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Physical Properities of Ellis County Adobe

William G. Read
Fort Hays Kansas State College

PHYSICAL PROPERTIES OF ELLIS COUNTY ADOBE

being

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by

William G. Read, B. S.
Fort Hays Kansas State College

Date May 15, 1948 Approved Harvey A. Zinszer
Major Professor

F. W. Albertson
Chairman Graduate Council

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INTRODUCTION

Houses made of soil have been built for centuries, but until recently the trend had been away from soil to some other building material. Now, however, adobe is again beginning to be recognized as a satisfactory, reliable building material for our time.

Recently, especially in the southwestern part of the United States, a surprising number of dwellers have turned again to earth for their building material. They are following in the footsteps of the early settlers, who constructed many missions and other buildings from sun-dried earth. Many of these buildings, although aged, are still in use or may be viewed as historical landmarks.

The adobe buildings constructed today range from small houses to impressive theological structures, one of the largest being the Cristo Rey Church in Santa Fe, New Mexico. Thus it is adobe, the oldest of building materials, that is becoming an active candidate for wide use in the house of tomorrow.

Since little work has been carried out in this part of the country on the use of modern adobe for building construction and since it is desirable to know the strength of any material used for constructional purposes, the following problem was thought worthy of investigation: To determine the physical properties of Ellis County, Kansas, adobe.

The classification or type of soil is given in table I in as full a form as was obtainable for correlation with soils of other localities. A series of four physical tests were performed: Thermal conductivity, modulus of rupture, tensile strength, and compressive strength. Principally the strength tests were performed on prescribed mixtures of soil and sand for adobe bricks (Read, 3) with varying amounts of stabilizer. The variation of strength with amount of stabilizer added was determined as well as variation of strength with different stabilizers. Tests for compressive strength and modulus of rupture were also performed on specimens with varying sand content. Thermal conductivity tests were carried out on two specimens. The specimens chosen were considered representative of all the soils tested.
In this paper it was believed feasible to take up each test in its entirety and correlate the results in a summary.

The testing procedures as set forth by the American Bitumuls Company (Technical paper, 1) and the Adobe Association (Ordinance, 2) were used when possible. In case equipment was not available to follow standard procedures, tests were improvised. In all, over 2500 samples were tested with special emphasis placed on the recommended blends of soil and admixtures for adobe bricks made with Ellis County soils as determined by B. W. Read (Read, 3).

TABLE I

SOIL TYPES*

Soil type**	Color	Hereinafter called
Crete silty clay	yellow	Crete
Boyd clay loam	yellow	Boyd
Hastings silty clay loam	dark yellow	Hastings
Tripp or Mankato silt loam	brown	Tripp
Colby or Zita silt loam	dark brown	Colby
Rokeby silty clay loam	black	Rokeby
Hall silt loam	black	Hall
Colby or Zita silt loam (red)	red	Colby (red)

*All soil samples were free of roots, leaves and trash. Sand for admixture with soil was clean and sifted through a #10 screen.

**From B. W. Read (Read, 3).

TENSILE STRENGTH

The ultimate tension or tensile strength is the maximum stress that can be applied to stretch a body without rupturing it. A material is tested for tensile strength by gradually increasing the stress until rupture or tearing apart of the material occurs. The elongation increases proportionally to the stress until the elastic limit is reached. The ratio of the unit-stress to the unit-elongation is constant until the elastic limit is reached and is called Young's modulus. After the unit-stress has exceeded the elastic limit the elongations increase more rapidly than the stresses until the ultimate tension of the material is reached (Merriman, 4).

Adobe is an inelastic material and because of this property the determination of Young's modulus requires elaborate apparatus. However to determine the tensile strength requires apparatus which may be easily improvised. A diagram of the apparatus used to perform the latter test is given in fig. 1. Special clamps, fig. 2, were made for holding the test specimens.

The stress is applied by the windlass and spring tension. With this arrangement, and the easily acquired technique of turning the windlass at the desired rate, the load can be applied at nearly a constant rate. The rate of application of the load was approximately 500 pounds per minute as prescribed by American Bitumuls Company (Technical paper, 1).

The test specimens were molded in the specially built form, fig. 3, to facilitate usage with the apparatus. It is essential that a form of this type be used since the shear modulus for adobe is less than Young's modulus (Merriman, 4). Otherwise the ends that are in the clamps would be sheared before the rupture occured in the thin part of the specimen.

In order that the mold could be slipped easily from the specimen, it was made of sheet aluminum with the inner surface polished. After the specimens were formed they were cured for at least three weeks and then dried to constant weight in an oven at 140° F. The reader is referred to the work of B. W. Read for the mixing and molding procedure used in making the test samples for all the tests. (Read, 3).

The thin parts of the samples were then squared with a fine wood rasp, as were the surfaces that fit in the clamps, to assure only a tensile force. The width and depth dimensions of the central part of each specimen were accurately measured with calipers before being tested. From the dimensions the tensile strength per square inch was calculated and the results of the various mixtures tested are recorded in table II.

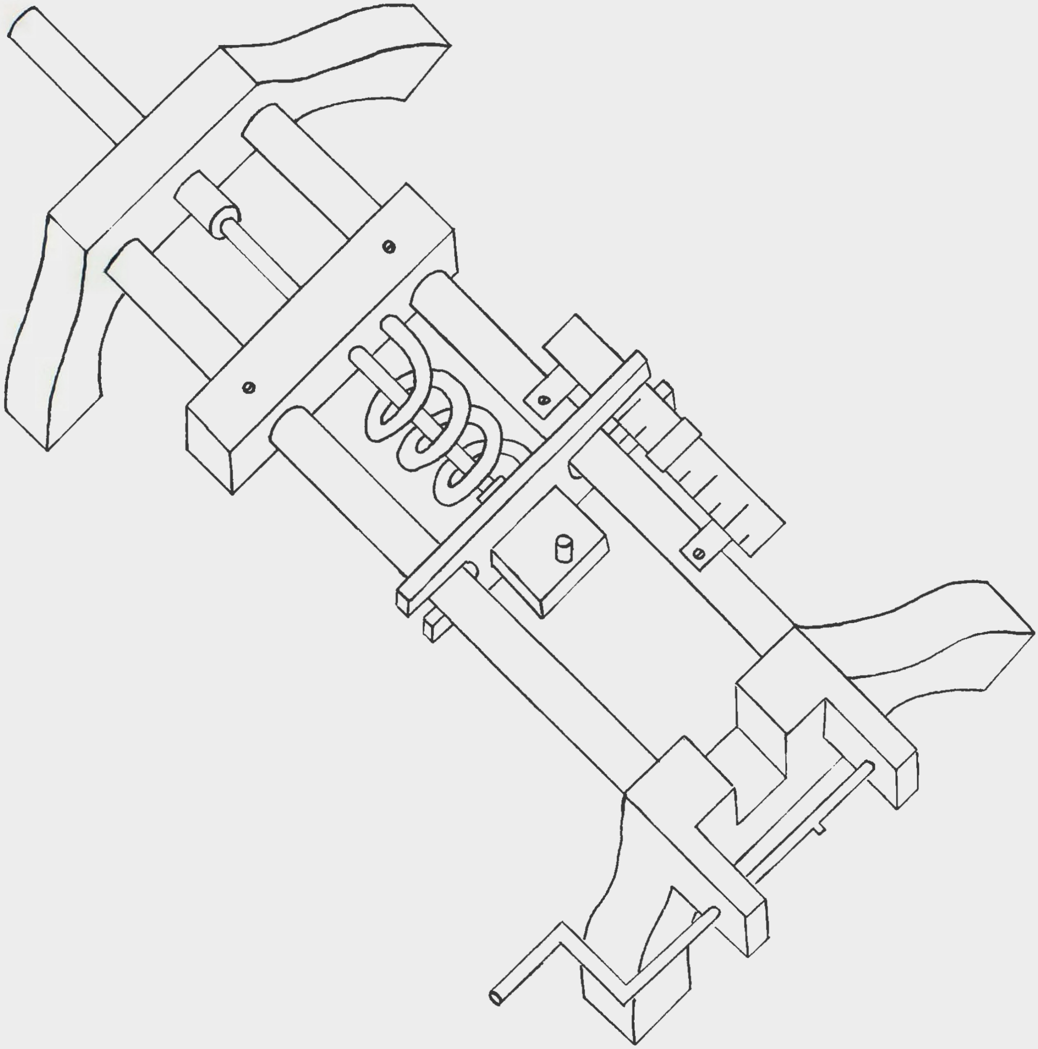

Fig. 1. Tensile strength apparatus.

