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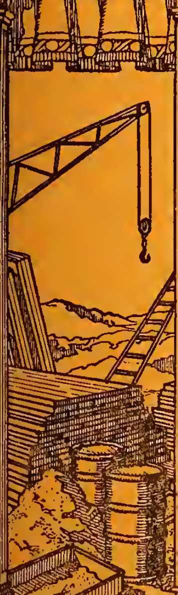


BUILDING MATERIALS AND STRUCTURES

REPORT BMS5

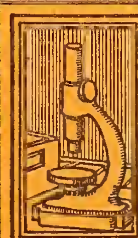
Structural Properties of Six Masonry Wall Constructions

by HERBERT L. WHITTEMORE

AMBROSE H. STANG, *and*

DOUGLAS E. PARSONS

NATIONAL BUREAU OF STANDARDS



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ISSUED NOVEMBER 21, 1938

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

Masonry Constructions utilizing brick, structural clay tile, and concrete units have been used for houses for many years and the behavior of such constructions in service is well known. Data on the structural properties of these constructions obtained in a series of standardized laboratory tests enable comparisons to be made with the structural properties of newer types of constructions.

This report gives the load-deformation relations and strength of these well-known constructions when subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods described in detail in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions. The results of these laboratory tests show the ability of such constructions to resist compressive loads far greater than those likely to be encountered in actual house construction.

They also show how the compressive strength and other properties may be influenced by changes in materials and workmanship, and provide data which may be compared with service behavior for estimating the limiting strengths for acceptable performance.

Lyman J. Briggs, *Director.*

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ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Masonry Construction Section of the National Bureau of Standards built specimens representing six masonry wall constructions as follows: High-strength brick, cement mortar, excellent workmanship; medium-strength brick, cement-lime mortar, commercial workmanship; medium-strength brick, cement-lime mortar, excellent workmanship; structural clay tile on end, cement-lime mortar, excellent workmanship; structural clay tile on side, cement-lime mortar, excellent workmanship; and stone-concrete block, cement-lime mortar, excellent workmanship.

The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads. For most of these loads three like specimens were tested. The deformation under load and the set after the load was removed were measured for uniform increments of load up to the maximum load, except for concentrated loads, for which the set only was determined. The results are presented graphically and in a table.

I. INTRODUCTION

In the Program in which the National Bureau of Standards is now engaged to determine the structural properties of low-cost house constructions, an important step is the determination of the properties of some constructions for which the behavior in service is generally known. Those selected for this purpose are masonry constructions, utilizing brick, structural clay tile, and stone-concrete block which form the subject of this report, and wood-frame construction, which has been studied by the Forest Products Laboratory of the United States Department of Agriculture, and which will be the subject of a subsequent report in this series.

The strength of masonry construction is dependent on a great many variables. In brick construction, for example, the principal variables are the type of brick, type of mortar, and workmanship, but some of the strength properties depend on other factors. Furthermore, it is practically impossible to determine which construction may be regarded as conventional or typical, because typical constructions vary in different parts of the country as well as with the individual contractors in their respective localities.

It was decided not to devote a large amount of effort to testing familiar types of construction. Therefore, six constructions only were selected, three of brick, two of structural clay tile, and one of stone-concrete block. In the brick constructions, two types of brick, two types of mortar, and two types of workmanship were used in an effort to determine the probable range of properties which might be expected in good practice. It is probable that the highest practical strength has been approached in one of the constructions. However, if brick, mortar, and workmanship are poor, values much lower than those found in these tests will be obtained. The construction consisting of medium-strength brick, cement-lime mortar, and commercial workmanship is believed to be as nearly "typical" as can be obtained without extensive field investigations of current practices.

In the laboratory, the specimens were subjected to compressive, transverse, concentrated, impact, and racking loads to simulate loads to which the walls of a house are subjected. In actual service, compressive loads are produced by the weight of the roof, second floor and second-story walls if any, furniture, and snow and wind loads on the roof. Transverse loads are produced by the wind; concentrated and impact loads by furniture, or accidental contact with heavy objects; and racking loads by the action of the wind on adjoining walls.

The deflection and set under various loads were determined, as well as the strength, since these properties are equally important, and, with some types of construction, are the significant factors in determining whether or not the performance is satisfactory.

II. SPONSOR

The Specimens were built by the Masonry Construction Section of the National Bureau of Standards.

The compressive and transverse strengths of some of these constructions have been determined in previous investigations, but few data are available on the other structural properties. These constructions were included in this program not only to obtain this information, but also to provide data for comparing the structural properties of other constructions which have not been widely used for houses.

III. SPECIMENS AND TESTS

The Specimens were built by an experienced mason employed by the Bureau and working under immediate supervision.

The constructions were assigned symbols in accordance with table 1, and the specimens were assigned designations in accordance with table 2.

Table 1.—*Construction symbols*

Construction symbol	Masonry unit	Mortar	Workmanship
AA	High-strength brick	Cement	Excellent.
AB	Medium-strength brick	Cement-lime	Commercial.
AC	do	do	Excellent.
AD	Structural clay tile on end	do	Do.
AE	Structural clay tile on side	do	Do.
AF	Stone-concrete block	do	Do.

Table 2.—*Specimen designations*

Specimen designation	Load	Load applied
C1, C2, C3	Compressive	Upper end.
T1, T2, T3	Transverse	Either face.
P1, P2, P3 [a]	Concentrated	Do.
I1, I2, I3	Impact	Do.
R1, R2, R3	Racking	Near upper end.

[a] These specimens were undamaged portions of the specimens used for the transverse or impact tests.

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-cost House Constructions.[1] The tests were begun November 9, 1937, and completed March 10, 1938. The specimens were tested 28 days after they were built.

