines) was purchased from a sand and gravel operation located north of Alamogordo, New Mexico.

The operation at La Luz produced 2,000-3,000 adobe bricks per day with a crew of two employees. Equipment used at the adobe yard included one front-end loader, three 7.5-cubic-yard ready-mix trucks, one mechanical adobe layer, one sand spreader, one 5,000-gal water tank, one 5,000-gal asphalt-emulsion tank, and one diesel flatbed truck, flatbed trailer, and forklift for deliveries. Adobe bricks were produced as follows:

(1) Seven cubic yards of adobe soil and a mixture of 340 gal of water and 80 gal of asphalt emulsion were placed in a ready-mix truck (Fig. 65), mixed for about 45 minutes, and conveyed to a special mechanical adobe layer attached to the rear of the truck. The adobe layer was operated hydraulically and powered by the truck.

(2)The mixer on the truck emptied the adobe mud into the hopper of the adobe layer, which fed into a steel mold that produced 42 bricks at a time. Scrapers attached to the mud hopper leveled the top of the mud mix. The mold was raised leaving the formed bricks on the ground (Fig. 66).

(3) The ready-mix truck and the attached adobe layer were moved forward. The mold was sprayed with water and lowered for the next filling. The procedure was repeated

FIGURE 66—The ready-mix truck dumping the mixed adobe mud into the hopper of the adobe layer, which produces 42 standard-size adobe bricks per laydown. The Adobe Patch adobe yard, La Luz.

FIGURE 68— Use of the spyder forklift requires only one employee for delivering and unloading the adobe bricks at the building site. The Adobe Patch adobe yard, La Luz.

until the ready-mix truck has been emptied (after producing approximately 630 bricks per load).

(4) After two or three days of drying, the bricks were turned on edge and were cleaned and scraped. They remained on edge to dry thoroughly for 15-20 days or until needed for shipment. The dried or drying adobe bricks were then stacked on pallets that had a holding capacity of 77 bricks. The loaded pallets were lifted by a Spyder forklift onto the flatbed company truck (Figs. 67, 68). The forklift was then fitted into a cradle built into the end of the flatbed, where it was carried to the construction site to unload the adobe bricks. The Spyder forklift weighs 2,350 lbs and requires only 3-5 minutes to load and unload from the carrying cradle

The Godbys' fully mechanized and quality-oriented method of adobe production produced a superior adobe brick that was fully stabilized and met all the state's building codes. The soil was alluvial-fan material consisting of 2% clay-, 18% silt-, and 80% sand+-size particles. The larger sand+-size particles were only those that pass through a 1/4-inch screen. The clay-size fraction consisted of five parts illite, three parts kaolinite, two parts I/S, and a trace of calcium smectite, with minor calcite, dolomite, and quartz.

Pressed-earth-block production

Smith (1982) defined pressed-earth blocks as pressed adobes manufactured using the hand-operated CINVA-Ram or a hydraulically operated, gasoline-powered machine that made one block at a time. The 1982 and subsequent revisions of the New Mexico Building Code identify pressed-earth blocks as "hydraulically pressed units." In 1987-88, however, most equipment manufacturers and block producers use the general term pressed-earth block.

In 1980, production of all types of pressed-earth blocks was limited, with only about 15,000 blocks manufactured statewide. The prices varied from 30 to 35¢ a block at the producer's yard. During the 1980 survey (Smith, 1982), the machines that made pressed-earth blocks produced traditional (untreated), semistabilized, and stabilized standard 4 **x** **10 x** 14-inch blocks. The hand-operated CINVA-Ram press, however, produced a 3 1/2 x 5 1/2 x 11 1/2-inch block. The major machines used to produce the pressed-earth blocks included (1) Adobe Farm's Hydra—BrikCrete Press; (2) David Griego's Porta Press; (3) W. S. Carson's CINVA-Ram; (4) Al Niblack's Sun Mountain Adobe Press; and (5) Bill David-son's Soil—Crete Solar Company Press.

In 1995, more than 395,000 traditional (untreated) pressed-earth blocks were produced by two companies, Adobe International and Santa Fe Adobe (Table 4). Traditional 4 **x** **10 x** 14-inch blocks that were produced using local or hauled-in soil at a builder's homesite.

Extensive and rapid development of greatly improved types of portable (trailer-mounted) pressed-earth-block machines and accessory equipment occurred in the early 1980s. In 1987-88, five manufacturers in New Mexico were making and selling various machines that can produce several thousand blocks per day. The blocks were usually of the standard 4 x 10 x 14-inch size and average 38-40 lbs. The major machines made by the five active manufacturers were: (1) Adobe International's Earth Press II, III, and IV, (2) Worldwide Adobe Inc.'s Goldbrick "5000"; (3) Rustech's Rustech; (4) Overview Consulting & Manufacturing's Impact 1000; and (5) Terra Manufacturing Co.'s Terra Rammed Block machine. The 1987-88 manufacturers and owners of the pressed-earth-block machines are listed in Table 4, and the 1995 machines are compared in Table 5. Six Goldbrick "5000" and seven Earth Press II and III machines made most of the 642,000 pressed-earth blocks produced in 1987. In the spring and summer of 1988, the prices for the machines varied from $9,000 for the Impact 1000 to $72,000 for the Goldbrick "5000" FOB. Certain optional and accessory equipment were priced separately.

In 1995, only Adobe International remained operational in New Mexico. Worldwide Adobe moved operations to San Antonio, Texas, and changed its name to Advanced Earth and Construction Technologies. Adobe International produced about 100 machines. However, none were sold in New Mexico; most went overseas.

A major advantage to using pressed-earth blocks for construction is that they have a higher average compressive strength and modulus of rupture than sun-dried adobe bricks. According to the procedures outlined by the New Mexico Building Code, various tests were performed on sample pressed-earth blocks at the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology, and at private laboratories. The tests showed the blocks to have an unusually good modulus of rupture of 46-279 psi and a compressive strength of 512-3,702 psi. However, unless a stabilizer such as portland cement, polymer, lime, or asphalt emulsion is added to the soil mixture, the blocks must be protected from moisture at all times. Without a stabilizer or other protection, the blocks rapidly disintegrate when subjected to intense rains.

Another major advantage to using pressed-earth blocks for construction is the convenient method of production. The pressed-earth-block machines are portable; they can produce blocks using local soils at the construction site. The finished blocks are uniform in at least two directions and can be conveyed directly from the machine to a wall or stockpiled for later use. The blocks are commonly placed into the wall without further drying. A thin mud slurry or the moist block surfaces bind the blocks together.

Only one pressed-earth-block construction company and one manufacturer, who also produced blocks for sale, were active in New Mexico in 1995. However because their historical impact, pressed-earth-block production techniques using the various machines, including gasoline-powered and the hand-operated ones, are described below.

Porta Press

The first Porta Press was manufactured in 1966 by Vern and N. N. Huffaker of Santa Fe, New Mexico. The Porta Press is mounted on a single-axle, two-wheel trailer that weighs approximately 3,000 lbs and is powered by a 7-hp

TABLE 5—Comparison of pressed-earth-block machines manufactured in New Mexico in 1989. The Earth Press II, III, and IV were the only machines still produced in 1995. Prices of the Earth Press machines are for 1995. Others prices are from 1989.

	Earth Press II	Earth Press III	Earth Press IV	Goldbrick "5000"	Rustech	Impact 1000	Terra Rammed Block
Weight	6,700 lbs	2,720 lbs	4,200 lbs	9,500 lbs	2,200 lbs	1,760 lbs	11,000 lbs
Dimensions	6 ft wide, 6 ft, 8 inches high 21 ft long	5 ft wide, 8 ft high, 16 ft long	5 ft wide, 8 ft high, 20 ft long	8 ft wide, 8 ft high, 16 ft, 6 inches long	7 ft wide, 6 ft, 6 inches high, 8 ft long	5 ft, 4 inches wide, 3 ft, 8½ inches high. 5 ft, 4 inches long	8 ft wide, 10 ft high 16 ft long
Power	4-cyl–72-hp John Deere, liquid-cooled, diesel engine	2-cyl–18-hp Tecumsech, air-cooled, gasoline engine or diesel engine	Two 2-cyl–20-hp Koehler, air-cooled, diesel engines	6-cyl–115-hp Onan L634, liquid-cooled, diesel engine	2-cyl–24-hp Koehler, air-cooled, diesel engine	4-cyl–8-hp Koehler, air-cooled engine; other power possible	6-cyl–110-hp Deutz, air-cooled diesel engine
Controls	manual or automatic	manual or automatic	manual or automatic	automatic (Rexroth Worldwide hydraulics with programmable controller)	automatic	manual	automatic
Press force	7-inch-diameter hydraulic cylinders, double RAM producing 2,500 psi	2-4-inch-diameter hydraulic cylinders, double RAM, producing 2,500 psi	2-5-inch-diameter hydraulic cylinders, double RAM, producing 2,500 psi	8-inch-diameter hydraulic cylinder producing 5,000 psi, up to 250,000 lbs on bricks	7-inch-diameter hydraulic cylinder producing 3,000 psi, up to 115,000 lbs on bricks	2-6-inch diameter hydrauliccylinder cylinders producing 2,000 psi to 132,000 lbs thrust on brick	10-inch-diameter hydraulic cylinder producing 1,750 psi, up to 250,000 lbs on brick
Production	14 blocks/minute	4 blocks/minute	6 blocks/minute	14 blocks/minute	3 blocks/minute	2 blocks/minute (1,000/8-hr day)	6–7 blocks/minute
Trailer	tandem axles, electric brakes, towing signals	tandem axles, electric brakes, towing signals	tandem axles, electric brakes, towing signals	tandem axles, electric brakes, towing signals	single axle	single axle	tandem axles, electric brakes, towing signals
Block sizes	4 x 10 x 16 inches 4 x 10 x 14 inches 4 x 10 x 12 inches	4 x 8 x 12 inches 4 x 8 x 8 inches	4 x 10 x 16 inches 4 x 10 x 14 inches 4 x 10 x 12 inches	4 x 10 x 14 inches 4 x 7 x 14 inches other sales available	4 x 10 x 14 inches (standard) 4 x 7 x 14 inches (optional)	3½ x 5½ x 12 inches	4 x 10 x 14 inches optional sizes available
Price	$50,000 FOB Grants, NM	$22,000 FOB (gasoline), $25,000 (diesel) FOB Grants, NM	$35,000 FOB Grants, NM	Manufactured in Ft. Worth, TX (1995)	$14,500 FOB Los Alamos, NM	$9,000–9,800 FOB Corrales, NM	$65,000–70,000 FOB Albuquerque, NM

FIGURE 69—Narciso Garcia house built of 10,000 Porta Press pressed-earth blocks, Cedar Crest.

FIGURE 71—Cleaning Porta Press pressed-earth blocks prior to stacking in the yard to dry. David Griego building site, Ledoux.

Briggs and Stratton, air-cooled engine. According to the manufacturer, the Porta Press is capable of producing 600-800 pressed-earth blocks per day with a crew of two. No longer manufactured, the unit was priced in 1966 at an average of $1,700 per machine. Approximately 15-20 machines were produced and sold throughout the Southwest and Latin America.

Two Porta Press machines were used in New Mexico during the summer of 1980 (Smith, 1982). With a Porta Press machine, David Griego of Ledoux, New Mexico, produced pressed-earth blocks that he used for an addition to his adobe house or sold for local projects. He produced 7,000 pressed-earth blocks on a part-time basis at the construction sites of several adobe buildings. The blocks sold for an average of 35¢ each.

A second machine at Tierra Amarilla, New Mexico, was used by A. Ulibarri in 1980. In the 1960s, this machine, owned by Dr. Dabbs, produced pressed-earth blocks for the construction of La Clinica del Pueblo. In 1987-88 Brenda Martinez of Cedar Crest, New Mexico, had purchased the machine from Narciso Garcia, a neighbor who used the equipment to construct a large home. The 1,950-sq-ft house was built over a three-year period on a part-time basis by Garcia, who produced 10,000 pressed-earth blocks (Fig. 69).

FIGURE 70—Porta Press in operation during the summer of 1980. David Griego building site, Ledoux.

In 1980, with a crew of two at the adobe yards of David Griego of Ledoux and A. Ulibarri of Tierra Amarilla, the production procedure was as follows:

(1) The Porta Press was set up adjacent to a stockpile of local soil. The soil was shoveled into a storage hopper from which a measured amount was pushed into the loading slot between two oiled wooden plates.
(2) Water was then added to produce a moist mixture and the slot door was closed and locked.
(3) A lever activated the hydraulic ram to apply approximately 20,000 lbs of pressure to the adobe soil.
(4) A second lever permitted the same ram to eject the 31/2 x 10 x 14-inch pressed-earth block from the machine (Figs. 70, 71).
(5) The pressed-earth blocks are then placed in the adobe yard to sun dry for several days.

Soil and test results

At Ledoux, New Mexico, the soil contained a relatively high percentage of clay and silt (20-30%). Test results on samples of the standard pressed-earth blocks in 1980 indicated a very high compressive strength of 1,036-1,071 psi and a modulus of rupture of 46-58 psi.

CINVA-Ram

The CINVA-Ram was developed in 1955 by Chilean engineer Raoul Ramirez working in conjunction with the National University of Chile and the University of Illinois Housing Mission to Colombia. The CINVA-Ram is a small, portable press made of steel, with a molding box in which a hand-operated piston compresses the moistened mixture of adobe soil (Fig. 72). The press has been used in over 40 countries, often by the Peace Corps that introduced it throughout the developing nations of the world. In 1995-96, no CINVA-Ram press was found in operation in New Mexico, but is included in this report because of its widespread use in the past. As outlined in the Volunteers for International Technical Assistance publication, *Making building blocks with the CINVA-Ram* (VITA, 1966), the overall equipment specifications are as follows:

Weight	140 lbs
Height and base width	10 x 16 x 26 inches
Application force of lever	80 lbs
Bearing strength (cured block)	200-500 psi
Size of blocks	31/2 x 51/2 x 11% inches
Size of tiles	11/2 x 51/2 x 11% inches
Average	20 lbs
Average number of blocks per 100 lbs of cement	150
Average number of blocks per 5 gal of asphalt emulsion and water mixture	40

In 1980, W. S. Carson of Columbus, New Mexico, hired wo workers to produce CINVA-Ram pressed-earth blocks Ind to construct a 3,000-sq-ft, two-story house near the Columbus airport (Smith, 1982). About 180 pressed-earth blocks of 31/2 x 51/2 x 11 1/2-inch size were produced during a normal eight-hour work day at the building site. The crew used a cement mixer to add asphalt emulsion to the soil mix to produce a semistabilized pressed-earth block. Other stabilizers such as lime or portland cement are also commonly used for waterproofing.

