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EFFECT OF SOIL TEXTURE UPON THE PHYSICAL CHARACTERISTICS OF ADOBE BRICKS

By

Harold C. Schwalen

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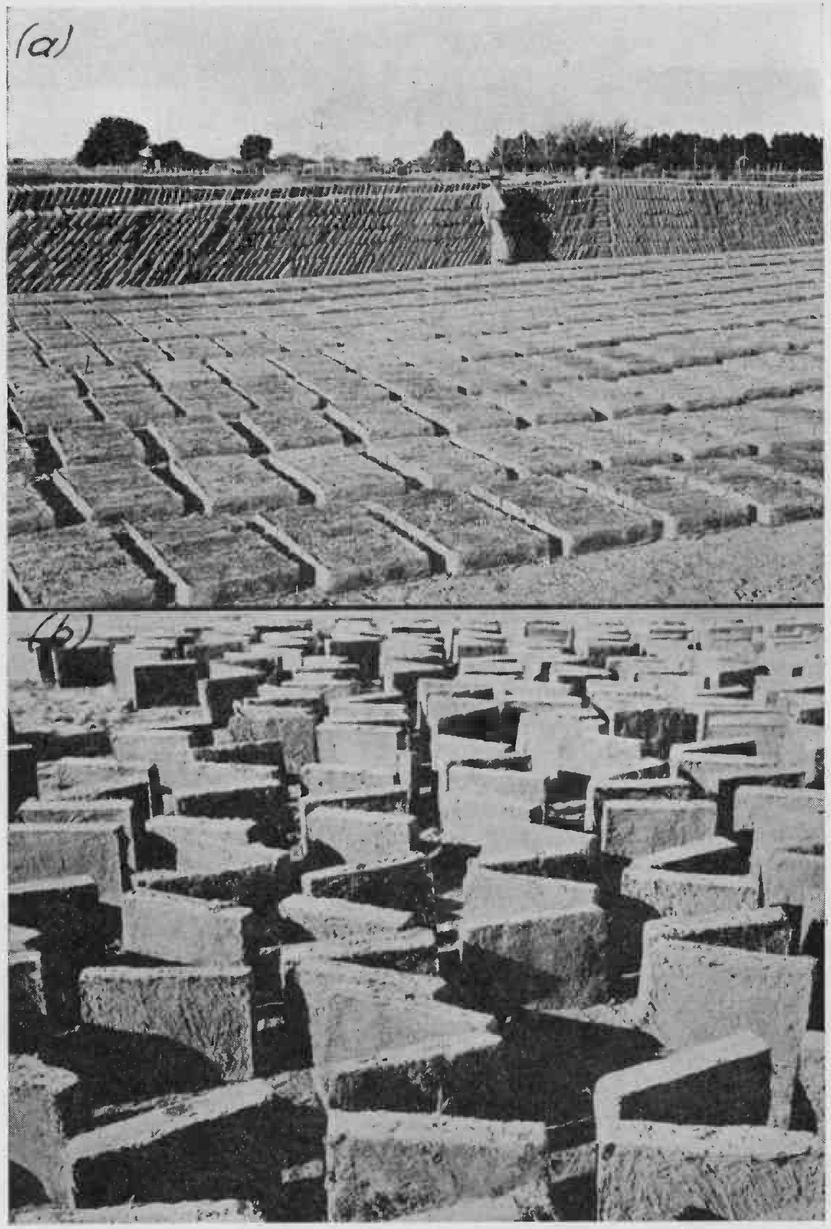
INTRODUCTION

The use of adobes for building purposes, which has increased greatly in the Southwest during the past two years, may be attributed in large measure to the fact that it meets particularly well the requirements of the various work relief programs. Equipment expense and cost of materials are almost negligible in the making of adobes, and presumably skilled labor is not required. Likewise their use in private construction has been greatly stimulated by the low costs of making and laying adobes at this time. Adobes are usually made and laid in the wall by workmen under contract at so much per thousand adobes. A very low standard of wages results since the men doing this kind of work are usually not connected with any of the building trades organizations nor are they protected by any of the codes for fair practice.

One of the work relief projects set up was on the University of Arizona Farm near Tucson, in which thirty thousand adobes were required for building purposes. The soil at the construction site is a Gila sandy loam (9), and from a casual inspection it was apparent that it was not suitable when used alone for making adobes because of its relatively low clay content. A heavier soil, Pima clay loam (9), was hauled from another part of the farm to the building site and there mixed with the local soil in making adobes. Both of these soils are comparatively recent alluvial bottom land soils. The Gila sandy loam is somewhat lighter in color than the dark grayish brown Pima clay loam, and also has a lower percentage of organic matter.

The original plan was to mix the two soils in the ratio of two parts of the heavier Pima clay loam to one part of the Gila sandy loam. In practice, however, this ratio was not adhered to, since the larger the proportion of the heavier soil the more difficult and laborious was the work of mixing the mud, handling it, and molding the adobes in the forms. As a result there was a constant tendency on the part of the workmen to increase the proportionate amount of the lighter sandy loam soil, and the



Photos by W. E. Bryan.

Plate I.—Adobes on the University of Arizona Farm made from a mixture of approximately 50 per cent Pima clay loam and 50 per cent Gila sandy loam. (a) Adobes drying on the ground about twenty-four hours after being molded, and stacked in the customary manner for complete curing. (b) Adobes turned on edge to promote a more uniform drying.

average mixture is believed to contain less than 50 per cent of the Pima clay loam. Part of the adobes are shown in Plate I drying on the ground and curing in the stacks.