For the transverse and impact loads, only three specimens were built because the specimens were symmetrical about a vertical plane midway between the faces, and the results for transverse and impact loads applied to one face of the specimens should be identical with those obtained by applying the loads to the other face. The concentrated loads were applied to only three specimens, because the inside and outside faces of the specimens were similar.

IV. MATERIALS

1. Brick

(*a*) *High-Strength Brick*

The high-strength bricks were obtained from the United Clay Products Co. and were made in Martinsburg, W. Va. The bricks were of shale formed by the stiff-mud side-cut process. The average dimensions were 8.15 by 3.75 by 2.30 in. (about 8⅛ by 3¾ by 2$\frac{5}{16}$ in). The physical properties, given in table 3, were determined in accordance with the American Society for Testing Materials Standard C67–37,[2] so far as this standard was applicable. When laid, the bricks were air-dried. The absorption for 1-min partial immersion was determined for two bricks taken about every 30 min from the mason's scaffold.

Table 3.—*Physical properties of brick*

Brick	Compressive strength	Modulus of rupture	Water absorption					Weight, dry
			24-hr cold, *C*	5-hr boil, *B*	Ratio *C/B*	1-min partial immersion [a]		
						Dry	As laid	
	lb/in.²	lb/in.²	%	%		g/brick	g/brick	lb/brick
High-strength	17,600	2,275	1.9	3.45	0.53	8	8	5.85
Medium-strength	2,670	550	11.3	15.1	.74	23	11	4.49

[a] Immersed on flat side in ⅛ in. of water. Absorption in grams per brick.

(*b*) *Medium-Strength Brick*

The medium-strength bricks were obtained from the Hydraulic Press Brick Co. and were made in Baltimore, Md., by the Baltimore Brick Co. The bricks were of clay, formed in sanded molds by the soft-mud process. The average dimensions were 8.05 by 3.70 by 2.25 in. (about 8$\frac{1}{16}$ by 3$\frac{11}{16}$ by 2¼ in). Between 25 and 30 percent of these bricks had frogs (depressed panels) on one side. The frogs were 6$\frac{13}{16}$ by 1$\frac{9}{16}$ by $\frac{5}{32}$ in. and had the name Homewood in raised letters. When laid the bricks were damp. The absorption for 1-min partial immersion was determined for two bricks taken about every 30 min from the mason's scaffold.

2. Tile

The structural clay tiles were obtained from the National Fireproofing Corporation and were made in Magnolia, Ohio. The tiles had six cells, as shown in figure 1, and were intended to be laid either on end or side. The average dimensions were 8.01 by 12.08 by 12.14 in. (about 8 by 12$\frac{1}{16}$ by 12⅛ in). The physical properties given in table 4 were determined in accordance with the American Society for

[1] Price 10 cents. See cover p. II.

[2] Am. Soc. Testing Materials Supplement to Book of ASTM Standards, p. 78–82 (1937).

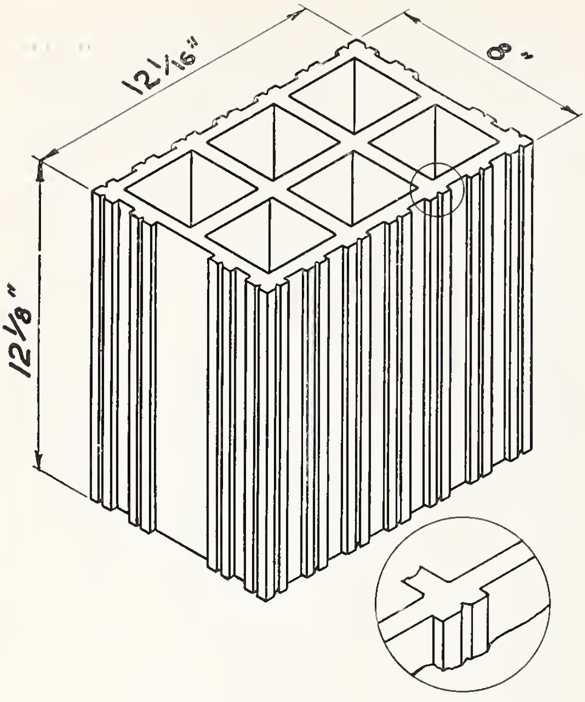


FIGURE 1.—*Structural clay tile.*

Testing Materials Standard C112–36 [3] so far as this standard was applicable. When laid the tiles were air-dried.

TABLE 4.—*Physical properties of tile*

[Each value is the average for 10 specimens]

Thickness of face shell, minimum	Ratio width of cell to over-all thickness of bearing shell	Compressive strength			Water absorption		Weight, dry
		Load applied to end		Load applied to side	24-hr cold	1-hr boil	
in.		lb/in.² net area	lb/in.² gross area	lb/in.² gross area	%	%	lb/tile
0. 50	4. 03	9, 510	3, 540	1, 590	3. 9	5. 6	35. 4

3. BLOCK

The stone-concrete blocks were made by the Cherrydale Cement Block Co., Arlington, Va. The blocks had two cells, as shown in figure 2. The average dimensions were 7.81 by 11.50 by 7.66 in. (about 7 13/16 by 11 1/2 by 7 11/16 in). The physical properties given in table 5 were determined in accordance with the American Society for Testing Materials Standard C90–36 [4] so far as this standard was applicable.

TABLE 5.—*Physical properties of block*

[Each value is the average for 10 specimens]

Thickness of face shell, minimum	Compressive strength		Water absorption, 24-hr cold	Weight, dry
in.	lb/in.² net area	lb/in.² gross area	lb/ft³ of concrete	lb/block
1. 25	2,050	1,190	10.1	29. 4

4. MORTAR

(a) *Cement*

The cement was Medusa Cement Company's "Medusa" portland cement. The cement conformed to the requirements of Federal Specification SS–C–191a for fineness, soundness, time of set, and tensile strength.