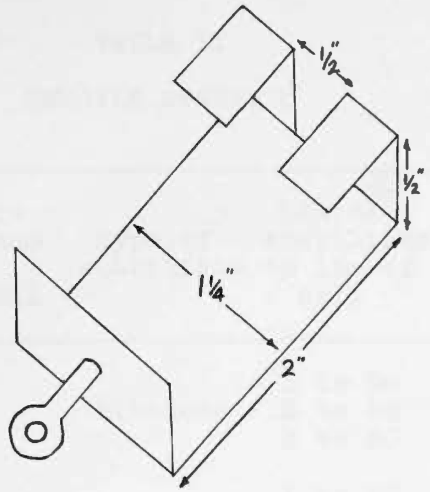

Fig. 2. _Clamps used for tensile strength tests.

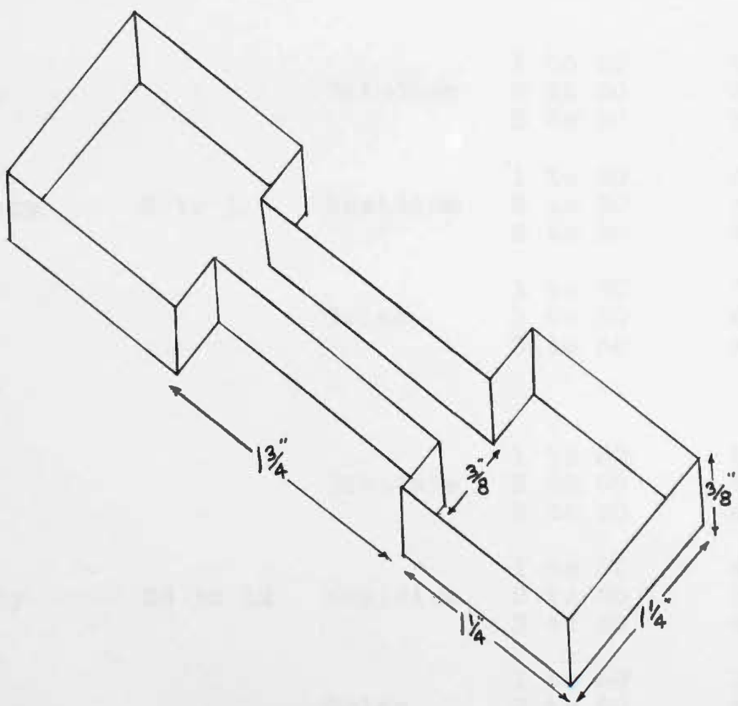

Fig. 3. _Mold for tensile strength samples.

TABLE II

TENSILE STRENGTH

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average tensile strength (lbs/in^2)
Tripp	0 to 1	Bitudobe	1 to 50	3	60
			2 to 50	4	46
			3 to 50	3	44
		Residium	1 to 50	4	48
			2 to 50	3	38
			3 to 50	3	30
		Colas	1 to 50	3	75
			2 to 50	3	55
			3 to 50	4	59
Rokeby	2 to 1	Bitudobe	1 to 50	4	40
			2 to 50	3	34
			3 to 50	3	34
		Residium	1 to 50	4	27
			2 to 50	3	23
			3 to 50	4	13
		Colas	1 to 50	3	39
			2 to 50	4	32
			3 to 50	4	22
Colby	28 to 12	Bitudobe	1 to 50	3	39
			2 to 50	4	37
			3 to 50	4	39
		Residium	1 to 50	4	26
			2 to 50	3	22
			3 to 50	4	19
		Colas	1 to 50	3	40
			2 to 50	4	34
			3 to 50	4	27

TABLE II

(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average tensile strength (lbs/in²)
			1 to 50	3	43
		Bitudobe	2 to 50	4	45
			3 to 50	4	42
			1 to 50	3	26
Hall	28 to 12	Residium	2 to 50	3	22
			3 to 50	4	19
			1 to 50	4	52
		Colas	2 to 50	4	43
			3 to 50	4	32
			1 to 50	4	47
		Bitudobe	2 to 50	4	50
			3 to 50	4	48
			1 to 50	4	33
Hastings	28 to 12	Residium	2 to 50	3	25
			3 to 50	4	21
			1 to 50	4	52
		Colas	2 to 50	4	34
			3 to 50	3	28
			1 to 50	4	38
		Bitudobe	2 to 50	4	40
			3 to 50	4	26
			1 to 50	4	28
Colby (red)	28 to 12	Residium	2 to 50	4	20
			3 to 50	4	16
			1 to 50	4	50
		Colas	2 to 50	4	33
			3 to 50	4	29

TABLE II
(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average tensile strength (lbs/in²)
			1 to 50	4	38
		Bitudobe	2 to 50	4	35
			3 to 50	4	25
			1 to 50	4	24
Boyd	3 to 1	Residium	2 to 50	4	26
			3 to 50	3	16
			1 to 50	4	34
		Colas	2 to 50	3	27
			3 to 50	4	22
			1 to 50	4	32
		Bitudobe	2 to 50	3	33
			3 to 50	4	27
			1 to 50	4	19
Crete	3 to 1	Residium	2 to 50	3	16
			3 to 50	4	15
			1 to 50	4	52
		Colas	2 to 50	4	46
			3 to 50	3	35

COMPRESSIONAL STRENGTH

The phenomena of compression are similar to those of tension provided the elastic limit is not exceeded, the shortening of the specimen being proportional to the applied force. Again after the elastic limit is passed the shortening increases more rapidly than the stress. In testing for compressional strength it is important that the length of the specimen be short. When the length is less than ten times the smaller cross-sectional dimension, failure usually occurs by an oblique splitting or shearing. If the length is large compared with the thickness, failure usually occurs under a sidewise bending, so that the case is not a simple compression (Merriman, 4).

The procedure prescribed by the American Bitumuls Company (Technical paper, 1) calls for the compression test to be made on full size bricks, or on sections squared to the shortest dimension if not less than 7½ inches. Using this procedure the length is one-half the shorter cross-sectional dimension since the full sized adobe block is usually 4 by 12 by 18 inches.

A hand operated hydraulic press was used for the compressional test, fig. 4. A cylindrical mold was used with a diameter of approximately three inches and a length of three-fourths inch. The mold was made from a #2 tin can. This small size was chosen becuase the capacity on the piston of the press was 5700 lbs per square inch. The length was chosen as such since the results obtained were to be compared with the specifications set forth by the American Bitumuls Company and the Adobe Association. It may be seen that smaller test specimens were used than recommended; however, since all values are reduced to pounds per square inch the results should still be comparable.

The specimens were allowed to cure at least three weeks and then dried to constant weight in an oven at 140° F. It is important in any compressional test that the faces be parallel to insure a uniform distribution of pressure over the surfaces (Merriman, 4). Thus before the samples were tested each was rasped so that the flat faces were parallel. (It was found that no matter how carefully the specimens were molded the faces had to be squared. The reason for this was that the mold seldom could be removed with a vertical motion. Also there was a tendency for the mixture to cling to the mold.) The diameter of each specimen was measured with calipers before being placed in the press. The pressure was applied at approximately 500 lbs per minute. The compressional force per square inch was calculated and the results are recorded in table III.