DESCRIPTION OF MATERIAL USED IN TEST ADOBES

The adobes made on the University Farm were not of first quality and for comparative purposes a series of test adobes was made with different mixtures of these soils and also of other soils used locally in the making of adobes. Test lots of adobes were made of mixtures of the two soils used on the University Farm, with mixtures of the Pima clay loam and varying amounts of a coarse arroyo sand, of a reddish brown soil classified as Tucson loam (gravelly), of a brownish colored mesa soil classified as Pinal gravelly stony loam, and a highly calcareous, grayish brown local soil classified as Pinal sandy loam (9). The three last named soils are older terrace or mesa soils with calcareous subsoils, and the two Pinal soils are underlaid by a caliche (4) hardpan within a foot of the surface (Plate II). The arroyo sand consists of angular grains of which about 60 per cent are quartz and the remainder felspar with a trace of mica and iron. The soils and soil mixtures, which are expressed in percentages

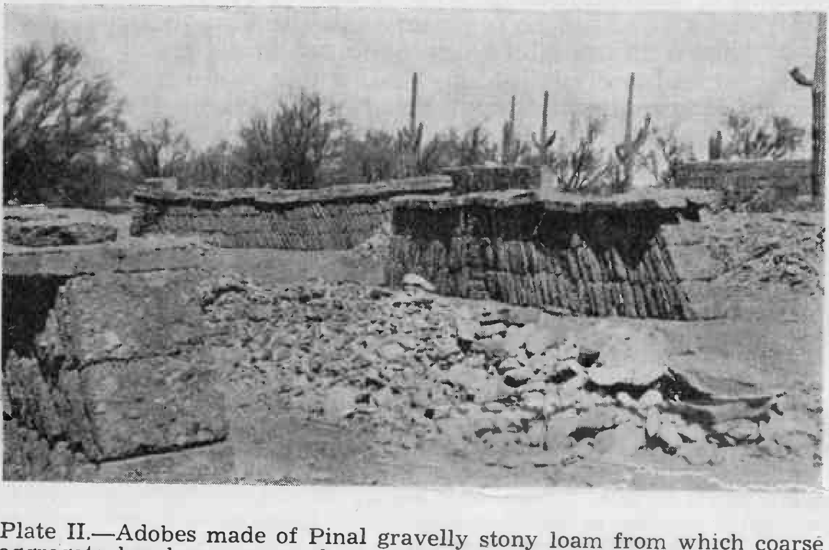


Plate II.—Adobes made of Pinal gravelly stony loam from which coarse aggregate has been screened out. Note that a large part of the waste consists of grayish white chunks of the caliche hardpan. This material represents about the extreme in coarse aggregate which may be used in making adobe. Lot 10 of the test adobes was made from this material, but more of the coarse aggregate was removed than in the case of those shown above.

by weight, used in making the test adobes are listed below with their corresponding lot numbers.

Lot 1. Pima clay loam, 100% (made by a different molder than the remaining test lots)
Lot 2. Pima clay loam, 100%
Lot 3. Pima clay loam, 57%; Gila sandy loam, 43%
Lot 4. Pima clay loam, 40%; Gila sandy loam, 60%
Lot 5. Pima clay loam, 83%; arroyo sand, 17%
Lot 6. Pima clay loam, 67%; arroyo sand, 33%
Lot 7. Pima clay loam, 55%; arroyo sand, 45%
Lot 8. Pinal sandy loam (calcareous), 100%
Lot 9. Tucson loam (gravelly), 100%
Lot 10. Pinal gravelly stony loam, 100% (screened)

With the exception of the soil used in Lot 8 mechanical analyses were made of all the soils, and the results are shown graphically in Figure 1 for the soils and soil mixtures used in the test lots. The analysis of another sample of Tucson loam (gravelly), No. 9a, which has been used by a local contractor in the construction of several large adobe houses, has also been included in Figure 1. In making the mechanical analyses the clay and silt fractions were determined by the hydrometer method (3) and the larger-size separates were made with a set of standard Tyler screens. The classification of the size of soil particles according to the diameter of grain is that of the U. S. Bureau of Soils and should not be confused with the same terms as used by engineers in describing aggregate for concrete.

A chemical analysis[1] of the Pinal sandy loam used in Lot 8 showed it to consist of 33 per cent of calcium carbonate. Because of this high calcium carbonate content a mechanical analysis of this soil by the methods used was not reliable, therefore no comparison can be made with the other test lots. A considerable portion of the tightly cemented calcareous sand and clay, which in preparation for mechanical analysis is finely divided, remains in the form of coarse aggregate in the adobe mud.

METHOD USED IN MAKING TEST ADOBES

Twelve full-size adobes of the nominal size 12 by 18 by 3½ inches were made of each of the ten test lots. Full-size adobes were made in an effort to obtain specimens for test purposes which would be the same as the adobes in common use. They were made four at a time in a single form constructed of 1-inch surfaced lumber in which the dividers between adjacent adobes had a net thickness at the top of ¾ inch and at the bottom 11/16 inch, allowing the forms to be lifted without distorting the edges of the adobes. With the exception of Lot 1, the adobes

[1]Chemical analysis by J. A. Williams, Agricultural Chemistry Department, University of Arizona.

were all made by the same two experienced adobe men working together.