(b) *Lime*

The lime putty was made by slaking powdered high-calcium quicklime. The quicklime was Standard Lime and Stone Company's "Washington." The putty contained about 40 percent of dry hydrate and had a plasticity of over 600, measured in accordance with Federal Specification SS–L–351.

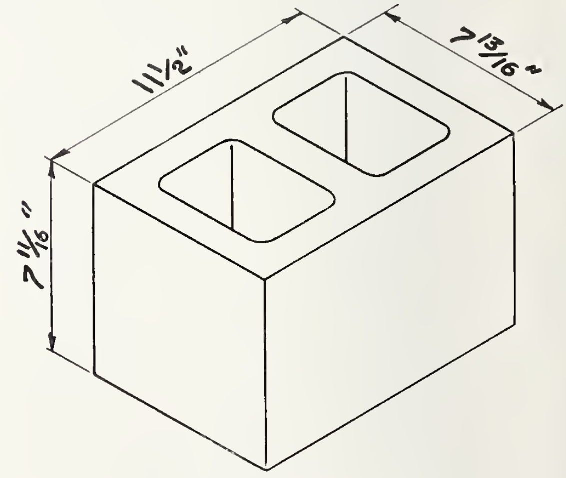


FIGURE 2.—*Stone-concrete block.*

[3] Am. Soc. Testing Materials Standards pt. II, 183–186 (1936).

[4] Am. Soc. Testing Materials Standards pt. II, 168–171 (1936).

(c) *Sand*

The sand was dry Potomac River building sand. The sieve analysis of the sand is given in table 6.

TABLE 6.—*Sieve analysis of sand*

Sieve number, U. S. Standard	Passing, by weight	Sieve number, U. S. Standard	Passing, by weight
	Percent		*Percent*
8	100	50	19
16	96	100	2
30	81	200	1

(d) *Mix*

(1) *Cement mortar.*—The cement mortar was 1 part cement, 0.11 part hydrated lime, and 2.6 parts dry sand, by weight. The proportions by volume were 1 part cement, 0.25 part hydrated lime, and 3 parts loose damp sand, assuming that portland cement weighs 94 lb/ft^3, dry hydrated lime 40 lb/ft^3, and 80 lb of dry sand is equivalent to 1 ft^3 of loose damp sand.

(2) *Cement-lime mortar.*—The cement-lime mortar was 1 part cement, 0.42 part hydrated lime, and 5.1 parts dry sand, by weight. The proportions by volume were 1 part cement, 1 part hydrated lime, and 6 parts loose damp sand.

TABLE 7.—*Physical properties of the mortars*

Construction symbol	Kind of mortar	Water content, by weight of dry materials,	Flow	Compressive strength	
				Air storage	Water storage
		%	%	lb/in.^{2}	lb/in.^{2}
AA	Cement	19.6	113	1,390	3,220
AB	Cement-lime	23.3	107	440	640
AC	do	23.2	106	465	640
AD	do	23.1	110	465	630
AE	do	23.2	113	500	645
AF	do	23.2	107	445	630

The mortars were proportioned by weight and mixed in a batch mixer having a capacity of about 2/3 ft^3. The amount of water added to the mortars was adjusted to the satisfaction of the mason. Samples were taken from every fifth or sixth batch of mortar, the flow determined in accordance with Federal Specification SS–C–181a, and six 2-in. cubes made. Three cubes were stored in water at 70° F and three stored in air on the specimen. The compressive strength of the cubes was determined on the day the corresponding wall specimen was tested. The physical properties of the mortars are given in table 7.

V. FABRICATION DATA

THE FABRICATION DATA are given in table 8. The time required for the construction of the first three specimens was not used in com-

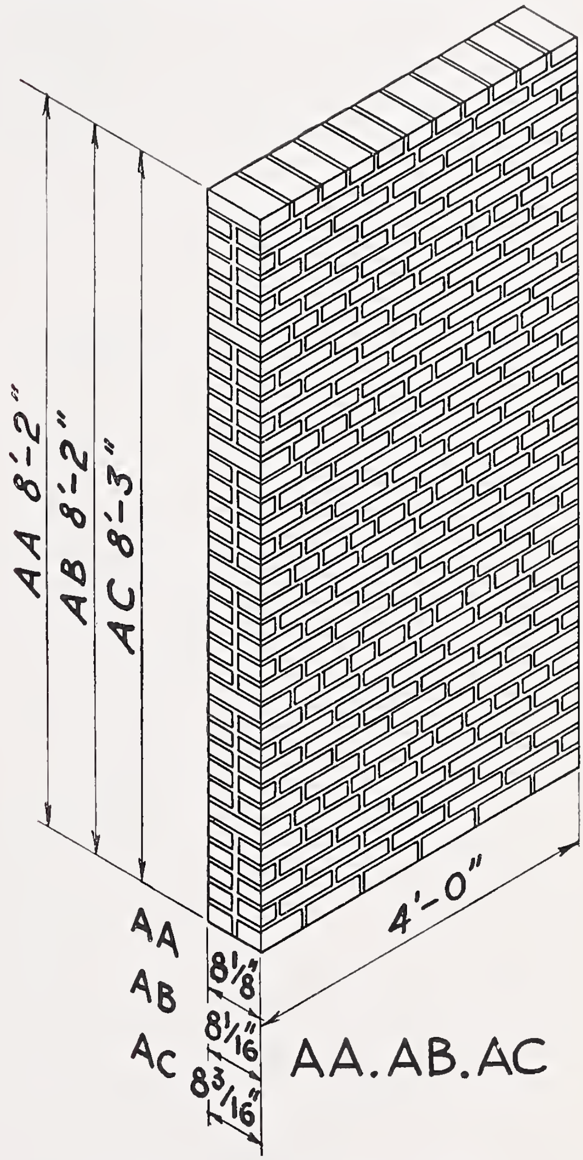


FIGURE 3.—*Four-foot brick-wall specimen.*

AA, high-strength brick, cement mortar, excellent workmanship; *AB*, medium-strength brick, cement-lime mortar, commercial workmanship; and *AC*, medium-strength brick, cement-lime mortar, excellent workmanship.

puting the values of the mason's time given in the table, because the mason was not familiar with the working conditions.