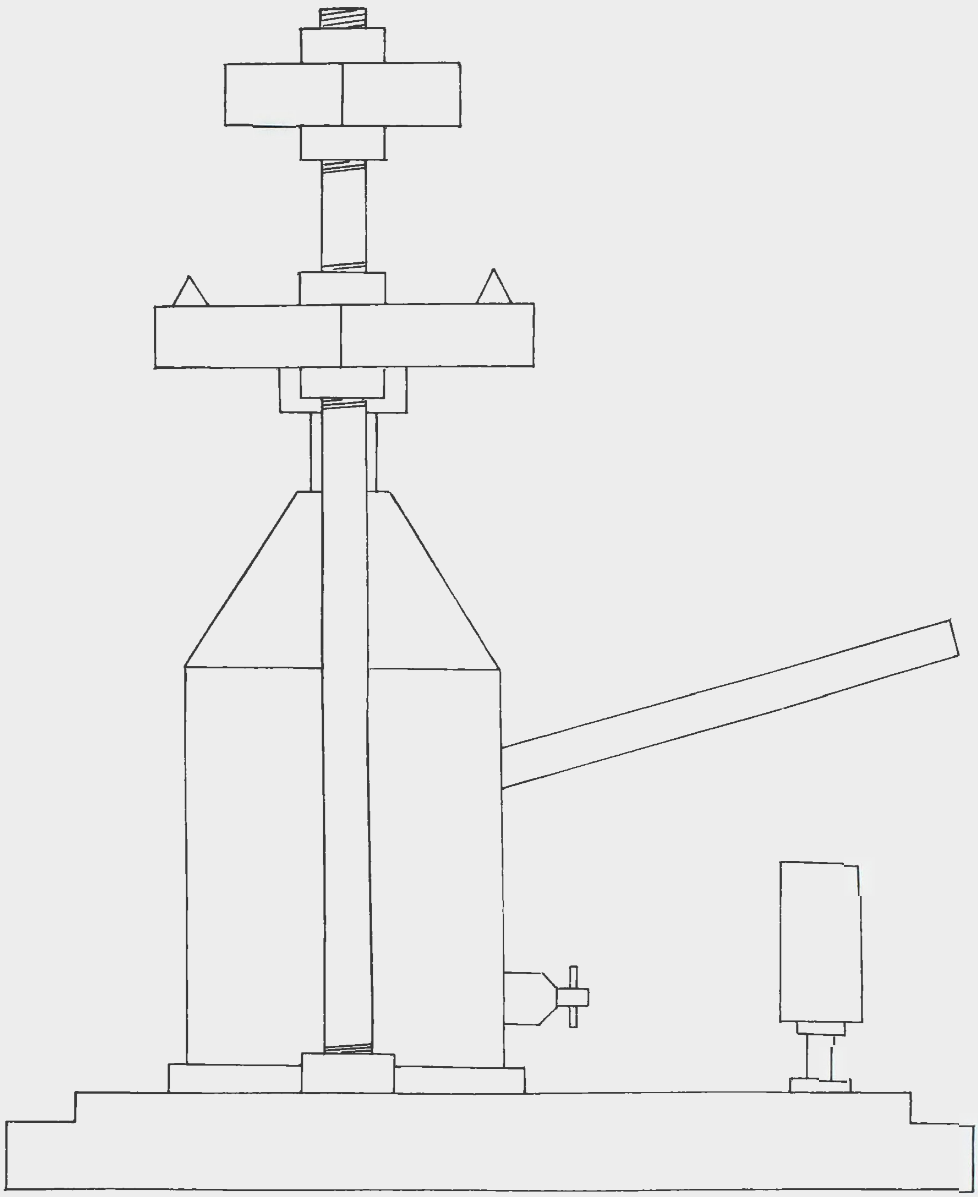

Fig. [illegible]

TABLE III

COMPRESSIONAL STRENGTH

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average compressional strength (lbs/in^2)
Tripp	0 to 1	Bitudobe	1 to 50	3	600
			2 to 50	4	550
			3 to 50	3	542
		Residium	1 to 50	3	500
			2 to 50	4	437
			3 to 50	4	365
		Colas	1 to 50	4	670
			2 to 50	4	565
			3 to 50	4	607
Rokeby	2 to 1	Bitudobe	1 to 50	4	394
			2 to 50	3	374
			3 to 50	4	388
		Residium	1 to 50	4	348
			2 to 50	4	269
			3 to 50	4	230
		Colas	1 to 50	3	440
			2 to 50	3	369
			3 to 50	4	315
Colby	28 to 12	Bitudobe	1 to 50	3	417
			2 to 50	4	369
			3 to 50	3	404
		Residium	1 to 50	4	352
			2 to 50	4	330
			3 to 50	5	292
		Colas	1 to 50	4	430
			2 to 50	4	395
			3 to 50	3	370

TABLE III

(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average compressional strength (lbs/in^2)
Hall	28 to 12	Bitudobe	1 to 50	4	450
			2 to 50	4	487
			3 to 50	4	438
		Residium	1 to 50	3	353
			2 to 50	3	343
			3 to 50	3	332
		Colas	1 to 50	4	512
			2 to 50	3	480
			3 to 50	4	398
Hastings	28 to 12	Bitudobe	1 to 50	4	502
			2 to 50	4	485
			3 to 50	3	465
		Residium	1 to 50	4	412
			2 to 50	3	349
			3 to 50	5	313
		Colas	1 to 50	4	510
			2 to 50	4	396
			3 to 50	3	356
Colby (red)	28 to 12	Bitudobe	1 to 50	3	480
			2 to 50	4	430
			3 to 50	4	342
		Residium	1 to 50	4	345
			2 to 50	4	331
			3 to 50	4	273
		Colas	1 to 50	3	506
			2 to 50	4	400
			3 to 50	4	357

TABLE III

(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average compressional strength (lbs/in^2)
			1 to 50	4	436
		Bitudobe	2 to 50	4	389
			3 to 50	4	357
			1 to 50	5	319
Boyd	3 to 1	Residium	2 to 50	4	328
			3 to 50	4	254
			1 to 50	3	385
		Colas	2 to 50	4	340
			3 to 50	4	339
			1 to 50	3	357
		Bitudobe	2 to 50	4	348
			3 to 50	5	343
			1 to 50	4	335
Crete	3 to 1	Residium	2 to 50	3	243
			3 to 50	3	234
			1 to 50	4	515
		Colas	2 to 50	4	477
			3 to 50	4	378
	0 to 1	______	______	4	540
Colby	1 to 9	______	______	4	486
	2 to 8	______	______	5	454
	0 to 1	______	______	4	739
	1 to 9	______	______	3	696
Crete	2 to 8	______	______	4	626
	3 to 7	______	______	5	562
	4 to 6	______	______	4	509

TABLE III
(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average compressional strength (lbs/in^2)
	0 to 1	______	______	4	590
Rokeby	1 to 9	______	______	3	532
	2 to 8	______	______	4	462
	0 to 1	______	______	4	782
	1 to 9	______	______	4	731
Boyd	2 to 8	______	______	4	733
	3 to 7	______	______	5	641
	4 to 6	______	______	5	532
	0 to 1	______	______	3	610
Hall	1 to 9	______	______	4	542
	2 to 8	______	______	4	472
	0 to 1	______	______	5	720
	1 to 9	______	______	4	692
Hastings	2 to 8	______	______	4	613
	3 to 7	______	______	4	546
	4 to 6	______	______	4	502
Tripp	0 to 1	______	______	3	570

MODULUS OF RUPTURE

Among the important moduli used in designating the strength of various materials is the quantity known as the "modulus of rupture". It may be defined as the unit stress for the rupture of a beam under a transverse load. In a uniform beam of any regular cross-section the resisting moment of the internal stresses in any section of material is equal to the bending moment of the external forces on each side of the section. Thus we may say,

$$\frac{R\ I}{c} = M \qquad (1)$$

where M is the bending moment, I the moment of inertia of cross-section, R the unit-stress, and c the vertical distance of unit stress from the center of gravity of the cross-section (Merriman, 4). To determine the "modulus of rupture" a beam is transversly loaded until rupture and the value of "R" is computed from the formula 1.