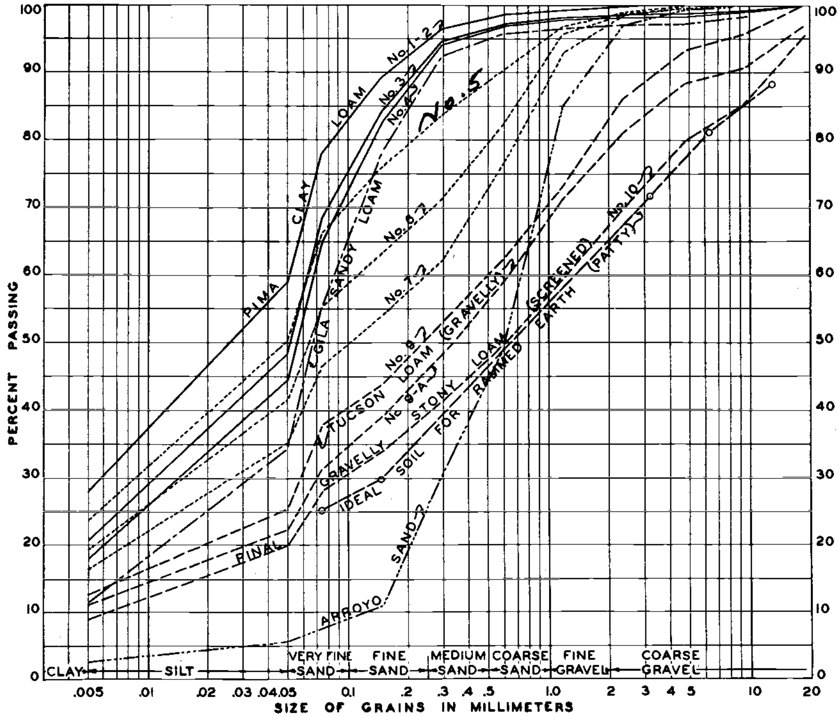


Figure 1.—Curves showing the results of mechanical analyses of soils and soil mixtures used in making test adobes. Curves No. 1-2 and No. 10 mark the approximate upper and lower limits of soils from which adobes can be made. The curve marked "Patty" was found ideal for rammed earth walls.

The soil used in making the adobes was wet for at least eighteen hours previous to mixing the mud, and the arroyo sand, when used, was added in a dry condition. The soils were thoroughly mixed in an ordinary mortar box and the straw spread uniformly over the surface. Water was added slowly with continued mixing until the plasticity desired by the molders was secured. From the practical standpoint the correct consistency of the mud should be such that it is sufficiently stiff to keep the adobe from slumping out of shape when the forms are lifted, and at the same time it must be wet enough to knead into the corners of the forms without difficulty. The addition of only a small amount of water to the mud will make a comparatively large change in its consistency. For example, the mud used in Lot 1 appeared to contain much more water than that used in Lot 2; the adobes in the former slumped when the forms were removed so that the sides of the adjacent adobes touched. The actual difference in the moisture content of the two muds was found to be but little over 1 per cent. However, most of the adobe contractors use the wetter mix, since the speed with which adobes can be made is somewhat increased, although the quality of the adobes is impaired with respect to shape and uniformity of appearance.

It is interesting to note that the moisture content of the samples taken at the time the adobes were made was from 1 to 5 per cent more than the computed moisture content of the saturated materials based upon an assumed specific gravity of 2.65.

The amount of straw ordinarily used in making adobes varies between one and three bales, of about 60 pounds each, per thousand adobes. Wheat straw at the rate of 122 pounds per thousand adobes (as nearly as was possible) was used in making the test adobes. Since the quantity of mud required to make twelve adobes varied somewhat with the different materials and mixtures, the amount of straw used is not exactly the same for all the test lots. In the process of mixing, the straw was broken up so that the longest pieces were not over 5 or 6 inches in length.

The adobes were made on a level ground surface which was covered with Sisalkraft paper to prevent the native soil from sticking to the bottom of the adobes. The adobes were carefully struck off across the top of the forms with a straightedge and the forms lifted vertically by a man at each end. They were left lying flat on the ground for two days to dry partially, and then turned up on edge. Five days after they had been made they were numbered and piled in stacks to cure. The adobes were made on May 5, 1934, and the mean maximum temperature during this month was 96.2 degrees F., reaching a maximum of 106 degrees F. Cured under these rather severe temperature conditions in the direct rays of the sun, they should be comparable to those used in common building practice. Adobes cured more slowly in the shade would undoubtedly be much less affected by shrinkage cracking.

PHYSICAL CHARACTERISTICS

By the end of May the adobes were thoroughly dried or cured, at which time they were weighed, measured, and the amount of shrinkage in volume was computed. Samples were taken of the mud at the time the adobes were made and also from the dry adobes and the moisture contents determined. The data giving the variation in weight, amount of straw, percentage of moisture, and average size of the different adobe lots have been summarized in Table 1.

From Table 1 it may be seen that lots 1, 2, 3, and 4 are approximately equal in volume weight, moisture content when made, and in moisture content after curing. However, a significant

TABLE 1.—WEIGHT AND SIZE OF ADOBES, AMOUNT OF STRAW, PERCENTAGE OF MOISTURE, AND VOLUME SHRINKAGE IN DIFFERENT TEST LOTS.