TABLE 8.—*Fabrication data*

Construction symbol	Thickness of bed joints	Masonry units	Mortar materials			Mason's time
			Cement, dry	Lime, dry	Sand, dry	
	in.	[a] No./ft^2	[a] lb/ft^2	[a] lb/ft^2	[a] lb/ft^2	[a] hr/ft^2
AA	0.398	12.6	6.37	0.70	16.55	0.161
AB	.447	12.6	2.72	1.14	13.85	.110
AC	.446	12.6	3.38	1.44	17.26	.165
AD	.326	0.915	1.44	0.61	7.35	.047
AE	.443	.917	1.11	.47	5.69	.047
AF	.441	1.47	1.48	.62	7.55	.055

[a] Face area of specimen.

VI. WALL *AA*

1. DESCRIPTION

The specimens were built with high-strength bricks laid in common American bond, as shown in figure 3, and cement mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 2 in. high, 4 ft 0 in. wide, and 8⅛ in. thick. The 8-ft wall specimens were 8 ft 3 in. high, 8 ft 0 in. wide, and 8³⁄₁₆ in. thick.

All the joints were completely filled with mortar. The bed joints were level. The head and collar joints were filled by buttering heavily the ends of bricks laid in the facing and both the ends and sides of bricks laid in the backing. The mortar was applied to the bricks by scraping the trowel against the lower edges, and unfilled portions of the joints were filled by slushing mortar from above. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was \$0.58/ft^2.

2. COMPRESSIVE LOAD

The results for wall specimens *AA–C1*, *C2*, and *C3* are shown in table 9 and in figures 4 and 5.

TABLE 9.—*Structural properties of masonry wall constructions AA, AB, AC, AD, AE, and AF*

Construction symbol	Weight	Load									
		Compressive [a]		Transverse [b]		Concentrated		Impact [b]		Racking	
		Designation	Maximum load	Designation	Maximum load	Designation	Maximum load	Designation	Maximum height of drop	Designation	Maximum load
	lb/ft^2 face area		kips/ft		lb/ft^2		lb		ft		kips/ft
		C1	249	*T1*	115	*P1*	[c] 1,000	*I1*	7.5	*R1*	[c] 6.25
AA	96.0	*C2*	378	*T2*	120	*P2*	[c] 1,000	*I2*	5.5	*R2*	[c] 6.25
		C3	344	*T3*	140	*P3*	[c] 1,000	*I3*	6.5		([d])
Average			324		125		[c] 1,000		6.5		[c] 6.25
		C1	63.2	*T1*	53.3	*P1*	[c] 1,000	*I1*	3.0	*R1*	[c] 6.25
AB	73.9	*C2*	52.5	*T2*	38.0	*P2*	[c] 1,000	*I2*	3.0	*R2*	[c] 6.25
		C3	65.8	*T3*	52.3	*P3*	[c] 1,000	*I3*	2.5	*R3*	[c] 6.25
Average			60.5		47.9		[c] 1,000		2.8		[c] 6.25
		C1	90.5	*T1*	85.0	*P1*	[c] 1,000	*I1*	4.0	*R1*	[c] 6.25
AC	78.9	*C2*	110.0	*T2*	80.0	*P2*	[c] 1,000	*I2*	3.5	*R2*	[c] 6.25
		C3	102.5	*T3*	81.7	*P3*	[c] 1,000	*I3*	3.5		([d])
Average			101.0		82.2		[c] 1,000		3.7		[c] 6.25
		C1	49.1	*T1*	41.3	*P1*	[c] 1,000	*I1*	1.0	*R1*	4.01
AD	42.6	*C2*	51.2	*T2*	35.0	*P2*	[c] 1,000	*I2*	1.0	*R2*	3.56
		C3	45.0	*T3*	39.8	*P3*	[c] 1,000	*I3*	1.5	*R3*	4.50
Average			48.4		38.7		[c] 1,000		1.2		4.02

See footnotes at end of table.

TABLE 9.—*Structural properties of masonry wall constructions AA, AB, AC, AD, AE, and AF*—Continued

Construction symbol	Weight	Load									
		Compressive [a]		Transverse [b]		Concentrated		Impact [b]		Racking	
		Designation	Maximum load	Designation	Maximum load	Designation	Maximum load	Designation	Maximum height of drop	Designation	Maximum load
	lb/ft [2] face area		kips/ft		lb/ft [2]		lb		ft		kips/ft
AE	38.9	*C1*	23.7	*T1*	58.0	*P1*	[c] 1,000	*I1*	2.5	*R1*	4.25
		C2	27.5	*T2*	76.8	*P2*	[c] 1,000	*I2*	1.5	*R2*	3.56
		C3	27.9	*T3*	56.8	*P3*	[c] 1,000	*I3*	1.5	*R3*	3.42
Average			26.4		63.9		[c] 1,000		1.8		3.74
AF	54.5	*C1*	41.2	*T1*	29.6	*P1*	[c] 1,000	*I1*	1.5	*R1*	3.49
		C2	38.8	*T2*	36.7	*P2*	[c] 1,000	*I2*	1.5	*R2*	3.05
		C3	38.2	*T3*	36.7	*P3*	[c] 1,000	*I3*	1.0	*R3*	3.00
Average			39.4		34.3		[c] 1,000		1.3		3.18

[a] Load applied at one-third the thickness of the specimen from the inside face.
[b] Span 7 ft 6 in.
[c] Specimen did not fail.
[d] A third racking specimen was not built.