If the beam under consideration is rectangular with width "b", depth "d", and length "L"; formula 1 may be reduced to a more usable form by substitution of the values of "I", "c", and "M". The moment of inertia "I" is

$$I = bd^3/12$$

The value of "c" is $\frac{1}{2}$d and the moment of bending of a simple beam with a load "W" at the center is

$$M = WL/4$$

Substituting these values in equation (1) and solving for "R" we obtain

$$R = 3WL/2bd^3 \qquad (2)$$

The test specimens were made with a rectangular mold constructed of wood, fig. 5. The inside dimensions of the mold were 2 by 2 by 8 inches with top and bottom open. The dimensions are merely suggestive, chosen in this case to facilitate the use of the apparatus available. The test samples were allowed to cure at least three weeks and then dried to constant weight in an oven at 140° F. The specimens were squared and the dimensions accurately measured with calipers. The length "L", of the beam, is constant once determined and is equal to the distance between the supports on the press.

The apparatus used for the modulus of rupture tests was the same as that used for the compression tests. The samples were placed on the specially provided supports and the pressure was applied at approximately 500 lbs per minute. From the data thus obtained, the results for the samples tested were calculated by formula (2) and are recorded in table IV.

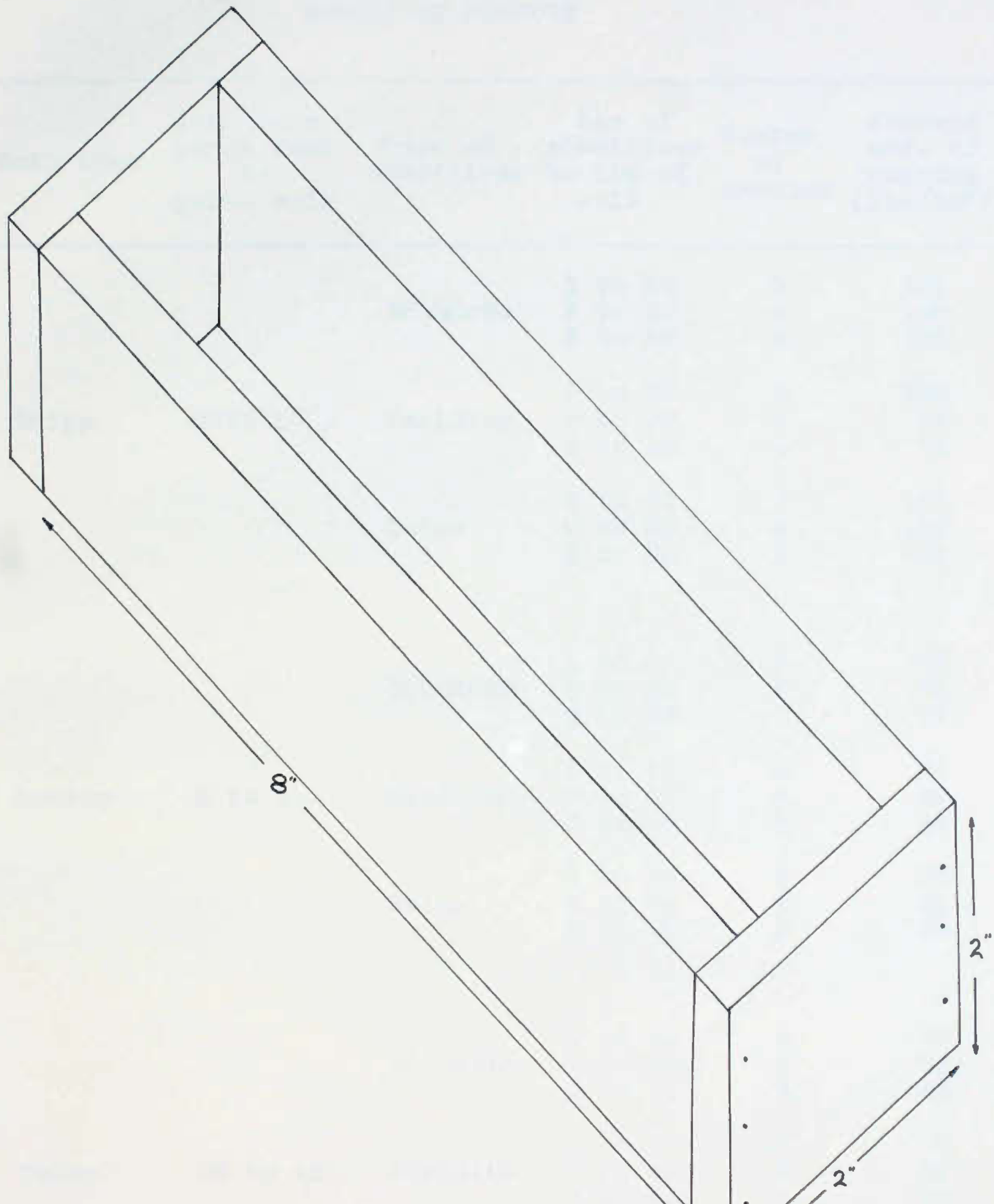

Fig. 5. —Mold used for modulus of rupture samples.

TABLE IV

MODULI OF RUPTURE

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average mod. of rupture (lbs/in^2)
Tripp	0 to 1	Bitudobe	1 to 50	5	141
			2 to 50	4	149
			3 to 50	4	144
		Residium	1 to 50	3	108
			2 to 50	4	94
			3 to 50	4	74
		Colas	1 to 50	5	194
			2 to 50	4	162
			3 to 50	5	165
Rokeby	2 to 1	Bitudobe	1 to 50	5	92
			2 to 50	4	75
			3 to 50	4	87
		Residium	1 to 50	4	65
			2 to 50	4	49
			3 to 50	4	38
		Colas	1 to 50	4	93
			2 to 50	4	81
			3 to 50	3	65
Colby	28 to 12	Bitudobe	1 to 50	5	93
			2 to 50	5	73
			3 to 50	5	88
		Residium	1 to 50	5	67
			2 to 50	5	52
			3 to 50	5	52
		Colas	1 to 50	5	93
			2 to 50	5	87
			3 to 50	5	67

TABLE IV

(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average mod. of rupture (lbs/in^2)
Hall	28 to 12	Bitudobe	1 to 50	4	110
			2 to 50	4	108
			3 to 50	4	79
		Residium	1 to 50	4	72
			2 to 50	4	58
			3 to 50	4	56
		Colas	1 to 50	4	103
			2 to 50	5	82
			3 to 50	4	76
Hastings	28 to 12	Bitudobe	1 to 50	5	117
			2 to 50	5	97
			3 to 50	5	79
		Residium	1 to 50	5	95
			2 to 50	5	66
			3 to 50	5	58
		Colas	1 to 50	4	94
			2 to 50	4	82
			3 to 50	3	66
Colby (red)	28 to 12	Bitudobe	1 to 50	5	110
			2 to 50	4	79
			3 to 50	3	56
		Residium	1 to 50	5	71
			2 to 50	5	69
			3 to 50	5	54
		Colas	1 to 50	5	92
			2 to 50	5	90
			3 to 50	5	74

TABLE IV

(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average mod. of rupture (lbs/in²)
		Bitudobe	1 to 50	5	97
			2 to 50	5	72
			3 to 50	5	63
			1 to 50	4	52
Boyd	3 to 1	Residium	2 to 50	4	55
			3 to 50	4	44
			1 to 50	5	77
		Colas	2 to 50	5	64
			3 to 50	5	68
			1 to 50	5	76
		Bitudobe	2 to 50	5	67
			3 to 50	5	56
			1 to 50	4	58
Crete	3 to 1	Residium	2 to 50	4	48
			3 to 50	4	40
			1 to 50	5	105
		Colas	2 to 50	5	89
			3 to 50	5	76
	0 to 1	———	———	3	209
Colby	1 to 9	———	———	4	136
	2 to 8	———	———	4	100
	0 to 1	———	———	4	510
	1 to 9	———	———	3	414
Crete	2 to 8	———	———	4	356
	3 to 7	———	———	4	307
	4 to 6	———	———	4	299

TABLE IV
(CONTINUED)