The equipment used at the Carson site included the CINVA-Ram press, a gravel screen, front-end loader, cement mixer, and various water and asphalt-emulsion containers. The adobe soil, sand, and gravel were obtained from a nearby arroyo and hauled to the construction site. Blended soil was placed in the cement mixer and the water and asphalt emulsion was added to dampen the soil (10 wt% moisture). The mixed material was dumped next to the CINVA-Ram

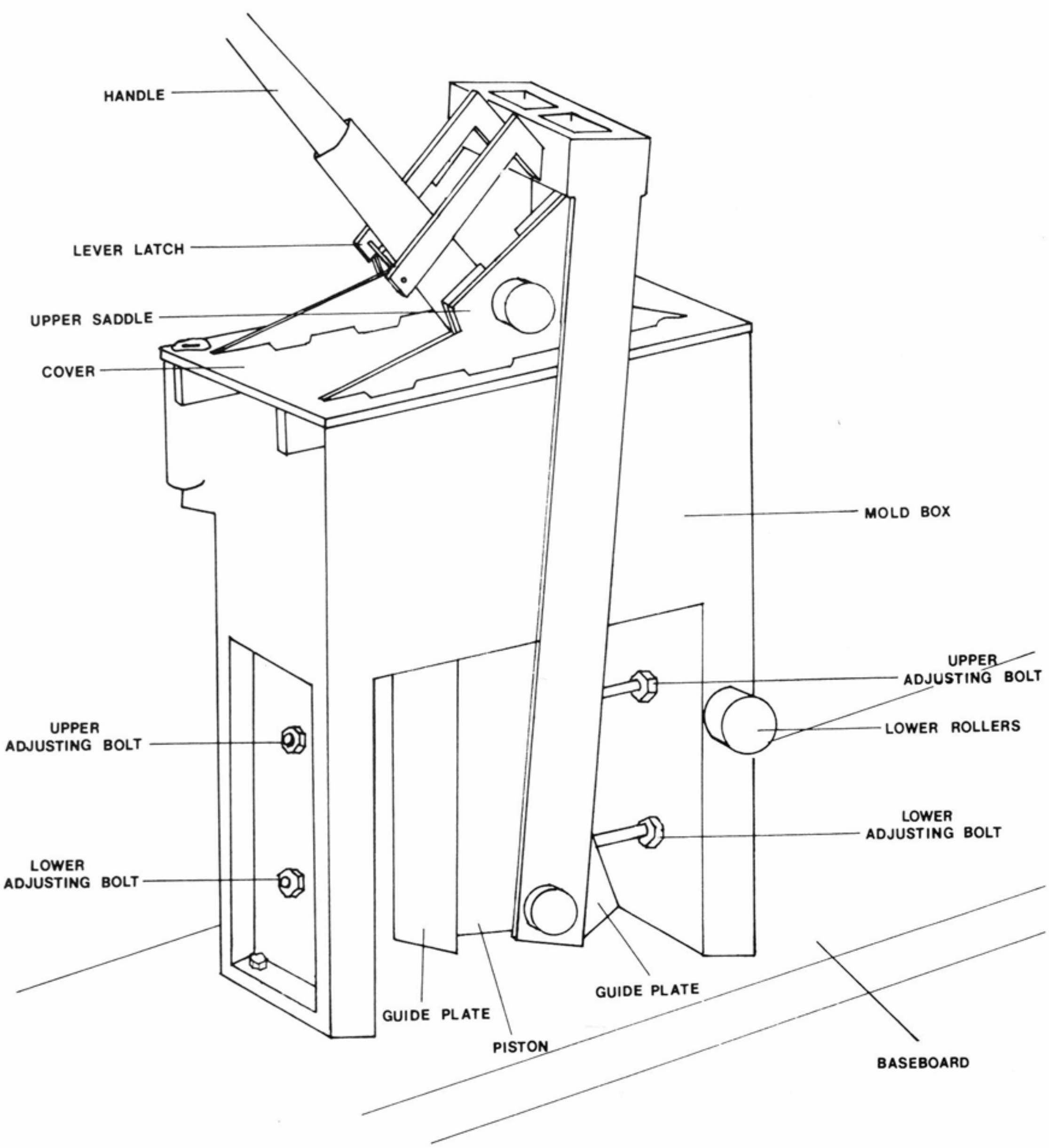


FIGURE 72—Diagram of CINVA-Ram press and its parts.

FIGURE 73—Loading the CINVA-Ram mold. Note drying pressed-earth blocks near building. W. S. Carson building site near Columbus.

FIGURE 74—Applying pressure to the soil mixture to produce the pressed-earth block from the CINVA-Ram. W. S. Carson building site near Columbus.

FIGURE 75—Removing the pressed-earth block from the CINVA-Ram mold. The pressed-earth block is then placed in the yard to dry. W. S. Carson building site near Columbus.

FIGURE 76—W. S. Carson CINVA-Ram pressed-earth-block house under construction in 1980 near Columbus. Note vertical steel reinforcements.

that was mounted on a 9-ft board to provide stability. The procedure used to produce the pressed-earth blocks was as follows:

(1) The cover on the press was opened and the piston moved to the bottom of the mold box. A flat 'Is x 51/2 x 111/2-inch steel plate was set in the mold. The soil mixture was added to the mold, tamped, and leveled off (Fig. 73). The operator wetted the bottom of the press cover and placed it over the mold box.

(2) The mold lever was moved to the vertical position which permitted the rollers to fall into place. The lever latch was disengaged and the lever was moved to a horizontal position on the side opposite the lower rollers for the compressive cycle (Fig. 74). The lever was moved down with two or three pushes to the vertical position and the lever latch was engaged. The lever was then returned to the resting position on the lower rollers and the cover was removed.

(3) The lever was depressed at a steady rate to eject the block and the block was lifted from the machine by hand and carried to the drying yard (Fig. 75). Blocks were sun dried for 5-10 days before being placed into the walls (Fig. 76).

Soil and test results

The CINVA-Ram manufacturer recommended that soils contain 33-66% coarse particles after screening through a 1/4- inch sieve and that 5-10 wt% cement or 10-20 wt% lime be added to make enough moisture to hydrate the mixture. The curing time is approximately eight days. Testing of the W. S. Carson untreated and semistabilized pressed-earth blocks in 1980 showed a high compressive strength of 512-769 psi and a modulus of rupture of 46-69 psi.

Earth Press II, III, and IV

Henry Elkins, the owner of Adobe International, began manufacturing pressed-earth-block equipment for use on building projects at his ranch in Grants, New Mexico, in 1969. After 10 years of research, Elkins developed his first commercial machine, which cost $40,000 and attracted few buyers.

Production is today largely limited to three models identified as Earth Press II, **III,** and IV. Prices for the equipment vary from $22,000 to $50,000 FOB Grants, New Mexico. Block output varies from 4 to 10 per minute. The most pop-

FIGURE 77—Henry Elkins standing in front of Earth Press II (left) and Earth Press III (right) pressed-earth-block machines, manufactured by Adobe International, Grants.

FIGURE 79—Goldbrick "5000" pressed-earth-block machine developed by John Wright and manufactured in 1988 by Worldwide Adobe, Inc., Grants.

ular model is the Earth Press **III** machine developed in 1986. The models Earth Press III and IV produce 4 x 8 x 12-inch block, while the Earth Press II can produce blocks up to 4 x 8 x 16 inches.

In the summer of 1988, nine Earth Press II and twelve Earth Press III machines (Fig. 77) were located and in operation in New Mexico. Most machines were used by individual owners on their own construction projects (Fig. 78), but several of the owners had formed small companies and were producing blocks, under a contract arrangement, at the customer's building site. One machine owner also rented his Earth Press equipment on a monthly basis. Elkins also contracts the use of his equipment to various builders who produce blocks at building sites. Elkins (Adobe International) produced 200,000 pressed-earth blocks for customers in 1987 and 250,000 in 1995 under this arrangement.

In 1995 Elkins produced about 100 machines; nearly all were shipped overseas. Contractors or government agencies in the Republic of South Africa, the Kingdom of Saudi Arabia, and the Peoples Republic of China, and in eastern Europe and both Central and South America have purchased Earth Press machines. Adobe International's main U.S. competitors are located in California, Texas, and

FIGURE 78—Hall Fouts of Gallup, with four untrained helpers and an Earth Press III machine, produced the walls of his solar pressed-earth-block house in five months beginning in November 1985.

Florida, far closer to overseas shipping ports, but charge much higher prices for comparable machines according tc Elkins.

In general, the three Earth Press machines (Earth Press II, III, and IV) produce blocks at the rate of 4-14 per minute, Several block sizes are available varying from the Mexicc 4 x 8 x 8-inch block, the New Mexico standard 4 x 10 x 14-inch block, to the 4 x 8 x 12-inch block. Other sizes are alsc available on special order or as optional equipment. Weighi of the machines varies from 2,720 lbs for the Earth Press **II]** to 6,700 lbs for the earlier Earth Press II machine (Table 5).

Soil and test results

According to Elkins, a soil that contains about 50% sand-and-larger particles and 50% clay-and-silt mixture produces the best pressed-earth block. A sample taken from soil at the Adobe International plant in June 1988, which Elkins said produced a very acceptable brick, contained 9% clay-, 22% silt-, and 69% sand+-size particles. The clay-size fraction consisted of five parts kaolinite, three parts calcium smectite, two parts illite, and a trace of mixed layer I/S plus minor amounts of calcite and quartz. Elkins also recommended a moisture content of 8-10 wt%. He stated that blocks can also be stabilized with 5-10 wt% portland cement to produce a high-strength, water-resistant block.

Test results performed by a private testing laboratory in Albuquerque in January 1986 on traditional (untreated) pressed-earth blocks made using the Earth Press II machine showed a modulus of rupture of 50-70 psi for an average of 60 psi and a compressive strength of 900-940 psi for an average of 920 psi The tests showed that water absorption varied from 1.3 to 2.7 wt%, averaging of 1.9 wt%.

Goldbrick "5000"

John Wright of Worldwide Adobe, Inc., in Grants, developer of the Goldbrick "5000" pressed-earth-block machine, was the second manufacturer of portable hydraulic pressed-earth-block equipment New Mexico. The first machine was produced in 1981 at Milan, New Mexico.

The Goldbrick "5000" machine has a gravity-fed hopper with a capacity of 2 cubic yards and is usually loaded by a front-end loader that removes soil from a nearby stockpile

FIGURE 80—Goldbrick "5000" pressed-earth-block machine equipped with pugmill mixer in operation. Ridge Adobe production yard, Santa Fe.

FIGURE 81—Large pressed-earth-block home built with Ridge Adobe pressed-earth blocks made by the Goldbrick "5000" machine, La Tierra area near Santa Fe.

(Fig. 79). The soil is then funneled into a 4 x 10 x 14-inch mold welded into a revolving wheel, where it is pressed into a block.

The diesel-powered unit also has a 5,000-watt belt-driven generator 120/240 volt, of which 60 or 50 hz supplies power to the machine's programmable controller; the excess wattage is used for operating power tools and a block conveyer system.

The machine presses a standard 4 x 10 x 14-inch block, with a 4 x 7 x 14-inch block available as an option, and has a production capacity of 750-850 blocks per hour. The basic Goldbrick "5000" machine was priced at $72,000 FOB Grants, New Mexico, in the spring of 1988. Other sizes of block molds and accessories, including power conveyers, straight gravity-roller conveyers, and portable block cutters, are also available. In 1994 and 1995 the machines were produced in San Antonio, Texas, by the Advanced Earth and Construction Technologies.

Ridge Adobe (Santa Fe)

The Ridge Adobe operation, owned by Chester Berridge of Santa Fe, New Mexico, is located on the 1-25 frontage road off NM-14 south of Santa Fe. The Goldbrick "5000" pressedearth-block equipment was purchased from Worldwide Adobe, Inc., in 1987 and was set up at Berridge's three-acre production yard (Fig. 80). Approximately 72,000 blocks were produced in 1987 with an estimated 300,000 under production in 1988; the equipment was inactive in 1994-95. With a crew of three, the company produced traditional (untreated), semistabilized, and stabilized pressed-earth blocks in the 4 x 10 x 14-inch and 4 x 7 x 14-inch sizes. In 1988, the traditional (untreated) blocks were priced at 30¢ each and the stabilized blocks were 45¢ each at the producer's yard. Examples of a large pressed-earth-block home and guest house under construction near Santa Fe, New Mexico, are shown in Figures 81 and 82.

Local soil from the nearby area and arroyos is delivered to the Ridge Adobe yard and is stockpiled by the screening equipment. The soil material is dampened (6 wt% or less) and blended with clay and sand as needed with the use of a front-end loader. Accessory equipment includes a screen on the conveyer and a pugmill for mixing portland-cement stabilizer. Other items include a 14-cubic-yard dump truck, two forklifts, front-end loader, and 21/2-ton flatbed delivery truck.

(1) The soil is stockpiled by the screening equipment.
(2) The front-end loader blends clay and sand with the moistened soil material.
(3) The material is transported from the pugmill to the hopper located above the hydraulic press.
(4) The blocks are pressed and conveyed directly for stacking on pallets. The stacked pallets are hoisted by a forklift onto a flatbed delivery truck.

Soil and test results—Particle-size analyses of the mixture used in April 1988 showed it to consist of 5% clay-, 24% silt-, and 71% sand+-size material. The clay-size fraction consisted of four parts kaolinite, three parts illite, three parts I/S, a trace of calcium smectite, and minor quartz, feldspar, and calcite.