Lot number	Weight of straw per 1000 adobes	Average weight per adobe	Weight per cubic foot	Moisture content when made	Moisture content of cured adobe	Size of cured adobe	Volume shrinkage in curing
	lbs.	lbs.	lbs.	%	%	inches	%
1	108	41.7	103.3	30.8	....	11⅞ x 17¾ x 3-5/16	7.7
2	131	42.2	102.5	29.6	2.7	11⅞ x 17¾ x 3⅜	6.0
3	128	43.9	102.8	28.8	2.6	12 x 17⅞ x 3-7/16	2.4
4	115	43.2	102.3	29.3	2.7	12 x 18 x 3⅜	3.6
5	122	45.9	108.0	23.9	2.7	11-15/16 x 17⅞ x 3-7/16	2.9
6	125	48.2	110.6	20.9	2.0	12 x 17-15/16 x 3½	0.4
7	122	51.6	118.7	18.2	1.5	12 x 17⅞ x 3½	0.7
8	122	43.1	100.3	29.9	2.8	11⅞ x 17⅞ x 3½	1.7
9	122	54.0	124.6	14.3	1.6	11-15/16 x 17-15/16 x 3½	0.8
10	129	52.0	119.9	14.6	1.8	11-15/16 x 17-15/16 x 3½	0.8
Average	122	46.6	109.3	24.0	2.3		2.7

difference occurs in volume shrinkage, given in column 8, in which lots 3 and 4 have much lower values than lots 1 and 2. This may be attributed to the lower clay and colloidal content of lots 3 and 4. In lots 5, 6, and 7 the addition of the arroyo sand to the Pima clay loam resulted in increased volume weight, decreased moisture content in the adobe mud, and in lower volume shrinkage. Lot 8, with a calcium carbonate content of 33 per cent, has the lowest volume weight, and although its moisture content when made was high the volume shrinkage was low in comparison with lots 1 to 5, inclusive. In curing, Lot 8 appeared to undergo a slacking process with partial disintegration rather than shrinkage as a unit. Lot 9, made up of a well-graded aggregate, had the highest volume weight and lowest moisture content at the time it was made. Lot 10 had a lower volume weight than Lot 9, which is believed to be due to a less well-graded aggregate particularly lacking in the finer grained particles.

COMPRESSIVE STRENGTH

Apparently there is a lack of published data available upon the compressive strength of adobes used in commercial building practice. Long (5) has reported that adobes from a twenty-year-old building in Brawley, California, had an average compressive strength of 109.5 pounds per square inch and that samples from the century-old Mission San Antonio de Padua at Jolon, California, averaged 260 pounds per square inch. The size of the specimens tested was not given. The same investigator (6) determined the compressive strength of small test specimens of six soil series, ranging from a sandy loam to a silty clay loam, which were mixed with various moisture contents and tamped damp or worked in a plastic condition into the molds. Their compressive strengths ranged from a minimum of 60 to a maximum of 785 pounds per square inch, and those specimens mixed with a mud consistency had an average value of more than twice that of the damp, tamped earth. The specimens, judging from the illustration given, were made in the form of cylinders about 2 inches in diameter and 4 inches in height.

Compressive tests of rammed earth blocks composed of admixtures of sand and gravel to fine-grained soils are reported by Long (6) and by Patty and Minium (8) in which increased strength resulted from the mixture. The partial mechanical analysis of a soil designated by the latter authors as almost perfect for rammed earth construction has been plotted on Figure 1 for comparison with the adobe test soils. It would appear to be unsuited for making adobes being deficient in fine material and clay binder. It had the highest volume weight, 138.87 pounds per cubic foot after being rammed, of any of the soils they used. Both investigators found that the admixture of straw in the tamped earth specimens increased the compressive strength.

Bodkin (2), in New Mexico, working with a Gila clay loam, a soil similar to the Pima clay loam on the University Farm, found that flocculation decreases the binding power of the colloids and that deflocculation increases it. Compression tests of 2-inch cubes of the untreated soil, which had a moisture content of 30 per cent when worked into the molds, gave values of between 437 and 538 pounds per square inch. The moisture content of this soil in a saturated condition is almost identical with that used in making the test adobes with the Pima clay loam and the greater strength in compression is probably due in part to the better curing conditions found in the laboratory.

Tests for strength of adobes in compression and flexure were made in an Olsen[2] 100,000-pound testing machine, according to the specifications of the American Society for Testing Materials, C67-31, Standard Methods of Testing Bricks (1), with the exception that the size of the test specimens was larger. Samples tested in compression were cut to 6 by 6 inches in cross section and the thickness varied between 3 and 3½ inches. The variation in thickness was due in large measure to the difference in the shrinkage of the test lots of adobes. The top and bottom surfaces of the test blocks were dressed down with a wood rasp, where it was necessary, to make them approximately parallel. The cutting of the test specimens to the 6- by 6-inch size required the least amount of work while the preparation of smaller-sized specimens would have been difficult without breaking them in the cutting process. This was particularly true in the case of the adobes containing coarse aggregate such as Lot 9 and Lot 10. A rough saw with teeth about ½ inch in length, made of 16 or 20 gauge galvanized iron was found most effective in cutting the adobes.