Soil type	Admixture parts sand to parts soil	Type of stabilizer	Lbs of stabilizer to lbs of soil	Number of samples	Average mod. of rupture (lbs/in^2)
Rokeby	0 to 1	———	———	4	270
	1 to 9	———	———	3	206
	2 to 8	———	———	3	185
Boyd	0 to 1	———	———	3	582
	1 to 9	———	———	4	545
	2 to 8	———	———	3	480
	3 to 7	———	———	4	407
	4 to 6	———	———	4	284
Hall	0 to 1	———	———	4	335
	1 to 9	———	———	4	320
	2 to 8	———	———	4	262
Hastings	0 to 1	———	———	5	505
	1 to 9	———	———	4	448
	2 to 8	———	———	3	352
	3 to 7	———	———	3	324
	4 to 6	———	———	4	249
Tripp	0 to 1	———	———	3	150

THERMAL CONDUCTIVITY

Theory

The rate of conduction of heat by any building material is an important property when considering its use for construction purposes. If heat is "propagated from one portion of a body to another, without the occurence of motion in any finite part or parts of the body, intermediate points being heated meanwhile, the process of transfer is termed conduction" (Edser, 5). The quantity of heat "H" transferred across a layer of material having parallel plane faces maintained at different temperatures T_2 and T_1, where T_2 is greater than T_1, is dependent upon the following factors: the material of the slab, the cross-sectional area "A" across which the heat flow takes place, the time "t", and the gradient of temperature or temperature difference per unit thickness, i.e., $(T_2 - T_1)/L$ where "L" is the thickness of the layer. Hence,

$$H = kAt(T_2 - T_1)/L \qquad (3)$$

The proportionality constant "k" is the coefficient of conductivity and is the value to be determined.

If a bar constructed of the material to be tested is heated at one end and the other end remains at the temperature of the atmosphere or room temperature, heat will travel along the bar and various points along the specimen will attain steady temperatures. Thus the heat entering the bar at the hot end is entirely given up to the atmosphere, or radiated into space from the surface of the bar.

Now if a part of the bar comprised between two planes perpendicular to its length and sufficiently close together is considered, the heat given off by the surface between the planes may be neglected in comparison with the heat given off by the surface beyond the planes. Hence, if the fall of temperature between the planes and the amount of heat given off by the surface of the specimen beyond the planes can be determined, the coefficient of conductivity can be calculated.

Method

The method used was one employed by Forbes (Edser, 5) which consisted of two types of observations. In one, the static, the sample is heated at one end at a constant temperature until a steady state is attained throughout the entire length. In this condition the temperatures at various points along the rod are observed, giving a temperature-length relationship. In the other observation, the dynamic, the sample is heated as a whole to a high temperature and allowed to cool. Measurements are made of the rate of cooling so that a temperature-time relationship is obtained.

From these two observations the coefficient of conductivity "k" can be evaluated.

Referring to equation 3, the coefficient of conductivity is equal to the ratio of the heat passing through one sq. cm. of cross-sectional area in one sec. to the fall of temperature per cm. length. The fall of temperature per cm. length is obtained from the statical curve of temperature.

To obtain the quantity of heat passing through one sq. cm. of cross-sectional area in one second, a new curve, representing the relation between the heat given up by unit length of the bar in one second and various mean temperatures, is plotted. The quantity of heat given up by the specimen during a given interval of time is then calculated from the experimental data of the temperature-time curve and the relation

$$Ms(t_2 - t_1) = H \qquad (4)$$

where "M" is the mass of the specimen, "s" is the specific heat, $(t_2 - t_1)$ is the temperature change, and "H" is the heat given up by the specimen in a given interval of time when at a known mean temperature.

From these values of "H", the heat given up by unit length of the bar in one second for each assumed mean temperature is calculated. A new curve is then plotted showing the heat given up by unit length of bar in one second for the various mean temperatures.

If the mean temperature of the specimen, beyond the point at which the fall of temperature per unit length was determined, is calculated, the heat that has passed through a section of the bar can be determined from the radiation curve. Thus, the area of the section being known, the heat passing through unit area of the section can be found and the coefficient of conductivity calculated.

Statical Observations

Two specimens of soil were cut from properly cured adobe blocks. One specimen was Tripp with an admixture of two pounds of residium to fifty pounds of soil (hereinafter called "block #1") and the other sample was an admixture of twenty-eight parts sand to twelve parts of Colby (hereinafter called "block #2"). The blocks were approximately twelve inches long. Block #1 had a cross-sectional area of eight square inches and block #2 had a cross-sectional area of thirteen square inches. Holes that would firmly inclose a thermometer bulb were bored in the upper surface of each block. The holes were placed approximately one inch apart and extended the length of the block.

The apparatus consisted of a heating can, an asbestos shield, a source of heat and a supporting stand for the block, and was arranged as shown in fig. 6. The heating can, closed at the top except for an opening in which to insert a ther-

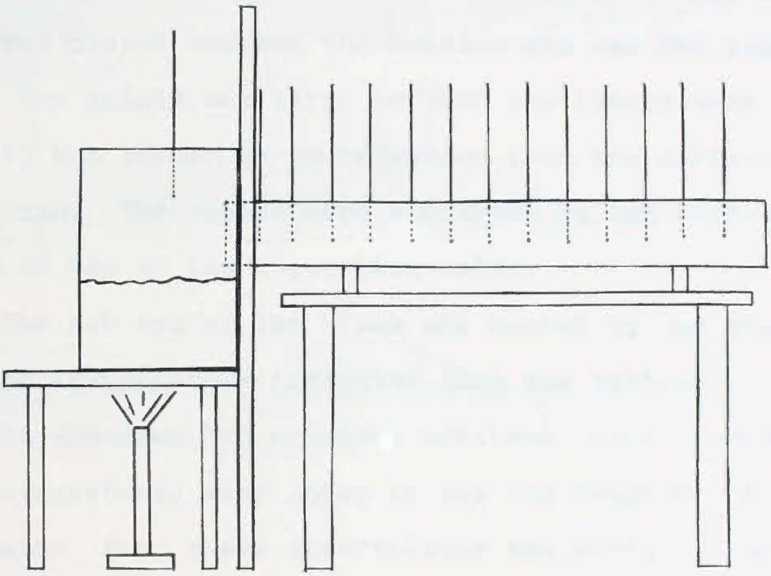

Fig. 6. —Thermal conductivity apparatus for static observations.

mometer, was rectangular with an opening in the side of the can into which the blocks fit snugly. A bunsen burner was used to heat water in the can and generate a steam bath to heat the end of the block inserted in the can. The level of the water was a little below the opening in the side of the can. The shield was made of sheet asbestos. A hole was provided in the asbestos that fit the blocks snugly and the shield was placed between the heating can and the supporting stand. The shield was large so that the blocks were not heated by the burner or by radiation from the surface of the heating can. The blocks were supported on two narrow strips of wood on top of the supporting table.

The hot end of the block was heated by the steam bath until the thermometers indicated that the various points along the specimen had acquired constant temperatures. These temperatures were noted as was the temperature of the steam bath. From these observations the statical curves of temperatures, fig. 7, were plotted.

Dynamical Observations

The blocks that were used in the previous statical observations were placed in an oven and heated uniformly throughout. The oven time was approximately eight hours. The blocks were then removed and the rate of cooling was determined.