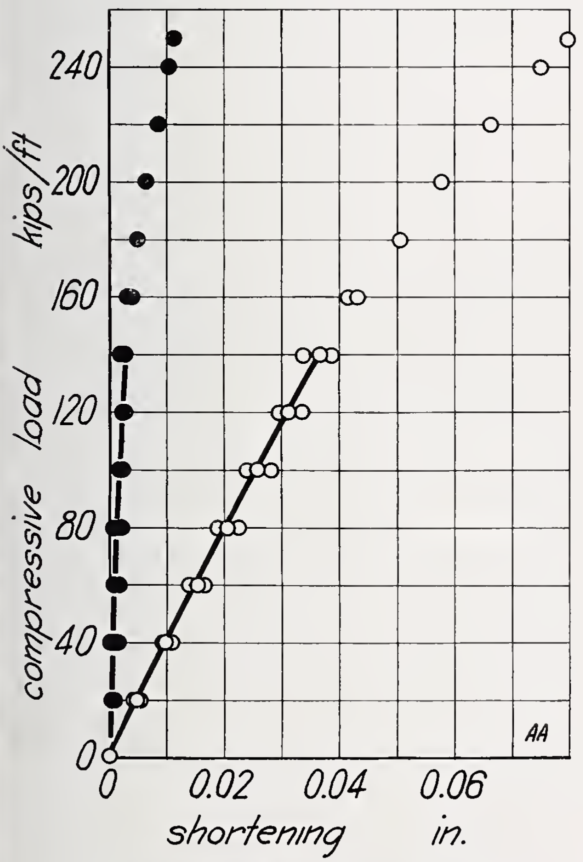


FIGURE 4.—*Compressive load on wall AA.*

Load-shortening and load-set results for specimens *AA-C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 2 in.

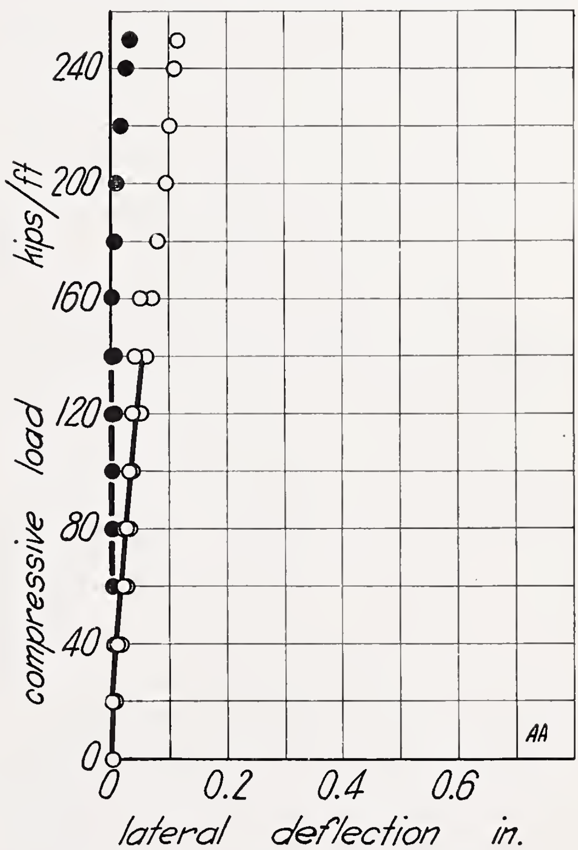


FIGURE 5.—*Compressive load on wall AA.*

Load-lateral deflection and load-lateral set results for specimens *AA-C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.

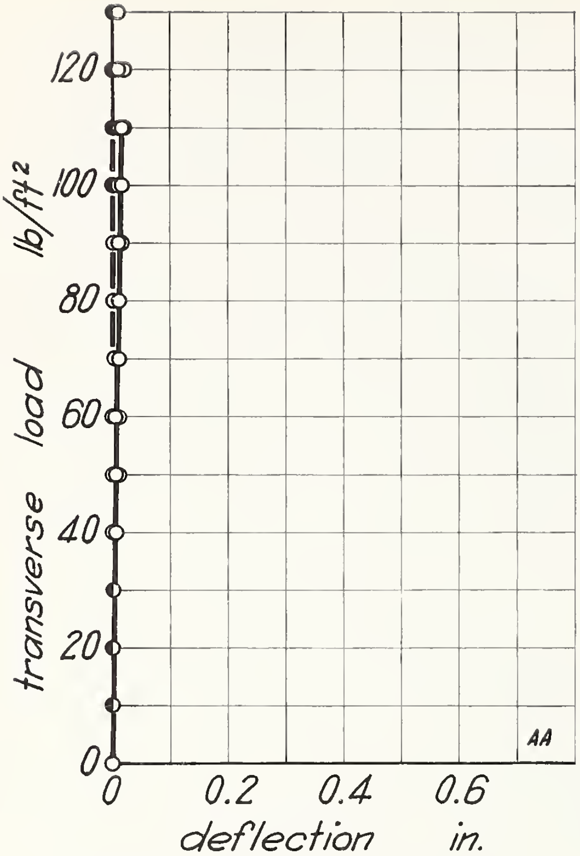


FIGURE 6.—*Transverse load on wall AA.*

Load-deflection and load-set results for specimens *AA–T1*, *T2*, and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.

Specimens *C1* and *C3* failed by rupture of the collar joints and breaking of the headers midway between the faces. Specimen *C2* collapsed suddenly, probably after the collar joints and headers broke.

3. Transverse Load

The results for wall specimens *AA–T1*, *T2*, and *T3* are shown in table 9 and in figure 6.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint between the loading rollers. In each case the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens *AA–P1*, *P2*, and *P3* are shown in table 9 and in figure 7.