Ten specimens, of which two were cut from each of five adobes selected from each test lot, were tested for compressive strength. In general, the test specimens were cut from those portions of the individual adobes in which shrinkage cracks were absent or as nearly absent as was possible. The results of these tests, therefore, represent approximately the upper limits in strength and not the average. The results of the compression tests have been summarized in Table 2, in which is also given the lowest value found in each series of specimens together with its percentage deviation from the average value for the test lot. It is believed that the results are as consistent as might be expected in tests of material of the nature of adobes.

From the pieces of adobe left after cutting out the 6- by 6-inch test specimens, three 4- by 4-inch test blocks were cut from each test lot and tested in compression for the purpose of comparison

[2]In the testing laboratory of the Department of Civil Engineering, University of Arizona.

TABLE 2.—SUMMARY OF THE RESULTS OF COMPRESSION TESTS OF 6- BY 6-INCH SPECIMENS OF ADOBES.

Lot number	Average compressive strength	Minimum compressive strength	Deviation from average
	lbs. per sq. in.	lbs. per sq. in.	%
1	353	270	23.5
2	411	382	7.1
3	332	282	15.1
4	382	356	7.0
5	359	290	19.2
6	419	346	17.4
7	422	346	18.0
8	358	316	11.7
9	544*	510	6.2
10	410	327	20.2
Average	399	342	14.3

*Nine specimens only.

with the tests of larger blocks. The results are somewhat inconsistent but no more than might be expected from the testing of such a small number of specimens. The comparative results given in Table 3 show that the average compressive strength of the 6- by 6-inch specimens, due to the effect of lateral confinement, is approximately 10 per cent greater than the 4- by 4-inch specimens of the same thickness.

TABLE 3.—COMPARATIVE RESULTS OF COMPRESSION TESTS OF 6- BY 6-INCH AND 4- BY 4-INCH SPECIMENS OF ADOBES.

Lot number	Average compressive strength		Excess of 6-in. over 4-in. size
	6 x 6 in.	4 x 4 in.	
	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
1	353	351	2
2	411	306	105
3	332	349	−17
4	382	315	67
5	359	363	− 4
6	419	378	41
7	422	385	37
8	358	278	80
9	544	517	27
10	410	329	81
Average	399	357	42

TRANSVERSE STRENGTH

The transverse strength of adobes is comparatively low and no allowance is made for it in ordinary building practice, because of the unreliability of the material with reference to shrinkage cracks. The computed modulus of rupture of short test beams of rammed earth, without straw, reported by Patty and Minium (8) was 37 pounds per square inch, with a corresponding strength in compression for the same material of 325 pounds per square inch. The admixture of oat and flax straw to the same soil, in an amount equal to one half that which would cause bunching, resulted in increased compressive strengths of 429.6 and 381 pounds per square inch respectively. Adobes having about the same compressive strength as the rammed earth with straw have an average modulus of rupture of almost twice that mentioned above. It appears probable that the inclusion of straw in the adobe is the most important single factor in its resistance to flexure although the differences in the straw content of the various test lots was too small to show any correlation with the quantity of straw used. Specimens for the tests in flexure were cut 6 by 12 inches in size from selected portions of the adobes as free from cracks as possible. In some of the test lots the modulus of rupture for the whole adobes would have been much lower than for the specimens tested. This would apply particularly to lots 1 and 2, in which shrinkage cracking was rather severe and yet specimens for the tests were cut out, which were comparatively free from cracks.

After a number of trial tests it was decided to use only a 7-inch span between supports in this test, the same span as is specified for the brick tests. The strength of the adobe in flexure is so low that the longer span was not considered advisable. From the flexure tests the modulus of rupture R has been computed by the formula $R=\frac{3\ WL}{2\ bd^2}$ and the results are summarized in Table 4.

TABLE 4.—SUMMARY OF FLEXURE TESTS OF ADOBES.

Lot number	Modulus of rupture		Deviation from average
	Average	Minimum	
	lbs. per sq. in.	lbs. per sq. in.	%
1	63	52	17.5
2	64	41	35.9
3	85	66	22.4
4	75	62	17.3
5	64	40	37.5
6	78	60	23.1
7	73	64	12.3
8	29	24	17.2
9	88	74	15.9
10	54	48	12.5
Average	67	53	21.2

NOTE: Results are averages of tests of five or more specimens from each test lot of adobes, except Lot 8 from which only four specimens were available.

RESISTANCE TO WASHING

The principal disadvantage of the use of adobe for building purposes is not, however, in its comparatively low strength, but in its susceptibility to washing from rain. The damage caused by small rivulets running down the side of the walls is fully as great as that due to the direct action of the rain impinging against them. In the case of unprotected walls the ability to withstand washing is therefore a quality of particular importance in adobes.

Photo by W. E. Bryan.

Plate III.—Exterior adobe walls protected by a cement plaster applied over nailed abodes. Four eightpenny nails were driven in each adobe and countersunk with about ¼ inch of the head of the nail exposed. Buildings in the background have been finished with a white brush coat over the plaster.

The general practice is to plaster exterior adobe walls for protection against rain, and to make the plaster stick to the walls a number of different methods which are more or less successful are used. Among these may be listed the following: nailing of adobes, scoring of walls, raking out mortar joints, laying adobes with lime mortar, chinking small fragments of brick or angular rock in fresh mortar joints, covering walls with 1-inch chicken wire mesh or metal lath, and using adobes made with a special plaster keyway. A cement plaster on nailed adobe walls was used on the University Farm buildings (Plate III). To a limited extent, painting with brush coats of whitewash, crankcase drainings, liquid asphalt, cement wash, linseed oil, and outside lead and oil paints are used. Of this group the linseed oil and house paint appear to be the only coverings which give promise of being semipermanent. Recently an emulsified asphalt product, developed primarily for subgrade stabilization (7), has been used by mixing it with the adobe mud in proportion to the fine material contained in the soil aggregate. Adobes made in this manner are said to be relatively impervious to the action of water.