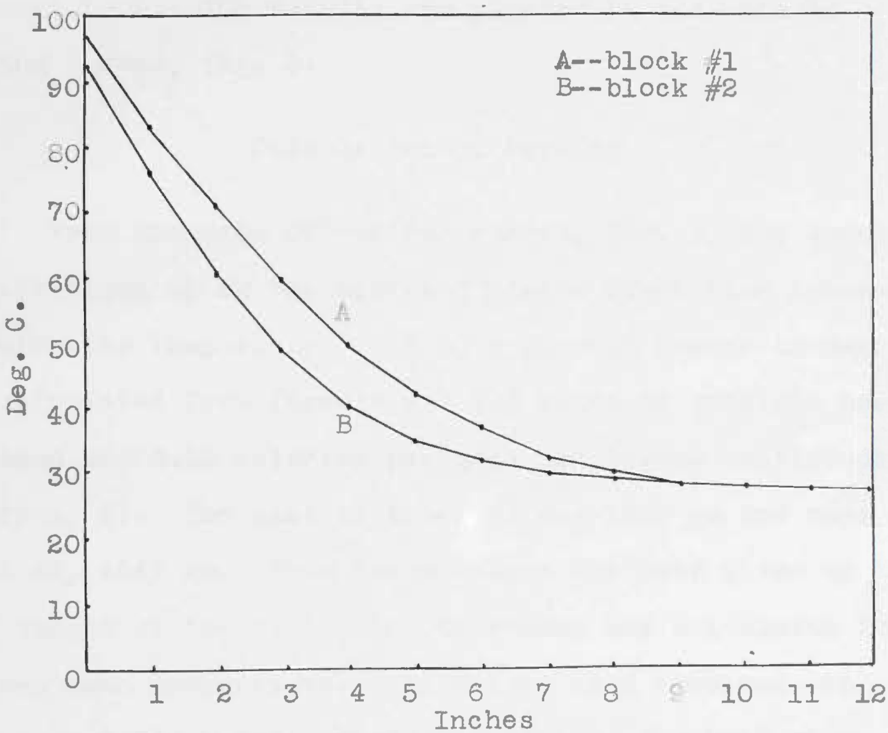

Fig. 7. _Statical curve of temperatures.

Three thermometers, one at each end and one in the center, were placed in the previously bored holes in the blocks, and readings were observed at various time intervals. The readings were taken at three minute intervals for the first half hour and at six minute intervals for the next hour. The results are plotted in the rate of cooling curves, fig. 8.

Calculation of Results

From the rate of cooling curves, fig. 8, the quantity of heat given up by the blocks during a given time interval, in which the temperature fell by a certain number of degrees, was calculated from formula 4. The value of specific heat "s" used was 0.25 calories per gram per degree centigrade. (Emerson, 6). The mass of block #1 was 1520 gm and mass of block #2, 4545 gm. From these values the heat given up by unit length of the blocks in one second was calculated for a given mean temperature. All values thus obtained are listed in table V and curves representing the heat given up by unit lengths of the blocks in one second are plotted in fig. 9.

Now referring to fig. 7, the fall in temperature for the unit length between two and three inches was determined. For block #1 the fall was eleven degrees centigrade and for block #2 the fall was twelve degrees centigrade. Next the

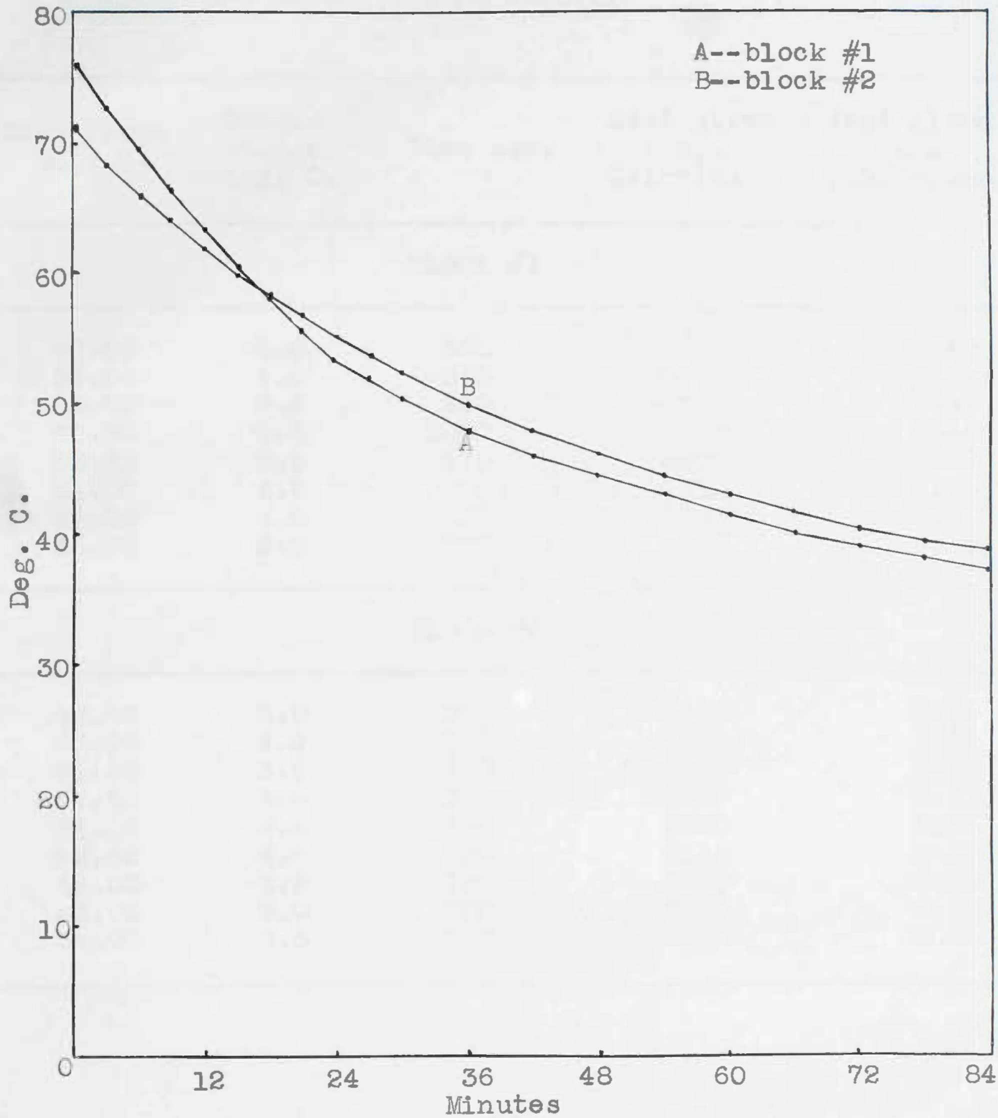

Fig. 8. —Rate of cooling curves.

TABLE V

THERMAL CONDUCTIVITY

Mean temp. Deg. C.	Temp. change deg. C.	Time sec.	Heat given up. Calories	Heat given up. cal/in/sec.
		BLOCK #1		
72.50	5.0	360	1900	0.67
68.00	4.0	360	1520	0.54
64.25	3.5	360	1330	0.47
60.50	9.5	1080	3600	0.42
56.50	5.5	720	2090	0.37
51.00	4.5	720	1710	0.30
49.00	4.0	720	1520	0.27
38.00	2.0	720	760	0.14
		BLOCK #2		
68.50	5.0	360	5680	1.30
63.50	4.0	360	4540	1.05
61.00	3.5	360	3980	0.92
57.50	3.0	360	3410	0.79
54.00	2.5	360	2840	0.66
52.00	4.5	720	5110	0.59
46.00	3.5	720	3980	0.46
43.00	3.0	720	3410	0.39
38.00	2.5	900	2840	0.26