Over 40 blocks were tested in May and June 1988 at the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology. The traditional (untreated) pressed-earth blocks showed a compressive strength of 1,218-1,612 psi and a modulus of rupture of 70-88 psi. The semistabilized blocks containing 5 wt% portland cement showed a compressive strength of 2,614-3,978 psi with a mean of 3,071 psi, and a modulus of rupture of 172-233 psi

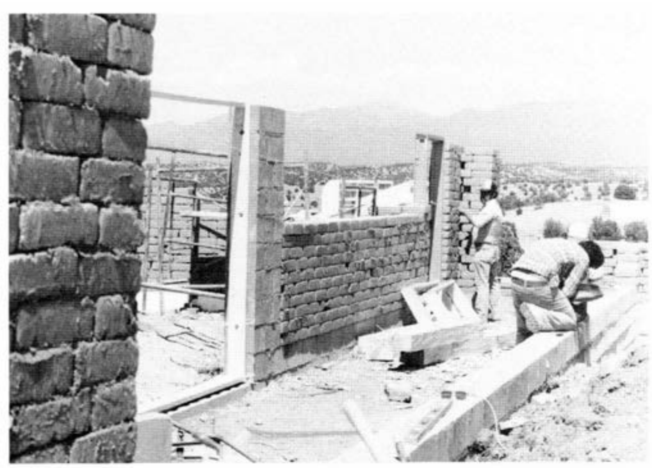


FIGURE 82—Guest house under construction using pressed-earth blocks from the goldbrick "5000" machine. Note use of adobe-mud slurry as mortar for the blocks. Ridge Adobe building site, La Tierra area near Santa Fe.

FIGURE 83—Pressed-earth-block production using the Goldbrick "5000" machine. HUD building site, Nambé Pueblo.

FIGURE 85—Completed HUD pressed-earth-block house built with the Goldbrick "5000" machine, Nambé Pueblo.

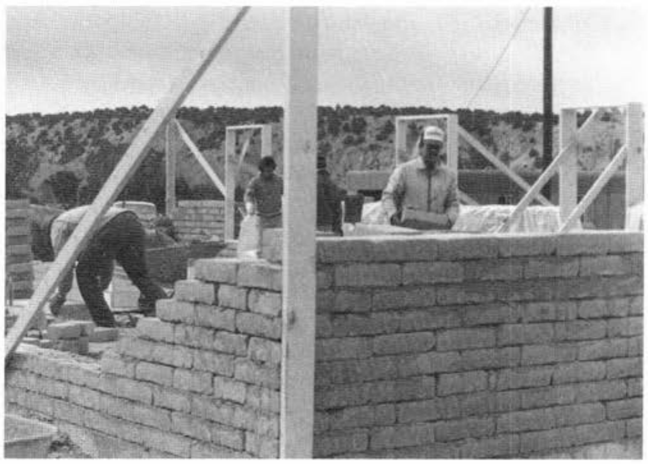


FIGURE 84—Pressed-earth-block house under construction. HUD building site, Nambé Pueblo.

with a mean of 194 psi. The moisture content varied from 6.47 to 7.72 wt% and the seven-day water absorption varied from 9.37 to 10.17 wt% with a mean of 9.75 wt%. The fully stabilized pressed-earth blocks containing approximately 10 wt% portland cement had a compressive strength of 3,448-3,702 psi and a modulus of rupture of 227-279 psi. The moisture content varied from 6.77 to 6.95 wt%, and the seven-day water absorption varied from 8.88 to 9.84 wt%.

Northern Pueblo Housing Authority

The Goldbrick "5000" machine owned by the Northern Pueblo Housing Authority at Nambé Pueblo, New Mexico, was in full-time use in 1988. With a crew of three, the machine produced 75,000 blocks in Nambé and Pojoaque Pueblos, where 15 new HUD housing units were under construction. The equipment was moved to each housing pad, where the blocks were pressed and stockpiled (Fig. 83). Each house requires approximately 5,000 blocks that are laid with a mud slurry, wired, and stuccoed (Fig. 84). An example of a HUD-approved pressed-earth-block house is shown in Figure 85.

Soil and test results—Tests of pressed-earth blocks from the Pojoaque Pueblo project performed in September 1988 at the United Nuclear Rock Mechanics Laboratory, New Mexico Institute of Mining and Technology, showed the pressed-earth blocks had a compressive strength of 664-819 psi with a mean of 751 psi, and a modulus of rupture of 39-51 psi with a mean of 44 psi.

Rustech

The Rustech hydraulic pressed-earth-block machine was developed in 1984 by Ken Rust of Los Alamos, New Mexico. This simple but unique machine contains two hydraulic cylinders and only three other moving parts. The machine is equipped with a gravity-fed hopper system. Its compact size and weight of 2,200 lbs allows easy towing and placement at various tight building sites (Fig. 86).

Soil and test results

According to the developer, a soil containing 70% sand and 30% clay and silt produces a strong pressed-earth block. The moisture content of the soil should be 6-12 wt%. Untreated blocks should be protected by a standard cement coat and stucco. Blocks can also be stabilized with 6-12 wt%

FIGURE 86—Rustech pressed-earth-block machine developed by Ken Rust and manufactured in 1988 by Rustech, Los Alamos. Note storage building constructed with Rustech pressed-earth blocks.

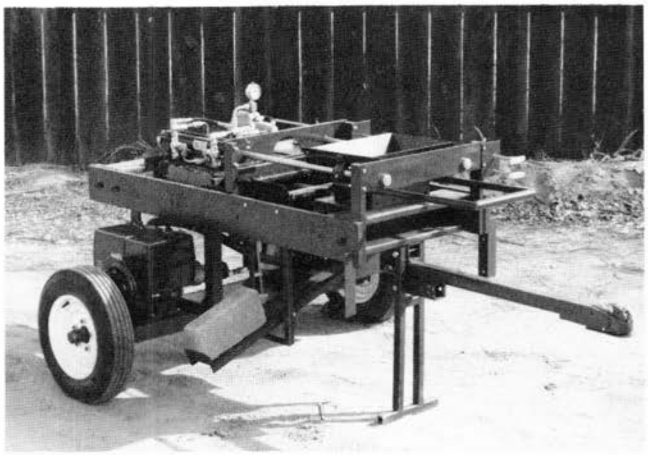


FIGURE 87—Impact 1000 pressed-earth-block machine developed by David Lineau and manufactured by Overview Consulting and Manufacturing, Corrales.

FIGURE 88—Terra Rammed Block pressed-earth-block machine developed by Mike Riddle and manufactured in 1988 by Terra Manufacturing Co., Albuquerque.

portland cement. The blocks should then be wet-cured for seven days under black plastic. With a 20% clay mixture, a strong block can be made with a modulus of rupture exceeding 70 psi and a compressive strength over 600 psi. The addition of a small amount of portland cement (3-6 wt%) produces a stronger block with a modulus of rupture of 200 psi. The blocks can be mortared into the wall directly from the machine or can be stockpiled at the building site.

Impact 1000

The Impact 1000 pressed-earth-block machine was introduced in 1987 by David Lineau of Overview Consulting & Manufacturing (in 1994 Southwest Alternatives Ltd.), Corrales, New Mexico, as an efficient and inexpensive method of producing pressed-earth blocks (Fig. 87). According to the developer, the light weight and small size allow the Impact 1000 to be easily towed by a small vehicle or by horse, oxen, or other animals.

Soil and test results

A soil mixture of 60% clay and silt and 40% sand is recommended for making the pressed-earth blocks. The developer also stated that the Impact 1000 pressed-earth blocks require only 4-7 wt% moisture. The blocks can be used immediately after they are made; no wet curing or sun drying is required. The untreated blocks require protection by a standard cement coat and stucco. The blocks may also be stabilized with 6-12 wt% portland cement or other stabilizers.

Test data furnished by David Lineau on the Impact 1000 pressed-earth blocks showed a compressive strength **of** 600-1,000 psi for an average of 850 psi, and a modulus of rupture of 77-84 psi for an average of 80 psi.

Terra Rammed Block

Mike Riddle developed and built his first pressed-earth-block machine in 1982. The present Terra Rammed Block machine (Fig. 88) was built in 1985 at the Western Metal Works facility in Albuquerque. The unit is capable of pressing several block sizes, including the standard 4 x 10 x 14-inch block. The basic Terra Rammed Block machine was priced at $65,000-70,000 FOB in the summer of 1988, but no additional machines have been assembled since that time.

(1) The machine is mounted on a 16-ft tandem-axle gooseneck trailer equipped with electric brakes and signals for towing.
(2) The 51/2-cubic-yard hopper is usually loaded by a front-end loader that moves soil from a local stockpile.
(3) The soil is screened to remove the larger-than-one-inch rocks at the hopper, and is then transported into the mixer where water may be sprayed depending on the moisture content of the soil. The stabilizer located by the mixer may also be added at this stage.
(4) The material is then moved automatically into the mold, where it is pressed by the platen into a block.

Soil and test results

Test data on 15 samples blocks manufactured in 1982 showed a compressive strength of 1,000-5,050 psi and a modulus of rupture of 47-384 psi, with the moisture content varying from 2.7 to 7.5 wt%. The soil mixture was composed of clay, silt, sand, and C-grade fly ash.

Rammed-earth production

Building with rammed earth (pisé de terre) is not a new invention. Pliny mentions it **in** his *Natural History* and the Romans introduced it into what is now France. Various rammed-earth buildings have been constructed in England, Africa, Australia, New Zealand, Mexico, and California, rep resenting a wide range of climates and soil types (Read, 1939). Although building with rammed earth has been practiced for many centuries in many countries, the process is not widely known and used.

Rammed-earth construction has also been used by "do-it-

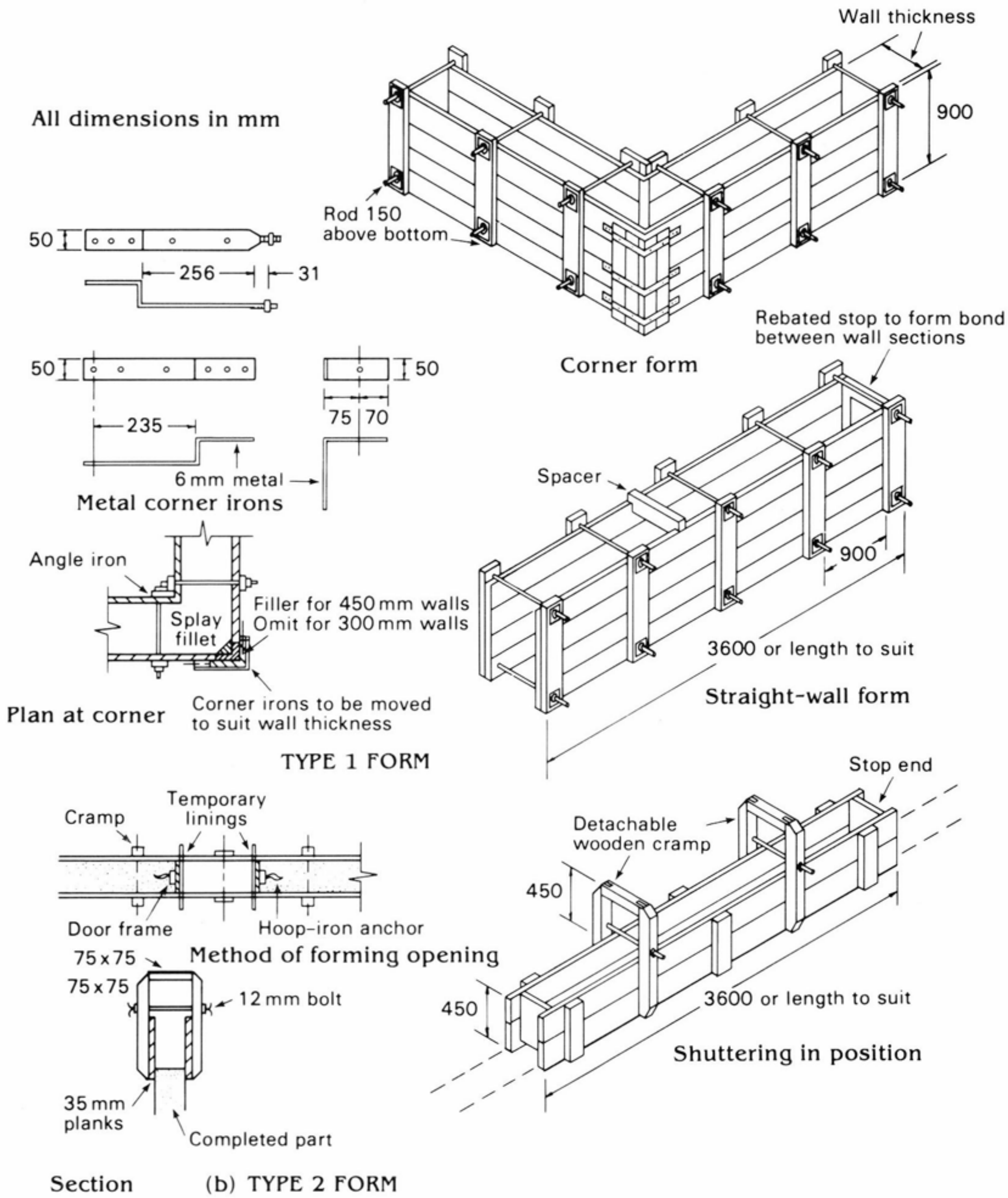


FIGURE 89—Types of rammed-earth forms developed in Australia (from Middleton, 1987).

yourself people who prefer to use their own soil and labor to construct buildings. The technique can be used to build substantial structures including houses, barns, commercial buildings, walls, and stables. Rammed-earth walls are similar to pressed-earth blocks, but the procedure differs because of the equipment and forms used.