There was no measurable indentation for any of the specimens after a load of 1,000 lb had been applied.

5. Impact Load

The results for wall specimens *AA–I1*, *I2*, and *I3* are shown in table 9 and in figure 8.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint near midspan. For specimens *I2* and *I3* the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

The results for wall specimens *AA–R1* and *R2* are shown in table 9 and in figure 9.

There was no measurable set for either of the specimens after a load of 50 kips (50,000 lb) had been applied. A third racking specimen was not built because for specimens *R1*

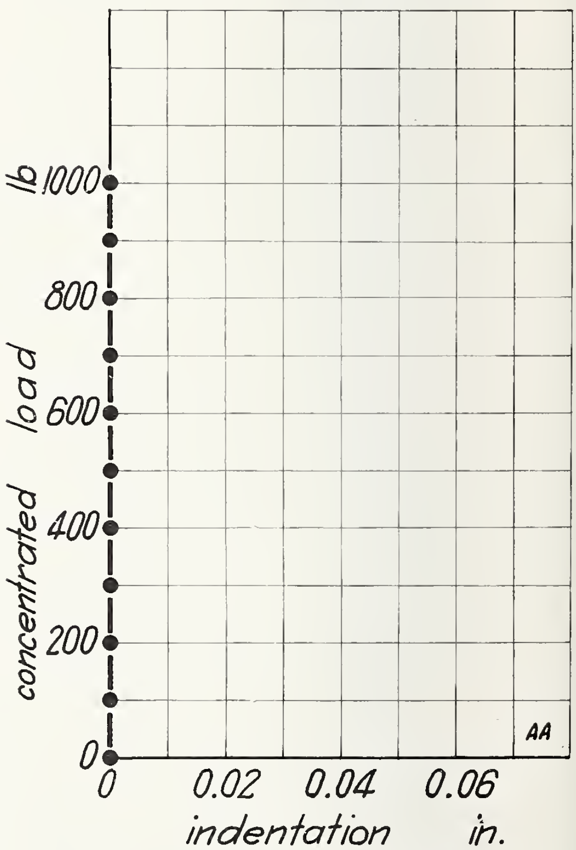


FIGURE 7.—*Concentrated load on wall AA.*

Load-indentation results for specimens *AA–P1*, *P2*, and *P3*.

and $R2$ the deformation and set were very small for a load of 50 kips.

VII. WALL *AB*

1. Description

The specimens were built with medium-strength bricks laid in common American bond, as shown in figure 3, and cement-lime mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 2 in. high, 4 ft 0 in. wide, and 8 1/16 in. thick. The 8-ft wall specimens were 8 ft 2 in. high, 8 ft 0 in. wide, and 8 1/16 in. thick.

The joints were not completely filled with mortar. The bed joints were furrowed, the collar joints were left open, as shown in figure 10, and only the outside of the head joints was filled by lightly buttering the outer edges of the bricks. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.38/ft².

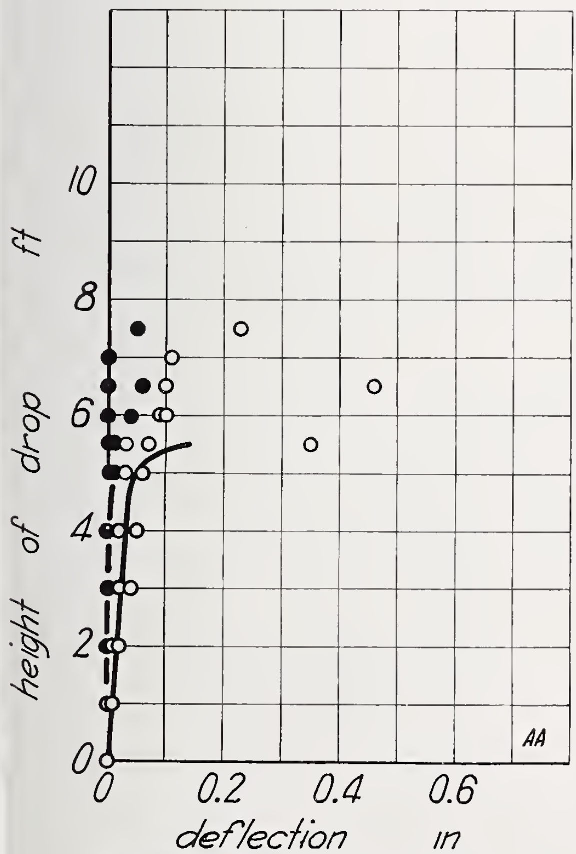


Figure 8.—*Impact load on wall AA.*

Height of drop-deflection and height of drop-set results for specimens *AA-I1, I2,* and *I3* on the span 7 ft 6 in.