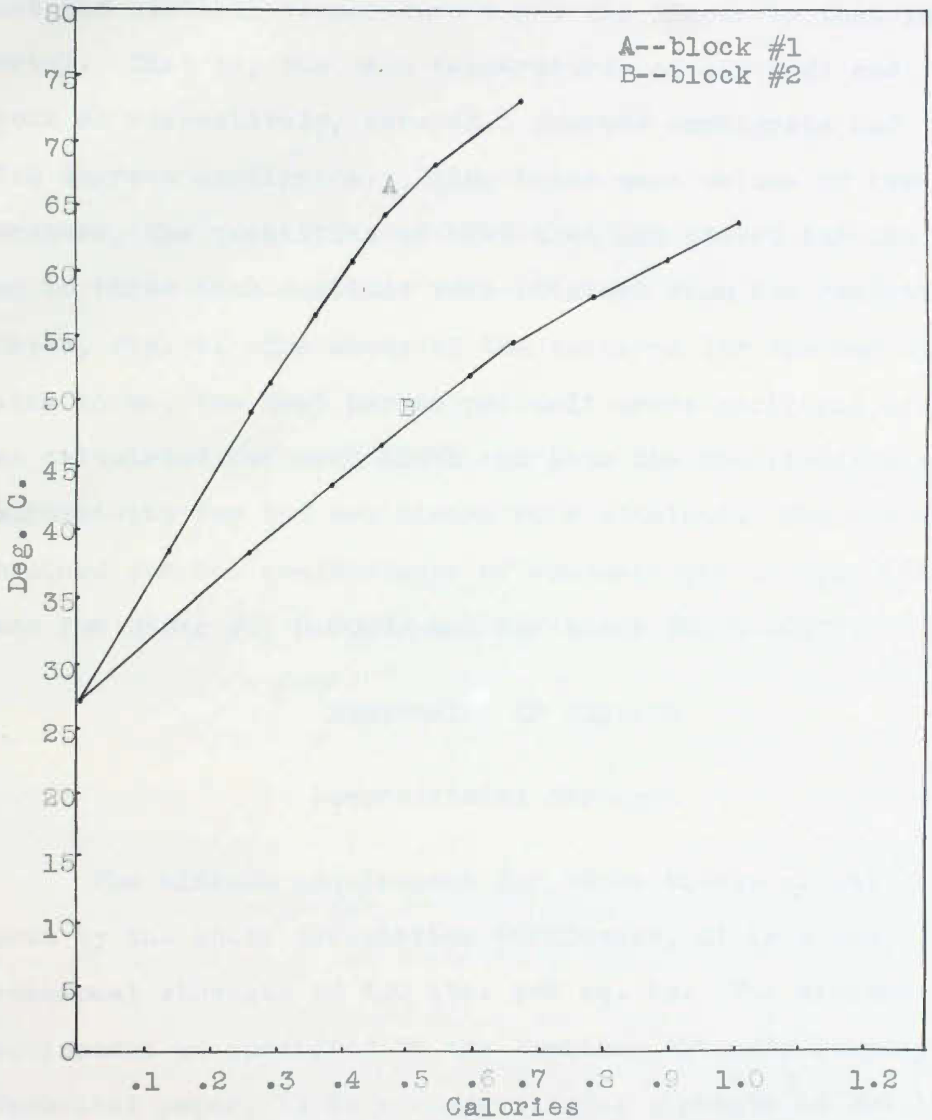

Fig. 9. —Radiation curves.

mean temperatures of the blocks for the length between three inches and twelve inches was determined on the assumption that the statical temperature curve was linear in that interval. That is, the mean temperatures of block #1 and block #2 respectively, were 43.5 degrees centigrade and 37.5 degrees centigrade. Using these mean values of temperature, the quantities of heat that had passed through the two to three inch sections were obtained from the radiation curves, fig. 9. The areas of the sections for the two blocks being known, the heat passed per unit cross-sectional area was calculated for each block and thus the coefficients of conductivity for the two blocks were obtained. The values obtained for the coefficients of conductivity in cgs units were for block #1, 0.00238 and for block #2, 0.00175.

DISCUSSION OF RESULTS

Compressional Strength

The minimum requirement for adobe blocks as set forth by the Adobe Association (Ordinance, 2) is a compressional strength of 400 lbs. per sq. in. The minimum requirement as specified by the American Bitumuls Company (Technical paper, 1) is a compressional strength of 300 lbs. per sq. in. These requirements are prescribed for blocks that have been suitably treated with a stabilizer.

The average compressional strength of all but seven of the series of samples tested, Table III, exceeded the required value of 300 lbs. per sq. in. The seven samples that had insufficient compressional strength were all treated with residium as the stabilizer. Two contained two lbs. of residium to fifty lbs. of soil and the other five contained three lbs. of residium to fifty lbs. of soil. If the value of 400 lbs. per sq. in. is taken as the minimum requirement, only twenty-nine out of seventy-three blocks pass the requirement. Tripp was the only soil that had a compressive strength of 400 lbs. per sq. in. when treated with residium. Tripp in general had the highest compressional strength while Boyd and Crete had the lowest. There was little variation among the other soils.

The variation of compressional strength with stabilizers was quite pronounced. There was no noticeable difference between the commercial stabilizers colas and bitudobe; however, the blocks treated with residium tested in general from 80 to 100 lbs. per sq. in. less in compressional strength.

The compressional strength in nearly every case decreased as the amount of stabilizer increased. This was true in every case that residium was used and only two exceptions were found with bitudobe and one with colas. The decrease of compressional strength when the stabilizer was increased from one pound stabilizer per fifty pounds soil to three pounds stabilizer per fifty pounds soil, was in general from 50 to 100 lbs. per sq. in.

The compressional strength of the specimens with varying amounts of sand admixture decreased with the amount of sand. The range of variation in two cases being over 200 lbs. per sq. in., while the other ranges were approximately 100 lbs. per sq. in. The soil samples of Boyd, Crete and Hastings with no admixture of sand had very high compressional strengths.

A comparison of the soil Tripp with stabilizer added and with no stabilizer shows that the addition of a small amount of either of the stabilizers bitudobe or colas increased the compressional strength to some extent. The addition of any amount of residium, however, apparently weakened the compressional strength as did the larger amounts of colas and bitudobe.

Modulus of Rupture

The minimum requirement for the modulus of rupture for adobe blocks, suitably treated with stabilizer, as set forth by both the Adobe Association (Ordinance, 2) and the American Bitumuls Company (Technical paper, 1) is 50 lbs. per sq. in.

The average moduli of rupture of all but five of the groups of blocks tested surpassed the requirement of 50 lbs.

per sq. in. The blocks that did not meet the standards were blocks in which the stabilizer was residium. Tripp had the highest modulus of rupture and Boyd, along with Crete, had the lowest moduli of rupture among the samples treated with stabilizer. There was no apparent difference between the samples made with bitudobe and those made with colas. The test blocks made with residium as the stabilizer had in general a modulus of rupture 10 to 20 lbs. less than blocks made with the other stabilizers.

The modulus of rupture in most cases decreased as the amount of stabilizer admixture was increased. With the stabilizer bitudobe, however, this tendency was not so pronounced as with the stabilizers colas and residium.

The tests carried out on the samples with varying sand content showed that the modulus of rupture varied inversely as the amount of sand admixture. The soils Boyd, Crete, and Hastings had the highest moduli of rupture. In fig. 10 the change of modulus of rupture with respect to percentage of sand content is plotted for four of the soils tested.

The soil Tripp had a modulus of rupture of 150 lbs. per sq. in. with no stabilizer, and with different amounts of the stabilizer colas, the moduli of rupture were 194, 162, and 165 lbs. per sq. in. respectively. The addition of the stabilizer bitudobe did not decrease the modulus of