Since there still remained a few of the adobes from each of the test lots, a special washing test was devised by which the face of the adobes was subjected to the spray from a shower head as shown in Plate IV. From the illustration it may be seen that the face of the adobe is sloping away from the spray head so that the drip will soak up the lower edge of the adobes as little as possible. The actual impact of the spray upon the face of the adobe was circular, with a diameter of approximately 7 inches. Water was supplied to the shower head[3] under a uniform pressure of 10 pounds per square inch, discharging at the rate of 5.7 gallons per minute, for a period of six minutes followed by a one minute rest interval and then by a final one minute wash period.

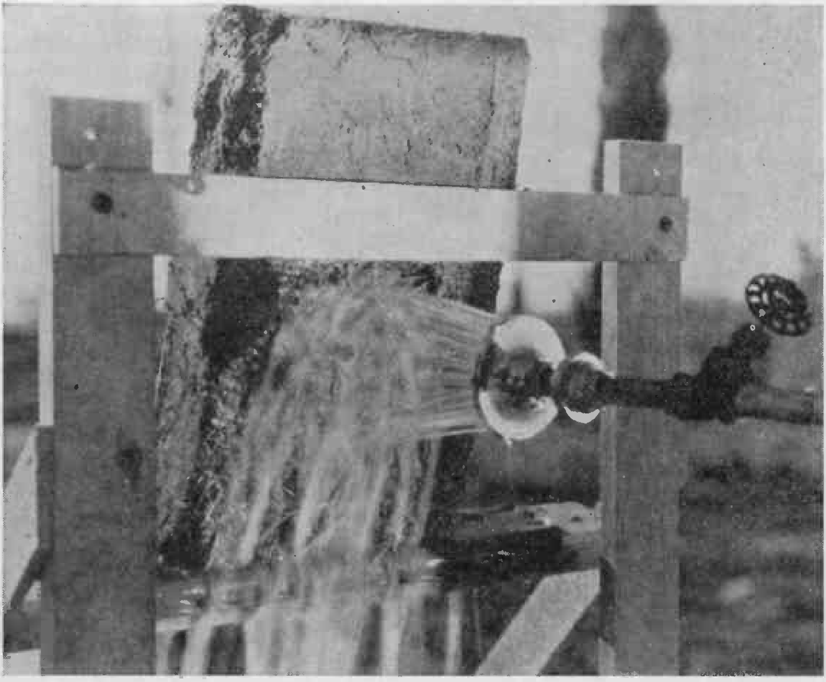


Photo by W. E. Bryan.

Plate IV.—Arrangement of the shower-head spray for washing tests. The pressure of the shower head was kept at 10 pounds per square inch. Adobe in the testing rack is from Lot 9. Note the rubber gasket arrangement at the bottom to prevent soaking of lower edge of adobe.

Each adobe was weighed, in air-dry condition, to the nearest ½ ounce previous to the wash test, and again after it had dried out, the second weighing being made twenty-four hours following the wash test. It was found that those adobes which had been wet on the ends from rain while in the stacks had ap-

[3]Ampinco shower head, 4½-inch size, factory no. 12364.

parently undergone air slacking, the erosion of the faces of these adobes being visibly more rapid than that of the others. Effects of washing were likewise more pronounced along the edges of shrinkage cracks, but were not serious except where the cracks extended through the adobes, in which cases the effects of washing were greatly accelerated, proceeding rapidly along the crack on the rear face of the adobes.

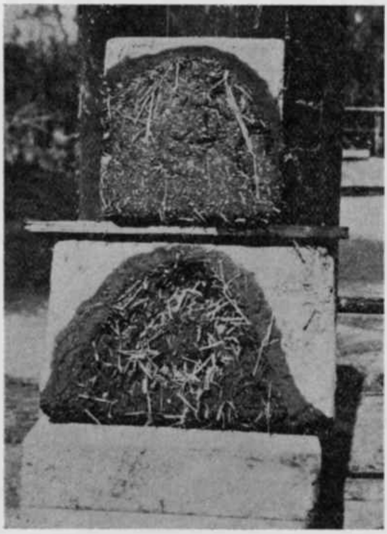


Plate V.—Results of preliminary washing test on adobes, upper adobe from Lot 7 and lower adobe from University of Arizona Farm stack. The melting away of the adobe at the lower edge of the latter is clearly shown.

The results of two of the trial washing tests are shown in Plate V in which the melting away at the lower edge is well illustrated. The water running down over the surface appears to have as much erosive action as does the direct action of the force of the spray. Representative specimens of the adobes showing the results of the washing test are shown in Plate VI, each adobe being numbered according to the test lot in which it belongs. Lot 1 is not represented since all of the adobes from this lot were destroyed before the picture was taken. Particular attention is directed to adobes 2 and 8 which show clearly the effect of the wash spray where contraction cracks are present. The cracks extend only part way through adobe number 2, while they extend completely through adobe number 8, which by the end of the test was badly disintegrated. Adobes number 9 and number 10 in Plate VI show clearly the coarse aggregate contained in them. The summary of the results of the washing tests is given in Table 5.