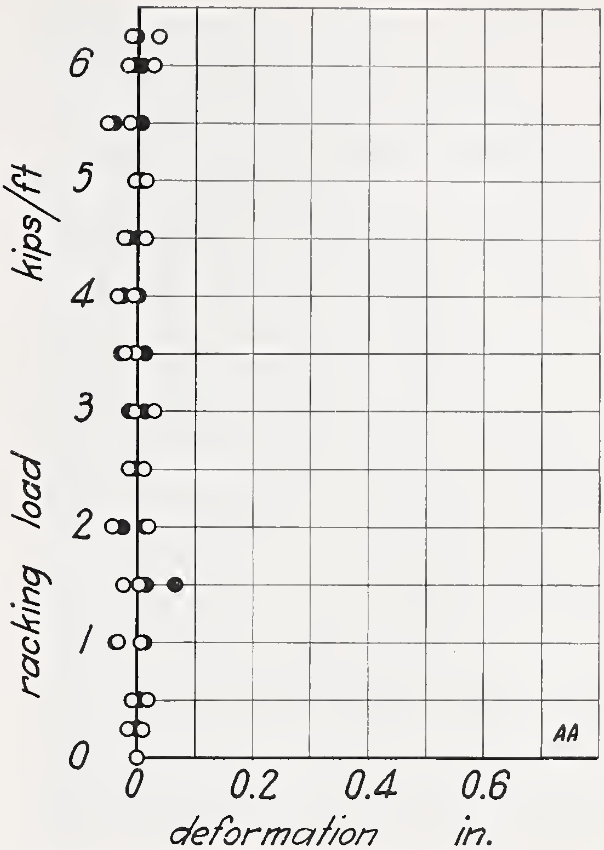


Figure 9.—*Racking load on wall AA.*

Load-deformation and load-set results for specimens *AA-R1* and *R2*. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 6 ft 0 in.

2. Compressive Load

The results for wall specimens *AB-C1, C2,* and *C3* are shown in table 9 and in figures 11 and 12.

Each of the specimens failed by breaking of the headers midway between the faces. In addition, for specimen *C1* a few stretchers cracked near the upper end of the specimen, and for specimen *C2* a few stretchers cracked on the inside face and bricks in two courses near the upper end crushed.

Figure 10.—*Wall specimen AB–T1 under transverse load.*

3. Transverse Load

The results for wall specimens *AB–T1*, *T2*, and *T3* are shown in table 9 and in figure 13.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint between the loading rollers. In each case the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens *AB–P1*, *P2*, and *P3* are shown in table 9 and in figure 14.

The indentations after a load of 1,000 lb had been applied were 0.002, 0.000, and 0.013 in. for specimens *P1*, *P2*, and *P3*, respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens *AB–I1*, *I2*, and *I3* are shown in table 9 and in figure 15.

Each of the specimens failed by rupture of a bed joint near midspan. For specimens *I2* and *I3* the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

The results for wall specimens *AB–R1*, *R2*, and *R3* are shown in table 9 and in figure 16.

The set after a load of 50 kips had been applied was less than 0.03 in. for each of the specimens and no other effect was observed.

VIII. WALL *AC*

1. Description

The specimens were built with medium-strength bricks laid in common American bond,

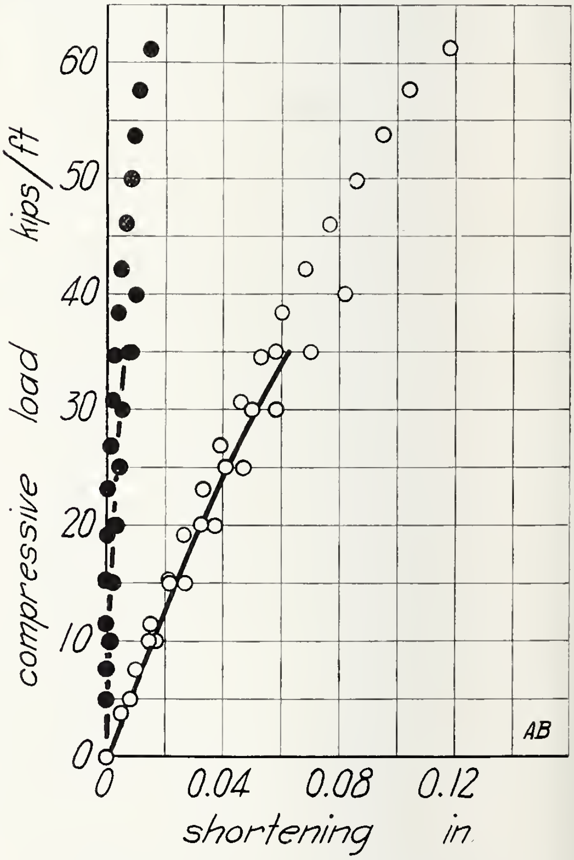


Figure 11.—*Compressive load on wall AB.*

Load-shortening and load-set results for specimens *AB–C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 3 in.

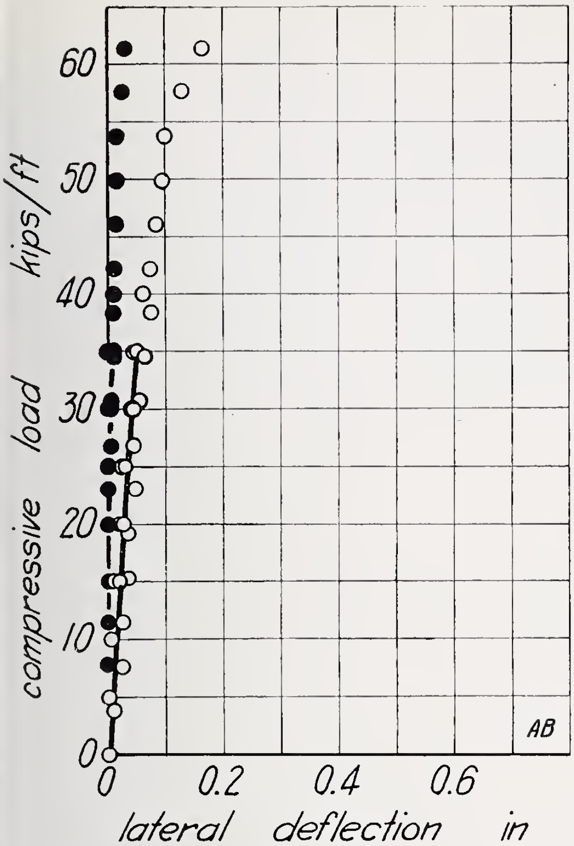


FIGURE 12.—*Compressive load on wall AB.*

Load-lateral deflection and load-lateral set results for specimens *AB–C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.

as shown in figure 3, and cement-lime mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 3 in. high, 4 ft 0 in. wide, and 8 3/16 in. thick. The 8-ft wall specimens were 8 ft 2 in. high, 8 ft 0 in. wide, and 8 1/8 in. thick.