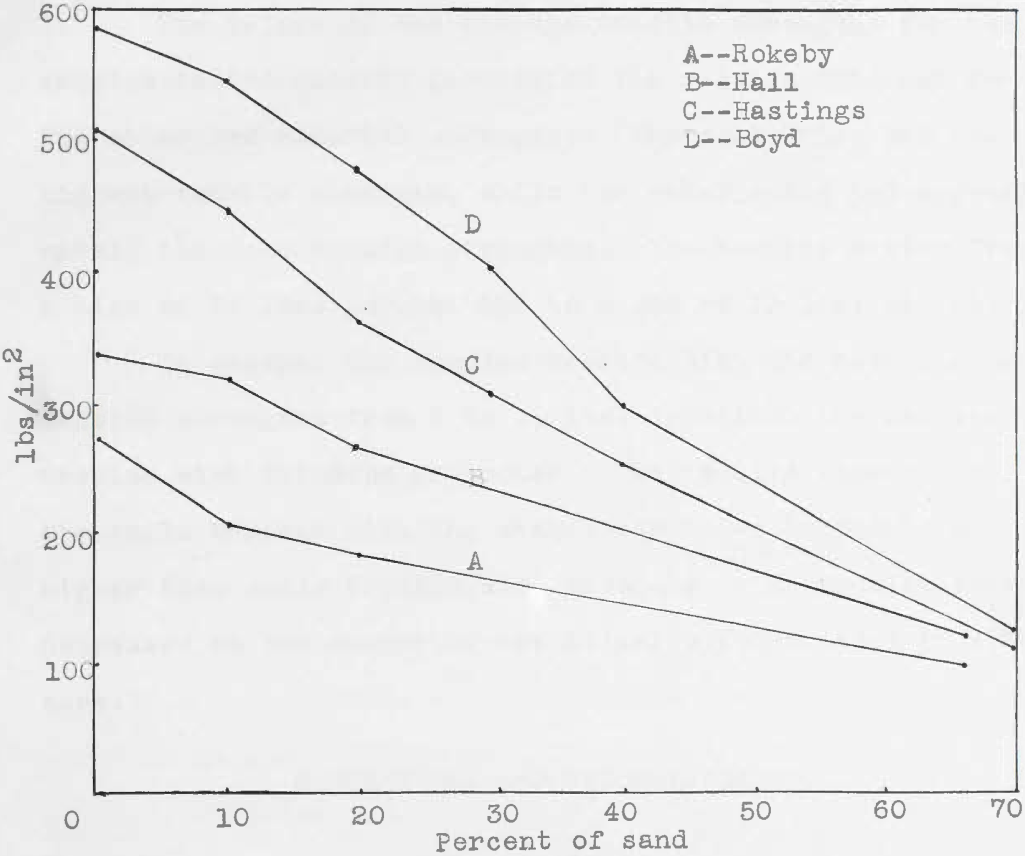

Fig. 10. —Variation of modulus of rupture with percent of sand admixture.

rupture an appreciable amount; however, the stabilizer residium reduced the modulus of rupture approximately 50 lbs.

Tensile Strength

The values of the average tensile strengths for the samples tested closely paralleled the results obtained for the other two material strengths. The soil Tripp had the highest tensile strength, while the other soils had approximately the same tensile strengths. The results varied from a high of 75 lbs. per sq. in. to a low of 13 lbs. per sq. in.

In general the samples treated with the residium had tensile strengths from 5 to 15 lbs. less than the samples treated with bitudobe and colas. The tensile strength of the soils treated with the stabilizer colas tended to be higher than soils treated with bitudobe. The tensile strength decreased as the amount of stabilizer was increased in every case.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It was found that the various mixtures of soils treated with stabilizer possessed the material strength requirements as prescribed by the American Bitumuls Company (Technical paper, 1) with seven exceptions. The adobe mixtures that failed to meet the necessary compressional strength failed also to meet the requirement for the modulus of rupture and although there is no prescribed tensile strength, the mixtures that had the lowest compressional strengths and moduli of rupture had the lowest tensile strength. In general there was a close parallel between the values of material strengths obtained for any one of the soil admixtures.

It was found that the samples treated with the commercial stabilizers bitudobe and colas had greater material strengths than the samples treated with residium. There was no appreciable difference in strength between the samples treated with either of the commercial stabilizers, bitudobe and colas.

The physical strengths of the adobe blocks decreased--in many cases only slightly or not at all--as the amount of stabilizer was increased. The decrease in physical strength was more marked with the stabilizer residium than with the stabilizers colas and bitudobe.

The tests made on the samples with varying sand content showed that the strength decreased as the sand content increased. The tenacity of the soil depends on the clay content or the number of particles of soil having a particle size of less than 0.005 mm. (Emerson, 6). The results that were obtained were in agreement with the above statement, as the soils with the highest clay content-- Boyd, Crete, and Hastings--had the highest material strengths.

In the series of tests on the samples made with varying sand content only, all results were much higher than the values obtained for the blocks treated with stabilizers. However, it should be noted that the sand contents--even at the ratio of four to six, which was the highest sand to soil ratio used in the varying sand content tests-- were much less than the prescribed ratios of sand to soil for bricks which were used in the tests employing the various stabilizers. The material strength seemed to depend more on the sand added than on the amount of stabilizer added, especially was this true with the stabilizers colas and bitudobe. For example the soil Tripp had no addition of sand in any of the test specimens and the material strengths for this soil were approximately the same for the samples with or without stabilizer. The material strengths were even a little higher in general for the specimens treated with the stabilizers bitudobe and colas, while for the stabilizer residium, they were slightly lower. A similar comparison cannot be made with the other soils since the sand contents were different for the specimens with and without stabilizers.

The tests for thermal conductivity showed that the adobe blocks have low coefficients of conductivity and in this respect the material should be desirable as a building material. The coefficients of conductivity in cgs units were 0.00238 and 0.00175 for blocks #1 and #2 respectively. In other words this would be equivalent to a heat transmission of 4.9 B.T.U. per hour per sq. ft. per deg. F. per inch thickness for block #1 and 3.6 B.T.U. per hour per sq. ft. per deg. F. per inch thickness for block #2. The heat transmission of bitudobe brick masonry as given by the American Bitumuls Company (Specification F-7, 7) is 4.0 B.T.U. per hour per sq. ft. per deg. F. per inch thickness. The results obtained were comparable to this value and there is apparently little effect on the thermal conductivity of a soil when it is treated with stabilizer. Block #2, the sample with no stabilizer, had a lower coefficient of conductivity than did block #1 which was treated with the stabilizer residium. However, block #2 had a much higher sand content than did block #1, and it should be noted that the addition of sand, if it alters the thermal conductivity, should decrease it since the thermal conductivity of sand in cgs units is about 0.0009 (Stewart,8).

Recommendations

For design specifications and plans of adobe constructions, the working stress (Ordinance, 2) may be computed by using a safety factor of five (or 20% of average laboratory tests). Otherwise the allowable unit working stresses of adobe brick masonry as proposed by the Adobe Association (Ordinance, 2) may be used. The working stresses are listed in table VI.

TABLE VI

ALLOWABLE MAXIMUM WORKING STRESSES

Compression	80 lb. sq. in.
Tension	10 lb. sq. in.
Extreme fiber stress in bending	50 lb. sq. in.
Shear (no web reinforcement)	5 lb. sq. in.
Modulus of elasticity	200,000 lb. sq. in.
Modulus of rupture	10 lb. sq. in.

It is not advisable to use adobe blocks in walls that have a ratio of height to thickness that exceeds ten to one. Also the exterior walls or bearing walls should in no case be less than twelve inches in thickness. The interior or non-bearing walls should not be less than eight inches in thickness (Ordinance, 2).

Foundations should not be less than the thickness of the wall above, and should extend not less than six inches above the finished grade. The footing should extand not less than twelve inches below the natural grade for one-story buildings, and not less than eighteen inches for two-story buildings; and all footings should be reinforced with not less than two one-half inch round reinforcing bars.

Openings in walls measured on any horizontal plane should not exceed 40% of the length of the wall. The recesses should be considered as openings and a minimum wall space of three feet measured horizontally should be between openings or from a corner to an opening (Specification F-7, 7). No wall constructed of adobe blocks should exceed thirty feet in length unless supported by cross walls, piers or buttresses of at least twenty-four in. sq.

In the laying of adobe blocks the joints should not be less than one-half inch and every fifth course should contain steel mesh hardware cloth with a width two inches less than the wall thickness. Two strands of barbed wire may be used in each fifth horizontal course in lieu of the steel mesh (Ordinance, 2).

The mortar for laying up of bricks may be either adobe mortar of the same soil and mixture as in the adobe blocks or concrete mortar. If concrete mortar is used it should consist of one part cement to four parts of sand and an approved waterproofing material should be added. One such waterproofing material is Hydropel Emulsified Asphalt, manufactured by the American Bitumuls Company (Specification F-6, 9). Each wall should have a continuous bond beam eight inches square with not less than two one-half inch reinforcing bars. The bond beam should be used at the roof or eaves line of all buildings and at the second floor line of all two-story buildings (Ordinance, 2).

For additional information regarding construction and design, reference may be made to the papers of the American Bitumuls Company and the Adobe Association listed in the bibliography.

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