Rammed-earth walls are built by thoroughly tamping layers of moist soil between vertical wooden, steel, or aluminum forms to form a layer several inches deep (Figs. 89, 90). When a section of wall is completed, the forms are moved upwards or sideways and the process is repeated. The ramming is done with hand-operated or pneumatic tampers that compress the volume of the soil material by 25-30% (Wolfskill et al., 1970; Fig. 91). The forms require accurate setting and must be held in place to keep the wall straight and true. Density of the wall depends on the soil type and the ramming. The tamping procedure works in two ways: repeated vertical blows of the rammer press the soil but seldom strike the same place and thus tend to work the soil particles also back and forth horizontally, increasing the density in both directions (DeLong, 1959).

Rammed earth is best suited for use in side walls and major interior partitions. Exterior walls are commonly stuccoed and finished interior walls are usually plastered and painted. Rammed earth should not be used for below-grade foundations that do not meet New Mexico Building Code requirements. Running water in contact with rammed-earth walls (without stabilizers) will cause excessive erosion. However, well-made rammed-earth walls are durable and can last hundreds of years, especially if the soils have been carefully selected and construction codes followed.

Rammed earth is a stable building material that has many

FIGURE 90—Close-up of tamped wall. Note layering produced by tamping. Huston Constructin Company building site, Edgewood.

FIGURE 91—Huston house built with 16-inch-thick interior and 36-inch-thick exterior rammed-earth walls, Edgewood.

advantages in the construction of homes, commercial buildings, garages, **and barns.** The walls, if thick enough (16-24 inches), have certain insulation and thermal characteristics that provide well-known comfort. According to McHenry (1984), the strength of the soil (8-10 wt% moisture content) at initial compaction is approximately 30 psi or more and, within a few weeks of drying in the wall, will achieve a dry strength of 300 psi or more. Clough (1950) showed that the compressive strength of rammed earth varies from 462 psi to as high as 850 psi, and it is known to increase with age (Patty, 1939).

More important than the compressive strength is the ability of the rammed-earth wall to resist weathering. Five factors that may affect the ability of **the** entire rammed-earth wall (rather than just its surface) to resist weathering were listed by DeLong (1959) in his study of mechanical abrasion and water erosion.

(1) When the moisture content of the wall is high, freezing and thawing loosen the structure and cause it to crumble. Rammed earth must be thoroughly dried before the onset of cold weather.

(2) Shrinkage due to the loss of 9-13 wt% moisture causes cracks and pulverization. Surface cracks appear soon after ramming, because the surface dries out first. Later on these cracks diminish or even disappear because the interior of the wall also shrinks. A test block eventually attained a maximum shrinkage at the 3% stable moisture content.

(3) A high sand content prevents excessive shrinkage and cracking. (A test wall containing 50-75% sand and otherwise suitable soil did not deteriorate due to the initial or continued effect of shrinkage.)

(4) "Colloids," which include all the clay and silt particles, are a second cause of shrinkage variation. The particles have more surface area than sand particles of equal weight. Therefore it takes more water to make the soil semiplastic for proper ramming, resulting in more drying and greater shrinkage.

(5) Various stabilizers reduce the effects of weathering. Lime, portland cement, and asphalt emulsion generally improve the wall, but all additional materials should always be well blended with the earth before ramming.

Rammed-earth construction companies

Although several individuals and rammed-earth contractors have been active in the past in New Mexico, the only companies active in 1987-88 and 1994-95 were the Huston Construction Company of Edgewood and the Soledad Canyon Earth Builders of Mesilla (Table 4). They produced four houses in 1987 and three in 1988. In 1995 they produced a total of 17 houses. The production techniques used by these two construction companies are outlined below.

Huston Construction Company (Edgewood)

The Huston Construction Company has been engaged in the production of rammed-earth systems since 1983 and has constructed homes and commercial buildings. In 1995 Huston Construction produced 11 homes in New Mexico and Colorado. The company, owned by Stan Huston, is located on 420 acres in Edgewood, New Mexico, approximately 30 miles east of Albuquerque.

To build the Don Huston house (Fig. 92), which was their first project, Stan Huston and his father Don used local soil adjacent to the construction site. The soil was screened and stockpiled. To secure the proper moisture content, a sprinkler placed on the top of the pile wetted the soil. The material was then removed and used to construct the walls.

Historically, traditional rammed-earth forms were made of planks and bracing. In 1995-96, rammed-earth builders used a variety of steel, plywood, and aluminum concrete-pouring systems that are available on the construction market. Stan Huston uses a modified concrete-pouring form made out of 4-ft-wide plywood and steel-reinforced panels. A crew of four worked on the rammed-earth walls of the first Huston house using the following procedure:

(1) The forms are stacked for an 8-ft-high and 16-inch-wide wall and are locked together at the corners to permit the walls to be rammed without a break (Figs. 93, 94).

(2) A Bobcat front-end loader is used to place the adobe soil in the forms in 6-8 inch layers.

(3) Two Ingersoll Rand 341 backfill tampers, hooked up to a 125 Schramm compressor (125 cfm, 110 psi), are used to tamp the 6-8 inch layers down to 41/2-5 inches (Fig. 95).

(4) The bottom row of forms is set for a given wall section,

FIGURE 92—Stan Huston displaying the 4 × 4-ft wooden forms used in rammed-earth construction. Huston Construction Company building site, Edgewood.

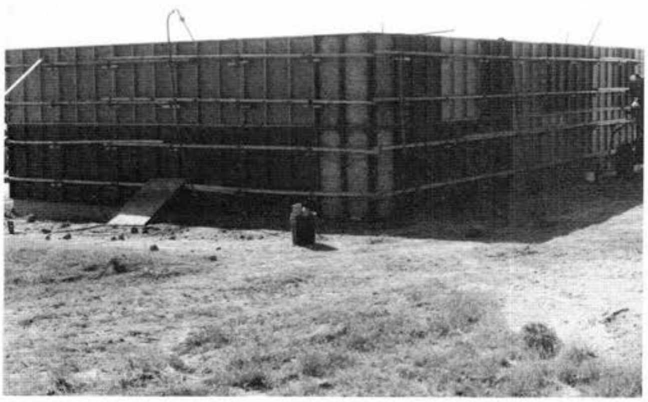


FIGURE 93—Setting of the wooden forms for construction of the rammed-earth walls, Huston Construction Company building site, Edgewood.

filled with adobe soil, and then rammed until the forms are three-quarters full. Then the top layer of the forms is stacked, the walls are rammed to their full 8-ft height, and a concrete bond beam is poured (Figs. 96, 97).

In general, the moisture content varies from 8 to 10 wt% and the clay content from 10 to 15 wt%. No stabilizers other than sand and crusher fines are added to the soil mixture. Samples collected in the summer of 1988 from Huston stockpiles contained 6% clay-, 25% silt-, and 69% sand+-size particles. The mineralogy of the clay-size fraction was four parts I/S, two parts kaolinite, two parts smectite, and two parts illite, plus calcite and quartz.

Soledad Canyon Earth Builders (Mesilla)

The only rammed-earth contractor in southern New Mexico is Soledad Canyon Earth Builders owned by Mario Bellestri. The company produced six rammed-earth homes near Las Cruces in 1995. Walls are typically 2-ft thick, but can be up to 3-ft thick. The soil material commonly consists of three parts crusher fines to one part clay soil. Bellestri uses Ingersoll Rand backfill tampers and a compressor to tamp each layer of about 8 inches of soil down to about 5 inches. The forms used are metal frames with wooden insets. A 5 wt% portland-cement stabilizer is commonly used, with as much as 10 wt% in the lowest one or two layers for enhanced stability Concrete bond beams, window

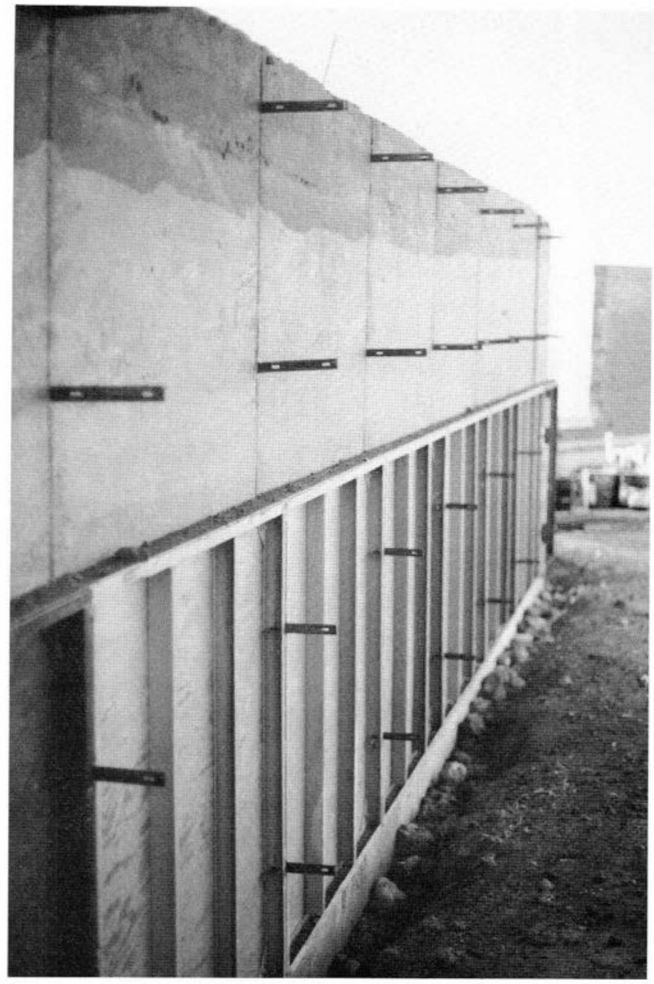


FIGURE 94—Removal of top forms exposing the metal form fasteners that are later cut off at the wall surface. Huston Construction Company building site, Edgewood.

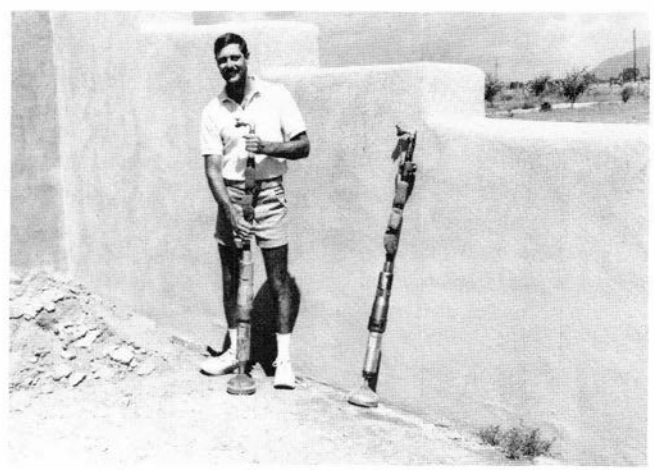


FIGURE 95—Stan Huston holding one of the Ingersoll Rand 341 backfill tampers that are hooked up to a 125 Schramm compressor for tamping rammed-earth walls. Huston Construction Company building site, Edgewood.

FIGURE 96—Huston house under construction, Edgewood. Note thickness of exterior walls (36 inches) and interior wall (16 inches) after removal of wooden forms.

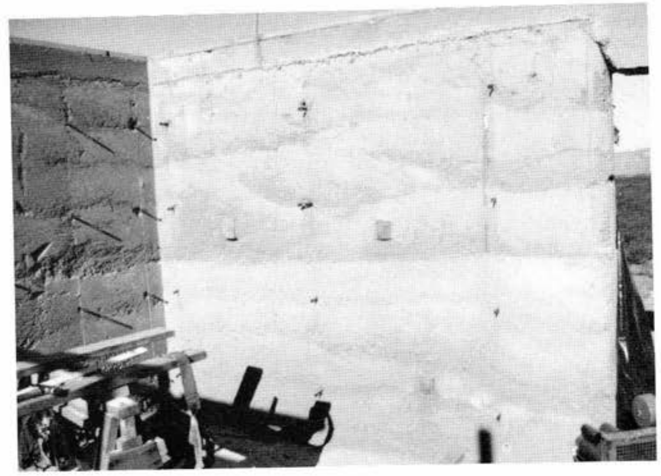


FIGURE 98—Exterior 2-ft-thick rammed-earth wall of home under construction. Note concrete bond beam topped by wooden frame. Soledad Canyon Earth Builders building site, Mesilla.

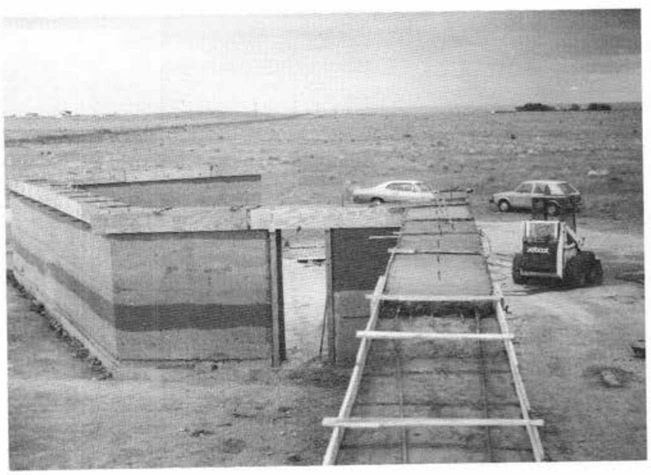


FIGURE 97—Rammed-earth walls and pouring of the concrete bond beam. Note the soil colors and the layering produced by tamping. Huston Construction Company building site, Edgewood.

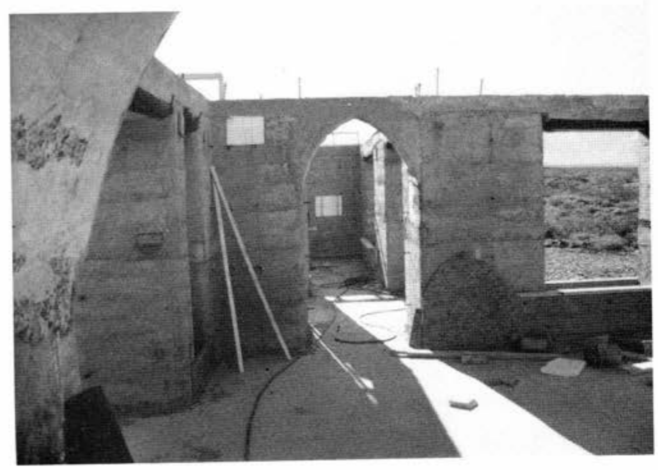


FIGURE 99—Rammed earth walls with arches and windows. Note concrete bond beam and form for concrete window sill at lower right. Soledad Canyon Earth Builders building site, Mesilla.

and door lintels, and reinforced concrete window sills add further strength (Figs. 98, 99). A compressive strength of about 450 psi is achieved after the walls cure for seven days.