Although only a few specimens were available for testing it is believed that the results given in Table 5 are fairly representative of the comparative resistence to washing of the different adobes. If the results for Lot 2 are taken as a basis for comparison, then the addition of coarse sand has produced a marked improvement in the resistance to washing. Lot 6 was the most resistant of all the lots; Lot 5 with lower sand content and Lot 7 with higher sand content showed less resistance than Lot 6. The addition of the Gila sandy loam to the Pima clay loam resulted in an adobe with less resistance than the latter alone. Lot 8 showed an abnormally low resistance to washing due prin-

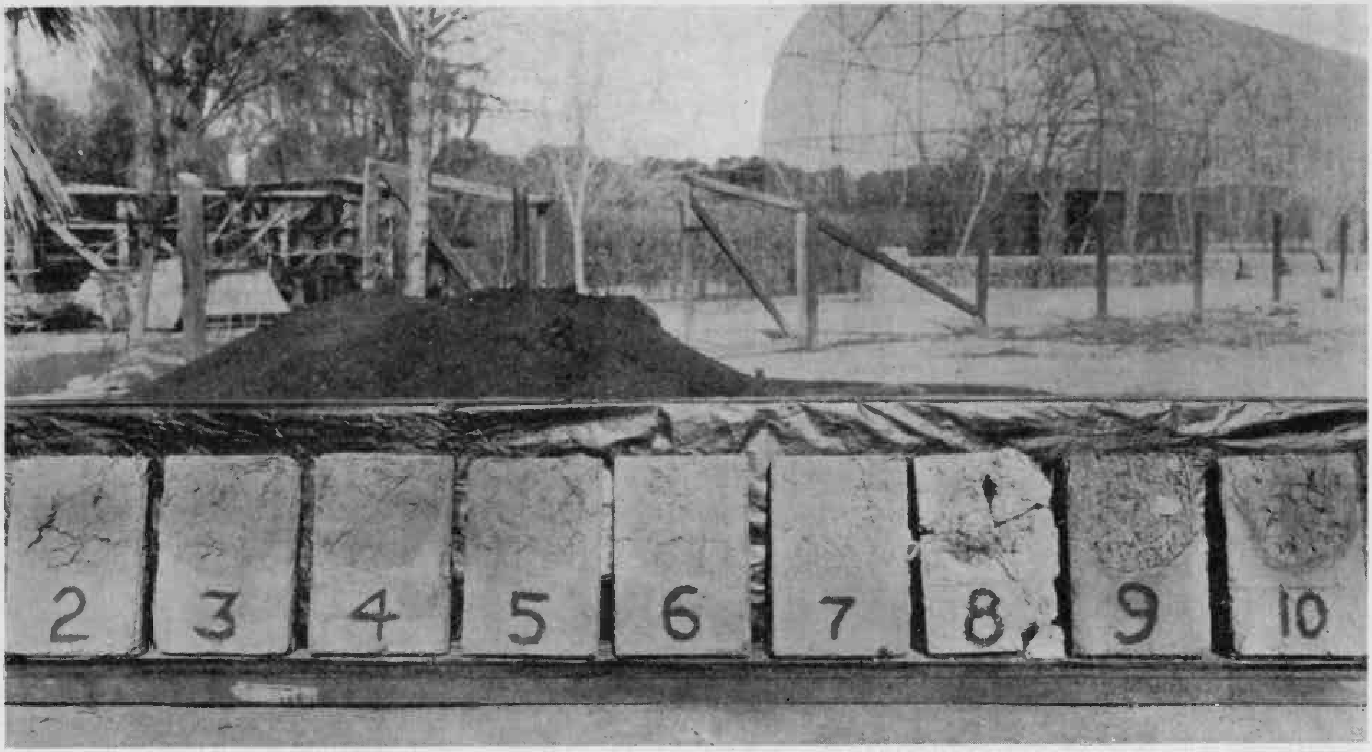


Plate VI.—Results of the washing tests showing the comparative loss of material from the different adobe lots. Note the effect of shrinkage cracks in No. 2 and the almost complete disintegration of No. 8. The coarse aggregate in adobes 9 and 10 may be clearly seen.

cipally to shrinkage cracks, however a satisfactory adobe may be made with this material by the addition of coarse sand and gravel.

TABLE 5.—SUMMARY OF RESULTS OF WASHING TESTS OF ADOBES.

Lot number	Total number of adobes tested*	Average loss in pounds per adobe*	Number adobes of average quality tested	Average loss in pounds per adobe
1	3	3.19	2	3.01
2	4	3.07	3	2.69
3	4	3.42	3	3.21
4	3	4.63	2	3.92
5	2	2.38	2	2.38
6	4	1.46	4	1.46
7	5	1.86	4	1.69
8	2	7.39	2	7.39
9	6	4.51	4	3.33
10	4	3.02	4	3.02
Average†	35	3.06	28	2.74

*Includes some adobes which are defective through one cause or another and of lower quality than average.

†Lot 8 not included in average.