Some interior walls are constructed of frame materials, but most are also of rammed earth. Soledad Canyon Earth Builders specializes in custom homes with passive solar designs.

Advantages in using native soils

Results of this study and various geologic reports indicate that there is an unlimited supply of adobe soil throughout New Mexico. Extensive deposits are found throughout the local floodplains, streams, arroyos, terraces, and alluvial fans. The deposits are widely used at present as sources of adobe soil by most commercial adobe-brick and pressed-earth-block producers in the Albuquerque and Espanola Basins of the Rio Grande valley.

Other major advantages in using adobe bricks, pressed-earth blocks, and rammed-earth walls for the construction of buildings include the following:

(1) Cost—Adobe bricks and pressed-earth blocks are most reasonable; prices in 1987 and 1988 are about the same as in 1980. In 1995 adobe bricks and pressed-earth blocks sold for 35-65¢ each at the local production yards.

(2) Soil stabilizers—Adobe soils can be stabilized at reasonable costs to produce tough, water-resistant or waterproof adobe bricks and pressed-earth blocks. Major stabilizers include asphalt emulsion, portland cement, and lime.

(3) Water resistance—Fully stabilized adobe bricks and pressed-earth blocks are most resistant to water penetration. A properly stabilized adobe brick will usually absorb less than 4 wt% water, which is much less than several other construction materials (after Ferm, 1985):

	Water absorption (wt%)
Lightweight cement bricks	20-25
Burnt brick	8-12
Cement stucco	8-11
Wood	4-8
Stabilized adobe brick	1/2-4
Stabilized pressed-earth block	8-9

(4) Durability—The durability and resistance to weathering and erosion are well demonstrated by the 19 Indian Pueblos located throughout the state. In particular, the five-storied Taos Pueblo has been continuously occupied for over 900 years. Many other examples of adobe durability are Spanish churches, old haciendas, and homes built in the state in the 1500s and 1600s that are still standing today. Another reason the historic pueblos and other adobe structures still exist is that the people inhabiting them realized that regular maintenance using like materials is essential for preservation.

(5) Thermal qualities—Where adobe bricks, pressed-earth blocks, and rammed-earth walls remain dry, buildings retain heat well in the winter. In the summer they are comfortably cool because the inside daytime temperature is usually lower than the outside temperature.

(6) Pest resistance—Adobe walls are unaffected by dry rot, termites, and other destructive organisms.

(7) Fire resistance—Adobe walls are not fire hazardous and structures can be made fireproof.

(8) Painting—Adobe structures may be easily painted any color or shade desired. Latex paints usually adhere well to adobe surfaces. A small-scale test should be made before any paint is used.

(9) Design and architecture—Adobe construction permits design flexibility and uniqueness; it is a southwestern architectural style that is environmentally and sculpturally compatible with the landscape.

(10) Energy budget—Adobe is an energy-efficient building material to manufacture because it is sun-dried, rather than fired, not produced with high temperatures as is cement or masonry brick. Architect David Wright (1978) stated that it takes over 300 times more commercial energy to produce a concrete block equal in volume to a sun-dried adobe block. Adobe is energy-efficient also because in many cases the soil can be mined at the building site, further eliminating transportation costs.

(11) Resistance to bullet penetration—A CINVA-Ram-made wall (ten parts soil, one part portland cement) of adobes that measured 31/2 x 51/2 x 111/2 inches was subjected to a Galil (Israeli) machine gun test. Bullets fired from a 20 m (60 ft) distance made holes only 11/2-2 inches deep (Lola, 1981).

Summary and conclusions

The use of adobe in construction has evolved in several of the arid and semiarid regions of the world as early as 7000 B.C. To this day, mud and soil are the primary building materials for at least 50% of the world population (Ferm, 1985). In the urban areas of developing countries, more than half the population has inadequate housing. The situation is worse in the rural areas, where seven out of ten dwellings are substandard (Ferm, 1985).

In the American Southwest, the Indian and Spanish populations have long used adobe to construct homes. This historic and cultural use of native soils has developed into the largest adobe industry in this country. New Mexico's adobe industry continues to maintain an average production rate of 21/2-4 million adobe bricks and pressed-earth blocks per year. A large segment of the local population, particularly Native and Hispanic Americans, continues to build adobe houses in the traditional architectural style. Interest in solar adobe construction has also made the adobe industry grow. It has been estimated that approximately 3% of the new homes built in New Mexico are adobe, averaging 500 to 600 homes each year (Gerbrandt and May, 1986). Much of the new housing is in the Rio Grande valley and includes the major cities of Belen, Albuquerque, Santa Fe, Espanola, and Taos.

Field investigations conducted in 1987-88 in New Mexico, located 33 commercial adobe-brick producers, 28 owners of pressed-earth-block machines, and two rammed-earth contractors. In 1987, 3,124,000 adobe bricks and 642,000 pressed-earth blocks were produced. In 1995, 13 commercial adobe-brick producers made 2,625,000 bricks and three pressed-earth-block producers made 395,000 blocks. Prices for traditional (untreated) adobe bricks varied from 35 to 45¢ each, for semistabilized bricks from 35 to 55¢ each, and for fully stabilized bricks from 50 to 65¢ each at the adobe yard. Prices for traditional (untreated) pressed-earth blocks were about 50¢ each using a soil mixture delivered to the construction site or production yard or the owner's local soil on site. Most adobe bricks and pressed-earth blocks were of the standard 4 x 10 x 14-inch size.

In general, the pressed-earth blocks tested have higher compressive strength and modulus of rupture than adobe bricks made the traditional way with or without stabilizers; however, untreated (unstabilized) pressed-earth blocks are as sensitive to water damage as the traditional adobe bricks.

Mineral analyses of the clay-size fraction of the adobe soils indicated that although the mineral content varies greatly, expandable (smectite and I/S) and nonexpandable (kaolinite, illite, and chlorite) clay minerals each constitute about 50% of the fraction. In addition, quartz and calcite are very common.

Particle-size analyses indicated that adobe soils used for bricks, pressed-earth blocks, and rammed-earth structures are about the same, but that the proportion of sand-and-larger-size (sand+-size) fraction of commercial mixtures is much greater than previously thought. Acceptable blocks can be made from material containing up to 89% sand+-size and as little as 1% clay-size particles. The soils have a significant amount of calcite in all particle-size ranges, and the water used to make adobe mud contains a large amount of dissolved calcium salts that precipitate when the mud dries.

The results show that the adobe, pressed-earth, and rammed-earth industries produce highly competent building materials.

Environmental hazards related to the concentration of radon and the effects of earthquakes do not appear to be significantly greater for adobe buildings than for buildings constructed of other material, provided that adobe buildings are designed to withstand these problems and are kept in good repair. In both cases, planning for and attention to possible problems preclude difficulties.

The continued growth of the adobe, pressed-earth, and rammed-earth industries in the state depends on the following: (1) ability of the adobe construction industry to compete with "stick" construction; (2) support and continued acceptance by HUD and other federal, state, and local governmental agencies of using native soils for construction; (3) availability of low-cost adobe soils near the major commercial adobe-brick yards and pressed-earth-block-production and rammed-earth-construction sites; (4) development of better and less expensive stabilizers for producing water-resistant and waterproof adobe bricks and pressed-earth blocks; and (5) establishment of a strong adobe, pressed-earth, and rammed-earth organization to improve specifications and promote the industry.

References

Agnew, N., Preusser, F., and Druzik, J. R., 1987, Strategies for adobe preservation, the Getty Conservation Institute Research Program; *in* 5th International Meeting of Experts on the Conservation of Earthen Architecture: International Centre for the Research and the Application of Earth Construction (CRATerre), Rome 22-23/X meeting, pp. 3-11.

American Geological Institute, 1962, Dictionary of geological terms: Dolphin Books, p. 95.

Austin, G. S., 1975, Clay and shale resources of Indiana: Indiana Geological Survey, Bulletin 42-L, 40 pp.

Bunting, B., 1976, Early architecture in New Mexico: University of New Mexico Press, Albuquerque, New Mexico, 122 pp.

Bunting, B., Booth, J. L., and Sims, W. R., Jr., 1964, Taos adobes-Spanish Colonial and Territorial architecture of the Taos Valley: Museum of New Mexico Press and Fort Burgwin Research Center, Santa Fe, New Mexico, Publication 2, 80 pp.

California Research Corporation, 1963, The manufacture and use of asphalt-emulsion-stabilized adobe bricks: California Research Corporation, Richmond, California, 54 pp.

Construction Industries Division, 1991, New Mexico Building Code, Chapter 24: Construction Industries Division, General Construction Bureau, Santa Fe, New Mexico, pp. 31-36.

Carter, W. D., 1965, Sand and gravel; *in* U.S. Geological Survey et al. (compilers), Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, pp. 353-361.

Clifton, J. R., 1977, Preservation of historic adobe structures-a status report: Institute for Applied Technology, National Bureau of Standards, Washington, D.C., NBS Technical Note 934, 30 pp.

Clough, R. H., 1950, A qualitative comparison of rammed earth and sun-dried adobe brick: University of New Mexico Publications in Engineering, Albuquerque, New Mexico, no. 4, 68 pp.

DeLong, H. H., 1959, Rammed earth walls: Agricultural Engineering Department, South Dakota State College, Brookings, South Dakota, Circular 149, 20 pp.

Ferm, R., 1985, Stabilized earth construction, an instructional manual: The International Foundation for Earth Construction, Washington, D.C., 74 pp.

Fine, A. H., 1976, The thermal properties of building materials: Adobe News, Albuquerque, New Mexico, no. 11, pp. 14, 26.

Gerbrandt, H., and May, G. W., 1986, The extent of adobe use in the United States: Solar Earthbuilder International, 505/524-1416, P.O. Box 16119, Las Cruces, New Mexico, Issue 47, pp. 12-15, 56-59.

Getty Conservation Institute, 1990, 6th International Conference on Conservation of Earthen Architecture-Adobe 90 Preprints: Getty Conservation Institute, Santa Monica, California, 469 pp.

Green, L., 1988, Radon-a threat you can deal with: Home Mechanix, Times Mirror Magazines Inc., New York, v. 84, no. 722, pp. 82-88, 92-94.

Grim, R. E., 1968, Clay mineralogy: McGraw-Hill Inc., New York, 2nd edition, 596 pp.

Jones, D., and Cordell, L. S., 1985, Anasazi world: Graphic Arts Center Publishing Company, Portland, Oregon, 87 pp.

Kelley, V. C., 1977, Geology of Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 60 pp.

Kelley, V. C., 1978, Geology of Espanola Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 48, text, scale 1:125,000.

Lola, C., 1981, Research efforts on soil stabilizers for low-cost housing in Nicaragua: A. T. International, 1331 H Street, Washington, D.C., p. 10.

Long, J. D., and Neubauer, L. W., 1946, Adobe construction: University of California (Berkeley), College of Agriculture, California Agricultural Experiment Station, Bulletin 472, 63 pp.

Lumpkins, W., 1977, Adobe (from the Arabic 'Atobé): unpublished paper, Museum of New Mexico, Santa Fe, New Mexico, 25 pp.

McHenry, P. G., Jr., 1984, Adobe and rammed earth building-design and construction: John Wiley & Sons, New York, 217 pp.

McHenry, P. G., Jr., 1985, Adobe, build it yourself: University of Arizona Press, Tucson, Arizona, revised edition, 158 pp.

Patty, R. L., 1939, Puddled-earth and rammed-earth walls: University of South Dakota Experiment Station, Agricultural Engineering, v. 20, no. 8, pp. 60-61.

Read, W. S., 1939, Pisé de terre-a cheap method of enclosing lands of field agriculture and livestock in India: Government of India, New Delhi, v. 9, pt. 4, pp. 392-400.

Robertson, D. K., 1981, Expanded revision of effective U-values: U-values for opaque wall sections, glazing, and passive solar wall types: New Mexico Energy Research and Development Institute, Albuquerque, New Mexico, EMD 2-68-1111, 62 pp.

Scawthorn, C., 1986, Dynamic test of adobe building model-preliminary report: Solar Earthbuilder International, (505) 524-1416, P.O. Box 16119, Las Cruces, New Mexico, Issue 47, pp. 30-34, 62-63.

Smith, E. W., 1982, Adobe bricks in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 188, 89

Smith, E. W., and Austin, G. S., 1989, Adobe, pressed-earth and rammed-earth industries in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 127, 60 pp.

Steen, C. R., 1972, An archaeologist's summary of adobe: Museum of New Mexico Press, Santa Fe, New Mexico, El Palacio, v. 77, no. **4,** pp. 29-39.

Steen, C. R., 1977, Pajarito Plateau Archaeological Survey and Excavations: Los Alamos Scientific Laboratory, Los Alamos, New Mexico, LASL-77-4, 70 pp.

Taylor, M. R., 1987a, Fort Selden Test Wall status report; *in* 5th International Meeting of Experts on the Conservation of Earthen Architecture: International Centre for the Research and the Application of Earth Construction (CRATerre), Rome 22-23/X meeting, pp. 91-102.

Taylor, M. **R.,** 1987b, Fort Selden Test Wall Project, second annual status report: unpublished paper, Museum of New Mexico, Santa Fe, New Mexico, 50 pp.

Tibbets, **J.** M., 1986, Of major importance to every earth-builder: Solar Earthbuilder International, 505/524-1416, P.O. Box 16119, Las Cruces, New Mexico, Issue 47, pp. 26-29, 64.

Volunteers for International Technical Assistance (VITA), 1966, Making building blocks with the CINVA-Ram: VITA Publication, 26 pp.