SUMMARY AND CONCLUSIONS

The selection of an adobe for building purposes cannot be made solely upon the basis of its strength in compression or flexure and its resistance to washing. Other qualities of much practical importance are the amount and seriousness of shrinkage cracking, the ability to withstand rough handling (toughness), and uniformity of size and shape. For these last-named qualities there are no definite standards for comparison or methods to measure their value. As a means of summarizing the results of the tests and the observations which were made, a table has been prepared in which the test lots of adobes have been rated according to their relative values for each of the qualities mentioned above.

It will be noted that column 8, Table 6, in which the relative value of the different test lots of adobes has been summarized, is based entirely upon the placings in the six preceding columns and that equal weight has been given to each of the qualifications considered. No attempt was made to correct for the variation which may exist in the intervals between the successive ratings in any one column of qualifications.

Lot 9, made of Tucson loam (gravelly), with a well-graded aggregate giving the largest volume weight and a low clay content with corresponding low shrinkage ratio, was unquestionably the best of the adobes tested, in spite of its relatively low resistance to washing. The mixtures of Pima clay loam with the coarse sand in lots 7, 6, and 5 are placed second, third, and fourth respectively. Ranking fifth is Lot 10 made of the Pinal gravelly stony loam (screened), which from all indications was lacking only in a small percentage of clay to keep it from being on a par with Lot 9. Of all the adobes made, Lot 8, due to shrinkage and apparent air slacking, was the only one found totally unfit for use. Lots 1 and 2 are placed next to the bottom of the list and should be classed as unsatisfactory for building purposes principally because of excessive shrinkage cracking.

TABLE 6.—COMPARATIVE RATING OF TEST LOTS OF ADOBES AS INDICATED BY COMPRESSIVE, FLEXURE, AND WASHING TESTS, AND OTHER QUALITIES UPON THE BASIS OF OBSERVATION.

Rating or placing	Cracking due to shrinkage	Uniformity of size and shape	Ability to withstand handling	Compressive strength	Flexural strength	Resistance to washing	Combined qualifications
1st	7	9	9	9	9	6	9
2nd	9	8	6	7	3	7	7
3rd	10	7	7	6	6	5	6
4th	6	10	4	2	4	2	5
5th	5	6	3	10	7	1	10
6th	4	5	5	4	2	10	4
7th	3	4	10	5	5	3	3
8th	2	3	2	8	1	9	2
9th	1	2	1	1	10	4	1
10th	8	1	8	3	8	8	8

Adobes for ordinary use, can be made from soils having a wide range in texture as is shown by the curves in Figure 1 of the mechanical analyses of the materials used in the test adobes. Within this range in soil texture are many of the Arizona soils nominally classified among the heavier sandy loams and loams, sandy clays and clay loams, together with the gravelly phases of these soil classes. Contrary to common belief the heavy clays and silty clay loams which are ordinarily called adobe soils contain much too high a percentage of clay to make satisfactory adobes. The curve No. 1-2 represents very closely the upper limit of the amount of clay in a fine grained soil from which adobes may be made. Representative of the lower limit in clay content is the gravelly sandy loam shown by curve No. 10, in which the clay fraction is only 9 per cent as compared to 28 per cent in the Pima clay loam.

To a certain extent at least the clay fraction of the aggregate used in making adobes may be compared to the cement used in concrete. With an aggregate composed entirely of fine-grained particles a comparatively high percentage of clay must be present to cement them together. Examples of soils of this type are shown by curves nos. 1-2, 3, and 4 especially, and probably those shown by curves nos. 5, 6, and 7 should be included in this group. Proportioning of the aggregate for increased strength likewise appears to follow the same law as for concrete, in that the more dense the mix, the higher the compressive strength of the adobe. This is indicated by the fact that the four lots of test adobes rating highest in the compressive tests are found in Table 1 to be those also having the greatest weight per cubic foot.

Although the experimental work with the test adobes covered only a small group of soils and soil mixtures it is believed that the following tentative conclusions are justified:

1. A soil similar to that represented by curve No. 9 in Figure 1, with well-graded aggregate, is required to produce an adobe of highest quality.
2. Adobes may be made from soils covering a wide range in texture, having a clay content varying between 9 per cent and 28 per cent depending upon the fineness of soil aggregate.
3. In general adobes made with soils of high clay content shrink greatly with resulting shrinkage cracks.
4. The addition of coarse sand to a fine-grained soil with high clay content is particularly advantageous in reducing shrinkage and increasing the resistance to washing.
5. Adobe muds have a moisture content of from 1 per cent to 5 per cent more than the computed requirements for saturation, varying from 14 to 30 per cent in the adobes tested.
6. Air-dried adobes will have a weight of from 100 to 125 pounds per cubic foot depending upon how well the soil aggregate is graded.
7. The moisture content of air-dried adobes is very low, varying from less than 1 per cent to almost 8 per cent, and is in general proportional to the clay content.
8. The average compressive strength of selected adobes made from first-class adobe material may run over 500 pounds per square inch, but a fair value for most selected adobes will be more nearly 400 pounds per square inch. The average for yard run of adobes will probably be considerably less than the latter figure.
9. The strength of adobes in compression appears to follow the same law as for concrete in that the greater the density, the higher the compressive strength.
10. The transverse strength of adobes is low and it is of importance principally in that it should be sufficient to withstand the rough handling before the adobes are laid in the wall.

The results of the observations and tests which were made, further emphasize the fact that adobes have a lower unit strength than other standard building materials. Therefore, extra precautions and care should be taken not only in the design of an adobe building, but also in the supervision of the workmanship in its construction.

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