Wakening, M., 1980, Radon transport processes below the earth's surface; *in* Natural radiation environment III: Technical Information Center/U.S. Department of Energy, Washington, D.C., CONF-780422, v. 1, pp. 90-104.

Wolfskill, L. A., Dunlap, W. A., and Gallaway, B. M., 1970, Handbook for building homes of earth: Department of Housing and Urban Development, Office of International Affairs, Washington, D.C., 160 pp.

Wright, **D.,** 1978, Natural solar architecture: Van Nostrand Reinhold, New York, 245 pp.

Additional reading

Austin, G. S., 1994, Construction uses-adobe and similar materials; *in* Carr, D. D. (ed.), Industrial Minerals and Rocks: Society for Mining, Minerals and Exploration, Littleton, Colorado, pp. 279-286.

Austin, G. S., and Goolsby, M. R., 1996, Modern New Mexico adobe: A response to some environmental concerns: New Mexico Bureau of Mines and Mineral Resources, Bulletin 154, pp. 63-74.

Bates, R. L., and Jackson, J. A. (editors), 1987, Glossary of geology: American Geological Institute, Alexandria, Virginia, 3rd edition, 788 pp.

Bergland, M., 1985, Stone, log, and earth houses: Taunton Press, Newtown, Connecticut, pp. 125-135.

Bunting, B., 1974, Of earth and timbers made-New Mexico architecture: University of New Mexico Press, Albuquerque, New Mexico, 85 pp.

CRATerre-EAG, 1995, Compression earth blocks: Manual of design and construction, GATE, Eschborn, Germany, 148 pp.

Dethier, J. (exhibition director), 1983, Down to earth, adobe architecture, an old idea, a new future (translated from the French by Eaton, R.): Facts on File, Inc., New York, 192 pp.

Doat, P., Hays, A., Houben, H., Matuk, S., and Vitoux, F,1979, Construire en terre: editions Alternative et Parallèles, collection AnArchitecture, Paris, 270 pp.

Fitzmaurice, R., 1958, Manual on stabilized soil construction for housing: United Nations Technical Assistance Programs, New York, Sales #58.11.H.4, 125 pp.

Folks, J. J., 1975, Soil survey of Santa Fe area, New Mexico-Santa Fe County and part of Rio Arriba County: U.S. Department of Agriculture, Soil Conservation Service, 114 pp.

Gustinus, J., and Robertson, D. K., 1984, Southwest thermal mass study-the effect of envelope thermal mass on the heating energy use of eight test buildings in a high desert climate (September, 1981 through December, 1982): New Mexico Energy Research and Development Institute, Albuquerque, New Mexico, EMD 2-67-1135, 105 pp.

Hacker, L. W., 1977, Soil survey of Bernalillo County and parts of Sandoval and Valencia Counties, New Mexico: U.S. Department of Agriculture, Soil Conservation Service, 101 pp.

Houben, H., and Guillaud, H., 1994, Earth construction-A comprehensive guide: Intermediate Technology Publications, London, UK, 362 pp.

Hubbell, E., 1943, Earth brick construction: U.S. Office of Indian Affairs, Education Division, Washington, D.C., Home Improvement Pamphlet, 110 pp.

International Institute of Housing Technology and California State University, Fresno Foundation, 1972, The manufacture of asphalt-emulsion-stabilized soil bricks and brick maker's manual: California State University Press, Fresno, California, 80 pp.

Lumpkins, W., 1961, Adobe past and present: Museum of New Mexico Press, Santa Fe, New Mexico, 39 pp

Lumpkins, W., 1986, La casa adobe: Ancient City Press, Santa Fe, New Mexico, 52 pp.

May, G. W. (editor), 1981, International workshop on earthen buildings in seismic areas: University of New Mexico Press, Albuquerque, New Mexico, Proceedings of International Workshop, v. 1, 693 pp.

Middleton, G. F., 1987, Earth-wall construction: Australian Government Publishing Service, National Building Technology Centre, P.O. Box 30, Chatswood 2057, Bulletin 5, 4th edition (revised by Schneider, L. M.), 65 pp.

Miller, L. A., and Miller, D. J., 1982, Manual for building a rammed earth wall: Rammed Earth Institute International, Greeley, Colorado, revised edition, 67 pp.

Nabokov, P., 1986, Architecture of Acoma Pueblo, the 1934 Historic American Buildings Survey Project: Ancient City Press, Santa Fe, New Mexico, 137 pp.

New Mexico Energy Institute, 1977, Energy conservation code-applications manual: University of New Mexico Press, Albuquerque, New Mexico, 3rd edition, 178 pp.

Patterson, S. H., and Holmes, R. W., 1965, Clays; *in* U.S. Geological Survey et al. (compilers), Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, pp. 312-322.

Pfister, S., Schnorr, **J.,** and Schrader, C., 1983, Earth materials bibliography: Arizona Energy Office, Phoenix, Arizona, 7 pp.

Romero, 0., and Larkin, D., 1994, Adobe-building and living with earth: Houghton Miffin Company, New York, 237 pp.

Scheuch, K. E., and Busch, R. **D.,** 1988, New Mexico conservation code application manual, residential buildings: Energy, Minerals, and Natural Resource Department, Santa Fe, New Mexico, 1988 edition, 108 pp.

Smith, E. W., 1981, Adobe brick production in New Mexico: New Mexico Bureau of Mines and Mineral Resources, New Mexico Geology, v. 3, pp. 17-21, 24.

Smith, E. W., 1982, Large-scale adobe-brick manufacturing in New Mexico; *in* Austin, G. S. (compiler), Industrial rocks and minerals of the Southwest: New Mexico Bureau of Mines and Mineral Resources, Circular 182, pp. 49-56.

Smith, E. W., 1983, Recommended specifications for adobe and construction details: Eight Northern Indian Pueblos

Council, San Juan Pueblo, New Mexico, 22 pp.
Smith, E. W., and Austin, G. S., 1996, Modern adobe in New Mexico: Energy, Minerals, and Natural Resources Department, Santa Fe, New Mexico, 1996 edition, 24 pp.
Smith, E. W., and Murray, S., 1982, Adobe for sale: New Mexico Magazine, v. 60, no. 4, pp. 28-33, 42.
Syvertson, E., 1988, Men, mud, and mustangs: Adobe promotions and news, Belen, New Mexico, v. 1, no. 1, pp. 4-5.
Tibbets, **J.** M., 1974, Down Tucson way, adobe quemado is alive and well: Adobe Today, Albuquerque, New Mexico, no. 1, pp. 3-4.
Tibbets, J. M., 1989, The earthbuilders encyclopedia: Southwest Adobe School, Bosque, New Mexico 87006, 196 PP.
Tibbets, J. M., 1994, Adobe codes, 3rd ed.: Southwest Solaradobe School, P.O. Box 153, Bosque, New Mexico 87006, 72 pp.
University of New Mexico, Center for Environmental Research and Development, and Four Corners Regional Commission, 1970, A study of the feasibility of mechanized adobe production: University of New Mexico, Center for Environmental Research and Development, and Four Corners Regional Commission, Farmington, New Mexico, 48 pp.
U.S. Department of the Interior, 1974, Earth manual—a manual on the use of earth materials for foundation and construction purposes: U.S. Government Printing Office, Washington, D.C., 810 pp.
Vance, M., 1985, Adobe building: Vance Bibliographies, Monticello, Illinois, Architecture Series Bibliography, revision of A 76,10 pp.

Glossary

adobe brick—sun-dried mud brick extensively used throughout the southwest United States.

adobe layer (mechanical)—a self-propelled and hydraulically operated machine developed by the Hans Sumpf Company of California for molding adobe bricks; the mechanical adobe layer uses various metal molds to produce adobe bricks of different sizes.

adobe soil—a mixture of clay, silt, and sand deposits found in the basins of the southwest United States and used to produce sun-dried bricks, pressed-earth blocks, and rammed-earth walls.

adobero—(from the Spanish) a person engaged in the production of adobe bricks and the construction of adobe buildings.

alluvial—pertaining to particular types of, or mineral associated with, deposits made by flowing water.

alluvial fan—a fan-shaped deposit of gravel, sand, and fine materials (clay and silt) dropped by a stream where the gradient lessens abruptly.

alluvium—soil material (clay, silt, sand, and gravel, or similar unconsolidated detrital material) deposited on land by streams and local wash.

arroyo—a channel or gully of an ephemeral stream, usually dry but can change into a temporary watercourse for a short-lived torrent after a rainfall.

asphalt emulsion—asphalt globules of microscopic size which are surrounded by and suspended in a water medium (International Institute of Housing Technology and California State University, Fresno Foundation, 1972).

basin—in the southwest United States, a depression on the surface of the land (a broad topographic low between mountain ranges), usually caused by subsidence, which may contain extensive sedimentary deposits of adobe soil.

bolson—an extensive flat alluvium-floored basin, into which drainage from surrounding mountains flows toward a central depression; a basin with internal drainage.

British thermal unit (BTU)—a measurement representing the amount of heat necessary to raise 1 lb of water (1 pint) 1°F.

caliche—a secondary (in-place) accumulation of calcium carbonate found in many soils of the southwest United States.

chlorite—a group of platy, usually greenish minerals characterized by magnesium and iron aluminosilicate compositions; can occur in clay sizes as well as in coarsely crystalline masses.

clay—a fine-grained, natural, earthy material composed primarily of hydrous aluminosilicates with grain diameters less than 2 micrometers (<2pm or <0.002 mm).

cohesion—the ability of various particles to stick together (Wolfskill et al., 1970).

colloid—a substance that, when apparently dissolved in water, diffuses not at all or very slowly through a membrane and usually has little effect on the freezing point, boiling point, or osmotic pressure of the solution; a substance in a state of fine particle subdivision, with particles ranging from 10^{-5} to 10^{-20} in diameter (American Geological Institute, 1962).

compressive strength—a physical property of a material that indicates its ability to withstand compressive forces, usually expressed in *psi.*

crusher fines—finely crushed or powdered material (gravel, silt, and clay), but not necessarily in the correct ratio for adobe-brick production; an engineering term for the clay- and silt-sized soil particles (diameters less than 0.074 mm) passing U.S. Standard Sieve Mesh Number 200.

curing—a time period during which the action of water in a stabilized soil mass causes the mass to be cemented together by the stabilizer (Wolfskill et a1.,1970).

detrital—pertaining to or formed from detritus; the term is often used to indicate a source from outside the depositional basin.

dry-bulb temperature—a measure of the air's cooling capacity.

durability—the resistance of a material to weathering and **erosion.**

earthquake—a sudden motion or trembling in the earth caused by abrupt release of slowly accumulated strain (by faulting or by volcanic activity).

effective U-value—value determined (in masonry-mass walls) as a factor of the resistance to the transfer of heat and of the capacity to hold heat.

eolian—pertaining to the wind.

erosion—the physical and chemical processes by which a material is removed, including the processes of weathering, mechanical wear, and transportation of the material.

gypsum—common evaporite mineral ($CaSO_4 \cdot 2H_2O$) used in making plaster of paris.

Hans Sumpf brick-molding machine—patented by **H.** C. **Sumpf** of Fresno, California, in 1946; the self-propelled, hydraulically operated adobe layer is capable of producing 25 4 x 10 x 14-inch adobe bricks per laydown; five machines were in use in New Mexico in 1995.

Holocene (Recent)—the interval of geologic time since the retreat of the last intercontinental ice sheets from North America and Eurasia, roughly 10,000 years ago to the present; also, the rocks and deposits formed during that time.

illite—a general name for a group of three-layer, mica-like clay minerals, relatively high in potassium with no expanding lattice characteristics.

impermeable—the ability of a material to restrict the flow of seepage of water to a negligible amount (Wolfskill et al., 1970).

I/S—mixed-layer illite-smectite with either fixed amounts of illite to smectite (ordered) or variable amounts (random)

jacal—a framework of vertical wooden poles and branches covered and bound together with **mud.**

kaolinite—a common two-layered aluminum-rich clay mineral and group with the chemical composition (Al4Si4O10(OH)8).

kiln—an oven, furnace, or heated enclosure used for processing bricks by burning or firing.

loam—a rich, permeable soil composed of a crumbly mixture of relatively equal and moderate proportions of clay, silt, and sand particles, and usually containing organic matter; it usually implies fertility; topsoil.

mechanized technique of adobe-brick production—the use of powered mixers, front-end loaders, and mechanical adobe layers to produce adobe bricks on a large scale.

micrometer—a unit of length equal to one-thousandth of a millimeter; symbol **pm.**

mineralogy—the science of the study of minerals.

mixed-layer clay minerals—a random or ordered interstratification of clay-mineral groups; generally interstratification of nonexpanding and expanding layer lattices such as illite and smectite (I/S) or chlorite and smectite.

modulus of rupture—a physical-property measure indicating the relative cohesion of the materials that make up the adobe and the ability of the material to resist tension or shear forces, usually expressed in *psi.*

moisture content—the amount of water contained in soil material expressed as the weight of the water divided by the weight of the dry soil material in percent (Wolfskill et al., 1970).

molding forms—a single or multiple mold of a particular size usually made of wood into which the mixed adobe soil is placed to produce a uniform brick.

mortar—a material used in a plastic state which can be troweled and which becomes hard in place to bond together building blocks.

mosque—a temple of worship in the religion of Islam.

New Mexico Building Code—used in conjunction with **the** broad principles outlined in the *Uniform Building Code;* this set of amendments was adopted in its most recently revised form by the New Mexico Construction Industries Division in 1982 (revised 1988, 1991, and 1993); the local code addresses construction concerns about building materials and conditions specific to the State of New Mexico; regulations concerning the use of adobe are handled in Section 2413 of the most recent code.

pallet—a flat wooden board base used to stack and store adobe bricks, designed to permit a forklift to lift the adobes and pallet on and off a flatbed truck.

pediment—a gently sloping plain at the foot of a mountain range in an arid region, usually covered with a veneer of *alluvium.*

pedogenic—pertaining to soil formation.

piedmont plain—a broad, continuous slope or gently inclined detrital surface extending along and from the base of a mountain range out, into, and around a basin, formed by the coalescence of a series of separate but confluent alluvial fans; a bajada.

pisé-(from the French) "pisé-de-terre" meaning rammedearth-type adobe construction (Wolfskill et al., 1970).

plasticity—the ability of a moist soil to be deformed and hold its shape; this indicates that the soil has cohesion and contains clay-size particles (Wolfskill et al., 1970).

Pleistocene—the older of two epochs in the *Quaternary,* from about 2 million years to 10,000 years ago; also, the rocks and deposits formed during that time.

pressed-earth block—a type of adobe brick made from *traditional* or *stabilized adobe* material pressed into dense bricks of various sizes using either a hydraulically operated gasoline- or diesel-powered machine or a hand-operated press (the CINVA-Ram).

psi—pounds per square inch (lbs /inch^2).

puddled adobe—adobe mud patted by hand into a wall shape without the use of wooden forms.

pugmill—machine in which materials (such as clay and water) are mixed, blended, or kneaded into a desired consistency.

Quaternary—the interval of geologic time from about 2 million years ago to the present, consisting of the *Pleistocene and Holocene (Recent)* epochs; also, the rocks and deposits formed during that **time.**

quemado (burnt adobe)—a sun-dried adobe brick that has undergone a modified low-firing process.

radon—a colorless, odorless, heavier-than-air, radioactive gas that is derived directly from the breakdown of radium-226 (Ra), one in a chain of radioactive elements produced from the radioactive decay of uranium-238 (238u).

rammed earth—damp or moist earth that is tamped into a wall between temporary, movable forms (Middleton, 1987); also known as *pisé* construction.

R-value—a measure of the ability to retard heat flow, rather than the ability to transmit heat; R is the numerical reciprocal of U, thus R = 1/U; R is used in combination with numerals to designate thermal-resistance units (R-11 equals 11 resistance units); the higher the R, the higher the insulating factor; all insulation products having the same R-value, regardless of material and thickness, are equal in insulating value (New Mexico Energy Institute, 1977).

sand—individual rock or mineral fragments in a soil that range in diameter from 0.05 to 2 mm (Folks, 1975); in this report, the sand size ranges in diameter from 0.0625 to 2 mm.

sand+—individual rock or mineral fragments coarser than 0.0625 mm (sand-and-larger-size particles).

seismically active area—a region that may be affected by earthquakes or earth vibrations.

semimechanized **technique of adobe-brick production—a** method similar to the traditional handcrafted method of adobe-brick production except for the use of some mechanical equipment—usually a front-end loader and a series of ladder molding forms.

semistabilized adobe—classified as a water-resistant adobe brick because of the addition of a small amount of asphalt emulsion (4 wt% or less).

shrinkage—the decrease in volume of soil material caused by evaporation of water (Wolfskill et al., 1970).

silt—individual mineral particles in a soil that range in diameter from the upper limit of clay (0.004 mm) to the lower limit of fine sand (0.05 mm; Folks, 1975); in this report, the silt size ranges in diameter from 0.002 mm (2 pm) t° 0.0625 mm.

slurry—a mixture of soil and water that results in a soupy liquid that is easily poured into wooden molding forms or is used as mortar.

smectite—common clay-mineral group consisting of three layer units with high expanding interunit positions and large cation exchange capacity

stabilization—the improvement of soil properties by the addition of materials which will either cement the soil, waterproof the soil, or reduce volume changes (Wolfskill et al., 1970).

stabilized adobe—the fully stabilized adobe (referred to by the *New Mexico Building Code* as a "treated adobe); defined as containing a sufficient amount of stabilizer to limit a brick's water absorption to less than 4 wt% in seven days.

stabilizer—a material such as asphalt emulsion, portland cement, lime, or one of many other chemicals that is added to *adobe soil* to waterproof or increase the weathering resistance of an adobe brick, pressed-earth block, or rammed-earth wall.

steady-state condition—the state when heat energy is passing uninterrupted from one side of the wall to the other at a constant rate.

strength—the ability of a material to resist applied forces; the strength of a soil mix is normally considered the strength in shear stress and is expressed in *psi* (Wolfskill et al.,1970).

terrace—one of a series of level surfaces in a stream valley, elongated parallel to the stream channel, representing the dissected remnant of an abandoned floodplain or valley floor produced during a former state of erosion or deposition.

terrón-(from the Spanish) meaning "a flat clod of earth"; the type of adobe brick made of cut sod or turf material found in the floodplain areas of the Rio Grande.

Tertiary—the interval of geologic time from about 66 to 1.6 million years ago; also, the rocks and deposits formed during that time.

traditional adobe—an untreated, sun-dried adobe made with soil composed of a uniform mixture of clay, sand, and silt; usually straw is added to the *adobe soil.*

traditional handcrafted technique of adobe-brick production—the process of making adobe bricks by hand, without the use of any mechanized equipment.

turtle-back adobe—adobe mud formed by hand into turtle-like shapes on the ground, allowed to dry, and then placed into a wall.

U-value—coefficient of heat transmission expressed in units of BTU per ft^2/hr /F (the time rate of heat flow); the U-value applies to combinations of different materials used in a series along the heat-flow path, such as single materials that comprise a building station, the air-space cavities, and the surface-air film on both sides of the building element (New Mexico Energy Institute, 1977).

Uniform Building Code—a standard code of building specifications established by the International Conference of Building Officials and adopted by local construction regulating agencies in most states; the code is founded on broad-based performance principles and is dedicated to the development of better building construction and greater public safety through the establishment of uniform building laws.

water absorption—the taking in of water into a soil mass (Wolfskill et al.,1970).

APPENDIX 1
Particle-size and clay-size-mineralogy analyses

Particle sizes (sand +, silt, and clay) and minerals of the clay-size fraction (particles less than 2 micrometers or <2 µm) of adobe bricks, pressed-earthblocks, and rammed-earth production materials in New Mexico (1988). Clay-mineral analyses are semiquantitative (parts in 10). **I/S,** mixed-layer illite/smectite; **tr,** trace amount; **–**, not present; **—**, did not produce product in 1995; * in earth materials business in 1995; **NA**, not available.

	Map no. (Fig. 1 and Table 4)	Particle-size percentages			Clay minerals					Other minerals in clay-size fraction in order of abundance
		Sand+	Silt	Clay	Smectite	I/S	Illite	Kaolinite	Chlorite	
A. D. Adobe Co.	—	85	13	2	4	1	3	2	–	quartz and calcite
*Adobe Factory	1	76	9	15	1	5	2	2	–	quartz and calcite
*Adobe International	A	69	22	9	3	tr	2	5	–	calcite and quartz
*Adobe Bricks of New Mexico	14	81	16	3	6	1	2	1	–	calcite
Adobes Unlimited	—	67	31	2	1	2	3	4	–	calcite
*Aguires Services	15	52	45	3	1	3	2	3	1	quartz and calcite
*Big "M" Sand & Cinder	2	34	60	6	3	2	2	3	–	quartz and calcite
Corrections Industries	—	54	40	6	–	3	3	4	–	quartz
(resample)	—	59	36	5	2	3	3	2	–	calcite and quartz
*Coyote Adobe Inc.	D	72	24	4	3	3	2	2	–	calcite, quartz, and feldspar
*DeLaO Adobe Brick Mfg	3	71	21	8	1	4	3	2	–	calcite and quartz
*Eloy Montano Sand & Gravel	4	61	35	4	2	2	3	3	–	calcite and quartz
Gallegos Sand & Gravel	—	84	10	6	2	4	1	3	–	calcite
*Habitat for Humanity (Santa Fe)	B	NA	NA	NA	NA	NA	NA	NA	NA	
*Huston Construction Company	⊗	68	25	7	1	4	3	2	–	calcite
(resample)		69	25	6	2	4	2	2	–	calcite and quartz
Jaquez Construction (*Santa Fe Adobe)	—	69	26	5	2	2	1	5	–	calcite and quartz
Paul Martinez	—	55	36	9	1	4	2	3	–	quartz and calcite
*Ralph Mondragon	16	54	42	4	1	5	1	3	–	calcite and quartz
*Gilbert Montano	5	NA	NA	NA	NA	NA	NA	NA	NA	
Nambé Pueblo	—	40	55	5	2	2	4	2	–	quartz and calcite
*New Mexico Earth	6	78	18	4	2	4	1	1	2	quartz and calcite
*Leroy Otero	7	NA	NA	NA	NA	NA	NA	NA	NA	
*Philip Otero	8	NA	NA	NA	NA	NA	NA	NA	NA	
*Simon Otero	9	NA	NA	NA	NA	NA	NA	NA	NA	
Pojoaque Pueblo	—	57	37	6	3	4	2	1	–	calcite
Picuris Pueblo	—	41	55	4	3	3	2	2	–	calcite and quartz
Pueblo of Isleta Adobe and Cinder Enterprise	—	89	10	1	2	3	2	3	–	calcite and quartz
(resample)	—	89	10	1	2	3	2	3	–	calcite and quartz
Ridge Adobe	—	71	24	5	tr	3	3	4	–	quartz, feldspar, and calcite
*Rio Abajo Adobe	11	77	21	2	1	1	2	6	–	quartz and calcite
Archie Rivera	—	83	15	2	1	3	3	3	–	quartz, calcite, and feldspar
Jim Rivera	—	60	31	9	1	2	1	6	–	quartz
Rodriguez Brothers	17	63	30	7	1	4	3	2	–	quartz and calcite
Steve Romero	—	77	19	4	4	2	2	2	–	calcite and quartz
Roman Sandoval	—	27	68	5	1	3	3	3	–	quartz
*Santa Fe Adobe (Jaquez Construction)	C	NA	NA	NA	NA	NA	NA	NA	NA	
Candelario Saucedo	—	66	26	8	2	2	2	4	–	calcite and quartz
*Soledad Canyon Earth Building	⊕	NA	NA	NA	NA	NA	NA	NA	NA	
*Sol Systems Adobe	10	73	20	7	2	4	2	2	–	calcite, quartz, and feldspar
Carl & Lorraine Steiner	—	55	37	8	1	4	2	3	–	quartz and calcite
The Adobe Farm	—	50	41	9	2	3	2	3	–	quartz
The Adobe Patch	—	80	18	2	tr	2	5	3	–	calcite, dolomite, and quartz
Tim's Adobes	—	81	8	11	1	4	3	2	–	calcite and quartz
Elias Vargas	—	83	16	1	1	4	4	1	–	quartz and calcite
*Trini Velarde	12	48	47	5	2	3	2	3	–	calcite and quartz
*Western Adobe	13	83	13	4	2	4	1	3	–	calcite and quartz

APPENDIX 2
Physical properties of adobe bricks and pressed-earth blocks

For any building project, certain minimum requirements or specifications have been developed regarding the durability, strength, thermal characteristics, and fire safety of the construction materials (Long and Neubauer, 1946). In New Mexico, the building of adobe structures is regulated by specifications adopted from the Uniform Building Code and the New Mexico Building Code. The section on unburned clay masonry (Section 2413) of the New Mexico Building Code is detailed in Appendix 3 and lists the basic requirements for adobe bricks, pressed-earth blocks, and rammed-earth walls. Included are standards of compressive strength, modulus of rupture, and water resistance, as well as construction specifications.

The New Mexico Building Code requires that adobe bricks have an average compressive strength of 300 psi (pounds per square inch). This standard assures that all units from the tested-brick batch will resist a compressive force equal to 300 lbs for each square inch of surface area. The importance of this test for a relatively heavy material such as adobe is apparent when considering the great amount of weight a typical wall unit must resist.

Another major test required on all types of adobe bricks, pressed-earth blocks, and rammed-earth walls is the modulus of rupture test. This test helps indicate the relative cohesion of the materials that make up the various earth blocks and walls and the ability of those materials to resist the tension or shear forces that may result from settling of foundations, earthquakes, or wind forces.

Other tests used on semistabilized and stabilized adobe bricks and pressed-earth blocks determine the water-resistance quality of the bricks. The New Mexico Building Code requires that, for a treated (stabilized) adobe brick, the mois ture content and the water absorption not exceed 4 wt%.

The code requires that samples of all bricks to be tested should be selected at random at a ratio of 5 units/25,000 bricks. Usually the selected bricks are from the same pro duction batch, to assure a more representative range of values. The major tests that are usually completed by various commercial testing companies or by the United Nuclear Rock Mechanics Laboratory at the New Mexico Institute of Mining and Technology, Socorro, New Mexico, are described below.

Compressive strength

In order to provide the necessary flat and smooth loading planes for this test, the adobes are capped with plaster of paris. Upon drying the adobe samples are placed in a standard hydraulically operated testing machine between two flat loading plates (Fig. 100). A loading rate of approximately 500 psi per minute is then applied to the plates. The compressive strength is calculated from the maximum load sus tained before the brick shows evidence of failure.

Modulus of rupture

To establish the rupture strength of the adobe, a three-points loading method is used. A dry brick is placed symmetrically on two supporting parallel pipes 2 inches in diameter that extend across the full width of the adobe. A third 2-inch pipe is placed on top of the brick midway between and parallel with the lower supports (Fig. 101). The load is applied to the top pipe at a rate of 500 psi per minute using a static loading device until the rupture occurs.

Water absorption

Four-cubic-inch adobe specimens are cut from all the bricks being tested and are dried at 140°F (60°C) to a constant weight. Upon cooling the specimens are placed on a water-saturated surface in the moisture cabinet (Fig. 102). The weight gain from the absorbed water after seven days is determined and recorded as a percentage of the dry weight.

Moisture content

Four-cubic-inch adobe specimens are first weighed and then dried to a constant weight. Moisture content is then calculated as the percentage of weight change relative to the dry weight (Fig. 103).

Simple field tests

In New Mexico, generally the small-scale adobe producers and builders have developed several simple techniques to evaluate the physical properties of adobes:

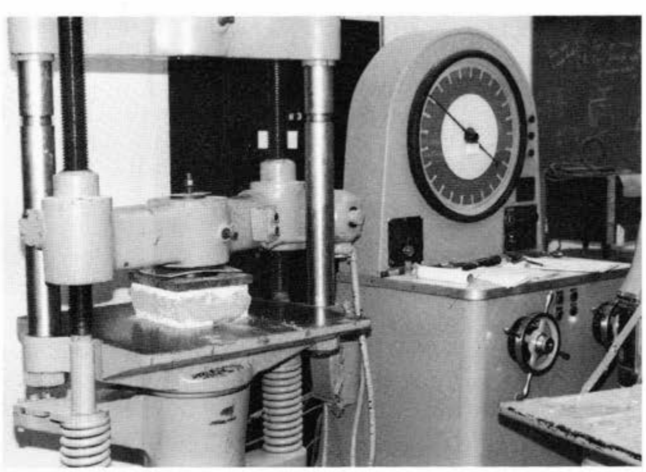


FIGURE 100—Adobe brick loaded between fixed and hemispherical mounting of hydraulically powered machine for compressive-strength test.

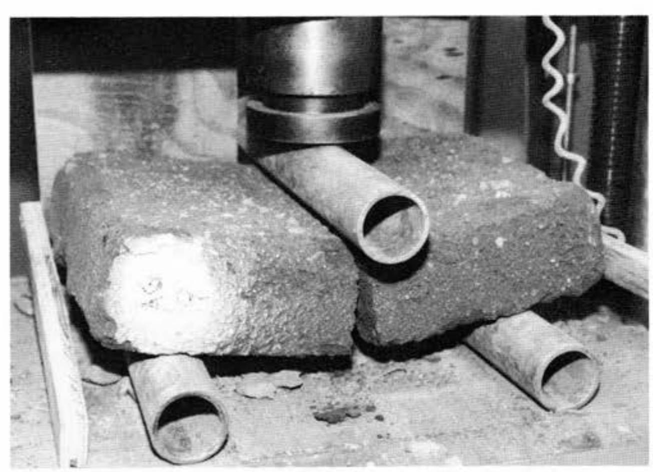


FIGURE 101—Three-points loading method used on typical adobe brick to establish rupture strength.

FIGURE 102—Four-cubic-inch adobe brick samples on wet, porous surface in moisture cabinet for water absorption test.

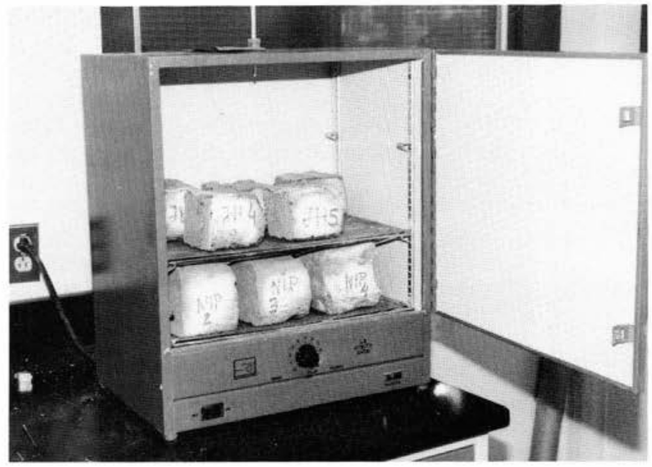


FIGURE 103—Four-cubic-inch adobe-brick samples drying for moisture content determination.

(1) For the compressive-strength test, various owners of adobe yards have been known to drive their cars, pickups, and, in some cases, their front-end loaders atop a series of adobes.

(2) The drop test or modulus of rupture test is outlined in McHenry's (1984) publication and consists of dropping a dry brick, on its corner, onto the ground from a height of 3 ft. A good brick will sustain little damage.

(3) The test for water absorption can be determined by using the blade of a common pocket knife to penetrate a brick. An easy penetration by the blade will indicate a poor quality or not completely dry brick.

Any or all of these tests can be performed in the field to determine the general character of soil materials. Many soils that appear to be poor performers can be upgraded by adding the proper materials.

APPENDIX 3
New Mexico Building Code, Section 2413

In most regions of the United States where adobe is widely used in construction, locally adopted amendments to the Uniform Building Code establish standard building specifications. In New Mexico, specifications for adobe are covered in Section 2413 of the 1991 New Mexico Building Code; an older version was approved and adopted by the Construction Industries Committee of the New Mexico Construction Industries Division on July 22, 1977. Prior to this 1977 version, which was developed under the auspices of the adobe industry and written by a team of four New Mexican adobe experts, the section on adobe had been regarded as severely limited and inconsistent in its coverage of the material and its specifications.

The method by which building codes in general are put together combines objective data gathering with the subjective interpretation of **that** data. Information derived from extensive engineering and construction experience and statistics collected from standardized laboratory tests all contribute to the store of practical and scientific knowledge about how a material behaves under a variety of conditions. However, the transition from raw data and information to a meaningful and workable building code relies on an interpretive and analytical process and ultimately on the quality of judgment of those individuals who produce the final written code.

Adobe codes have traditionally suffered from deficiencies in both areas of objective data gathering and subjective interpretation of the data. Until 1982, the amount of "official" data concerning adobe had been quite small relative to that of many other building materials.

Among the major revisions in the 1977 edition of the New Mexico Building Code were the legalization of untreated (traditional) adobes, already used throughout the state, and the removal of the requirement that buildings constructed with sufficiently stabilized adobe and mortar be coated with some other protective substance. In addition, many other minor revisions were included, such as the allowance of the use of wooden "gringo" blocks and soil for mortar, as well as changes in the required thicknesses of load-bearing walls.

The second revision of the adobe code was approved in 1983. The revision recognized stabilized adobes, untreated adobes, hydraulically pressed units (pressed-earth blocks), terrónes, burned adobes (quemados), and rammed earth. In the 1988 revision, characteristics of hydraulically pressed units (pressed-earth blocks) were qualified; a curing period of 14 days and physical-property tests were recommended. In addition, the allowed percentage of water absorption for stabilized adobes was increased from 21/2 to 4 wt%.

Section 2413 of the New Mexico Building Code (Construction Industries Division, 1991) is reprinted below in its entirety. Any further questions concerning the code should be addressed to the Construction Industries Division, Bataan Memorial Building, Santa Fe, New Mexico 87503 (telephone: 505 /827-6251).

Chapter 24 - Masonry

Unburned Clay Masonry (Adobe)

Sec. 2413.

(a) **General:** Masonry of unburned clay units shall not be used in any building more than two (2) stories in height. The height of every wall of unburned clay units without lateral support shall be not more than ten (10) times the thickness of such walls. Exterior walls, which are laterally supported with those supports located no more than 24 feet apart, are allowed a minimum thickness of 10 inches for single story and a minimum thickness of 14 inches for the bottom story of a two story with the upper story allowed a minimum thickness of 10 inches. Interior bearing walls are allowed a minimum thickness of 8 inches. Upward progress of walls shall be in accordance with acceptable practices.

(b) **Soil:** The best way to determine the fitness of a soil is to make a sample brick and allow it to cure in the open, protected from moisture. It should dry without serious warping or cracking. A suitable adobe mixture of sand and clay shall contain not more than two (2) percent of water soluble salts.

(c) **Classes of Earthen Construction:**

1. **Stabilized Adobes:** The term "stabilized" is defined to mean water resistant adobes made of soils to which certain admixtures are added in the manufacturing process in order to limit the adobe's water absorption. Exterior walls constructed of stabilized mortar and adobe require no additional protection. Stucco is not required. The test required is for a dried four (4) inch cube cut from a sample unit and shall absorb not more than *four* (4) percent moisture by weight when placed upon a constantly water saturated porous surface for seven (7) days. An adobe unit which meets this specification shall be considered "stabilized."

2. **Untreated Adobes:** Untreated adobes are adobes which do not meet the water absorption specifications. Use of untreated adobes is prohibited within 4 inches above the finished floor grade. Stabilized adobes and mortar may be used for the first 4 inches above finished floor grade. All untreated adobe shall have an approved protection of the exterior walls.

3. **Hydraulically Pressed Units:** Sample units must be prepared from the specific soil source to be used. Production units must be cured for a period of *fourteen (14) days prior placement.* The building official may require *additional* test *procedures outlined in paragraphs D, G, H,* and *I at his discretion.*

4. **Terrones:** The term terrone shall refer to cut sod bricks. Their use is permitted if units are dry and the wall design is in conformance with this code.

5. **Burned Adobe.** The term "burned adobe" shall refer to mud adobe bricks which have been cured by low temperature kiln firing. This type of brick is not generally dense enough to be "frost proof" and may deteriorate rapidly with seasonal freeze-thaw cycles. Its use for exterior locations is discouraged in climate zones with daily freeze-thaw cycles.

6. **Rammed Earth.**
   a. **Soils:** See Section 2413 (b).
   b. **Moisture Content:** Moisture content of rammed earth walls shall be suitable for proper compaction.
   c. **Forms:** Suitable forms shall be used.
   d. **Lifts and Compaction:** Uncompacted damp soil shall be compacted in lifts not to exceed six (6) inches until suitable compressive strength is achieved.
   e. **Tests:** Testing of rammed earth construction shall be in accordance with approved standards.
   f. **Curing:** The building officials may allow continuous construction of rammed earth prior to the full curing process, provided proper compaction methods are followed.

(d) **Sampling:** Each of the tests prescribed in this section shall be applied to sample units selected at random at a ratio of 5 units/25,000 bricks to be used or at the discretion of the building official.

(e) **Moisture Content:** The moisture content of untreated units shall be not more than four (4) percent by weight.

(f) **Absorption:** A dried four (4) inch cube cut form a sample unit shall absorb not more than four (4) percent moisture by weight when placed upon a constantly water saturated porous surface for seven (7) days. An adobe unit which meets this specification shall be considered "stabilized."

(g) **Shrinkage Cracks:** No units shall contain more than three shrinkage cracks, and no shrinkage crack shall exceed two (2) inches in length or one-eight ($^1/8$) inch width.

(h) **Compressive Strength:** The units shall have an average compressive strength of 300 pounds per square inch when tested. One sample out of five may have a compressive strength of not less than 250 pounds per square inch.

(i) **Modulus of Rupture:** The unit shall average 50 pounds per square inch in modulus of rupture when tested according to the following procedures:

1. A standard 4 4x10x14 cured unit shall be laid over (cylindrical supports two (2) inches from each end and extending across the full width of the unit.

2. A cylinder two (2) inches in diameter shall be laid midway between and parallel to the supports.

3. Load shall be applied to the cylinder at the rate of 500 pounds per minute until rupture occurs.

4. The modulus of rupture is equal to: 3WL/2Bd2

   W = Load of rupture
   L = Distance between supports

B = Width of brick
d = Thickness of brick

(j) Mortar: The use of earth mortar is allowed if earth mortar material is of same type as the adobe bricks. Conventional lime/sand/cement mortar of Types M, S, N are also allowed. Mortar "bedding" joints shall be full SLUSH type, with partially open "head" joints allowable if surface is to be plastered. All joints shall be bonded (overlapped) a minimum of four (4) inches.

(k) Use: No adobe shall be laid in the wall until fully cured.

(l) **Foundations:** Adobes may not be used for foundation or basement walls. All adobe walls, except as noted under Group M Buildings, shall have a continuous concrete footing at least eight (8) inches thick and not less than two (2) inches wider on each side that support the foundation walls above. All foundation walls which support adobe units shall extend to an elevation not less than six (6) inches above the finish grade.

Foundation walls shall be at least as thick as the exterior wall. Where perimeter insulation is used, a variance is allowed for the stem wall width to be two (2) inches smaller than the width of the adobe wall it supports. Alternative foundation systems shall be approved by the building official.

All bearing walls shall be topped with a continuous belt course or tie beam (except patio walls less than six (6) feet high above stem).

(m) **Tie Beams:**

1. **Concrete:** Shall be a minimum of six (6) inches thick by width of top of wall. A bond beam centered to cover 2/3 of the width of the top of the wall by six (6) inches thick shall be allowed for walls wider than 24 inches. All concrete tie beams shall be reinforced with a minimum of two (2) No. 4 reinforcing rods at each floor and ceiling plate line. All bond beam construction shall be in accordance with accepted engineering practices.

2. **Wood Tie Beam:** Shall be a minimum of six (6) inch wall thickness except as provided for walls thicker than 10 inches above. Wood tie beams may be solid in the six (6) inch dimension or may be built up by applying layers of lumber. No layer shall be less than one (1) inch nominal thickness. The building official shall approve all wooden tie beams for walls thicker than ten (10) inches.

(n) Wood Lintels: Shall be minimum in size six (6) inches by wall width. All ends shall have a wall bearing of at least twelve (12) inches. All lintels, wood or concrete, in excess of nine (9) feet shall have specific approval of the building official.

(o) Anchorage: Roof and floor structures will be suitably anchored to tie beams. Wood joists, vigas, or beams shall be spiked to the wood tie beams with large nails or large screws.

Fireplaces shall be secured to the wall mass by suitable ladder reinforcement such as "durowall" or equivalent.

Partitions of wood shall be constructed as specified in Chapter 25 of the 1991 Uniform Building Code, wood and metal partitions may be secured to nailing blocks laid up in the adobe wall or by other approved methods.

(p) Plastering: All untreated adobe shall have all exterior walls plastered on the outside with portland cement plaster, minimum thickness seven-eighths (7/8) inches. Protective coatings other than plaster are allowed, provided such coating is equivalent to portland cement plaster in protecting the untreated adobes against deterioration and/or loss of strength due to water. Metal wire mesh minimum 17 gauge by one-and-a-half (11/2) inch opening shall be securely attached to the exterior adobe wall surface by nails or staples with minimum penetration of one-and-a-half (11/2) inches. Such mesh fasteners shall have a maximum spacing of sixteen (16) inches from each other. Alternative plastering systems shall be approved by the building official.

EXCEPTION:

1. Exterior patio, yard walls, etc. need not have portland cement coating.

(q) Floor Area: Allowable floor area shall not exceed that specified under Occupancy. Adobe construction shall be allowed the same area as given in Type V-N construction.

(r) Wall Insulation: All methods of wall insulation shall comply with the manufacturer's recommendations.

(s) Stop Work: The building inspector shall have the authority to issue a stop work order if the provisions of this Section are not compiled with. (See Section 202 (b) of this code.)

Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, μm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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Nancy Gilson

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Rebecca J. Titus

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