All the joints were completely filled with mortar. The bed joints were level. The head and collar joints were filled by buttering heavily the ends of bricks laid in the facing, and both the ends and sides of bricks laid in the backing. The mortar was applied to the bricks by scraping the trowel against the lower edges, and unfilled portions of the joints were filled by slushing mortar from above. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.51/ft².

2. Compressive Load

The results for wall specimens *AC–C1*, *C2*, and *C3* are shown in table 9 and in figures 17 and 18.

Each of the specimens failed by cracking of the collar joints and breaking of some of the headers midway between the faces. In addition, for specimens *C1* and *C2* a few stretchers cracked, and for specimens *C2* and *C3* several courses of bricks fell from the facing at the upper ends of the specimens.

3. Transverse Load

The results for wall specimens *AC–T1*, *T2*, and *T3* are shown in table 9 and in figure 19.

Each of the specimens failed by rupture of either the mortar or the bond between the

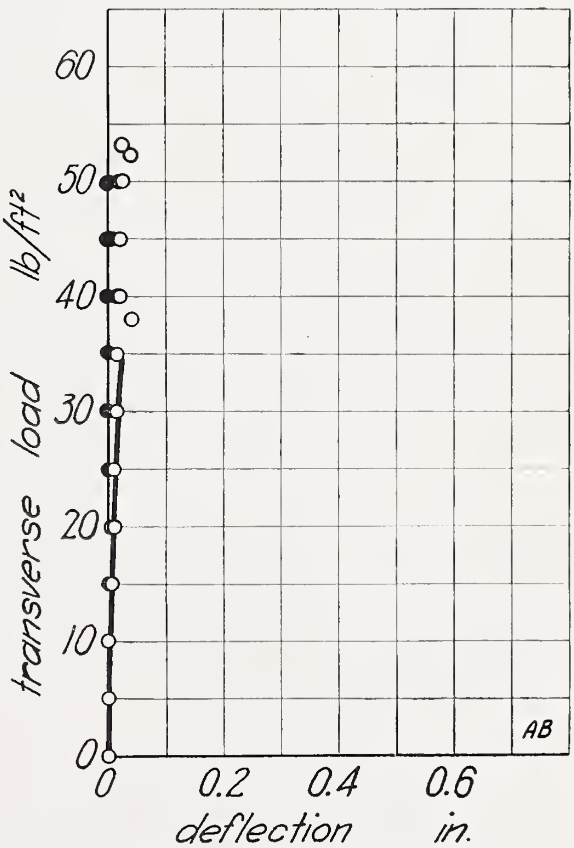


FIGURE 13.—*Transverse load on wall AB.*

Load-deflection and load-set results for specimens *AB–T1*, *T2*, and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.

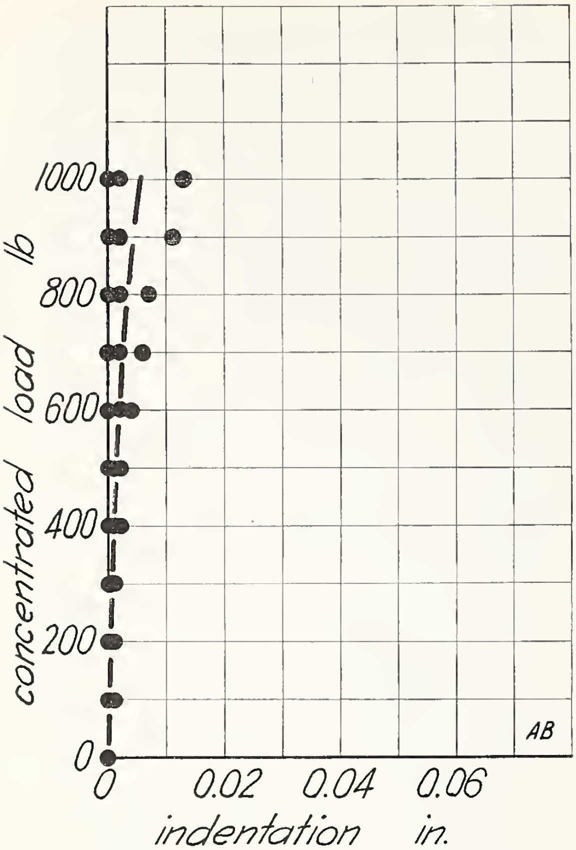


Figure 14.—*Concentrated load on wall AB.*

Load-indentation results for specimens *AB–P1, P2,* and *P3.*

bricks and the mortar at one or more bed joints between the loading rollers. For specimens *T2* and *T3* the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens *AC–P1, P2,* and *P3* are shown in table 9 and in figure 20.

The indentations after a load of 1,000 lb had been applied were 0.002, 0.000, and 0.001 in. for specimens *P1, P2,* and *P3,* respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens *AC–I1, I2,* and *I3* are shown in table 9 and in figure 21.

Each of the specimens failed by rupture of a bed joint near midspan. For specimens *I1* and *I2* the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

Wall specimen *AC–R1* under racking load is shown in figure 22. The results for wall specimens *AC–R1* and *R2* are shown in table 9 and in figure 23.

The sets after a load of 50 kips had been applied were 0.000 and 0.010 in. for specimens *R1* and *R2,* respectively, and no other effect was observed. A third racking specimen was not built because for specimens *R1* and *R2* the deformation and set were very small for a load of 50 kips.

IX. WALL *AD*

1. Description

The specimens were built with structural clay tiles laid on end, as shown in figure 24, and cement-lime mortar. The head joints were

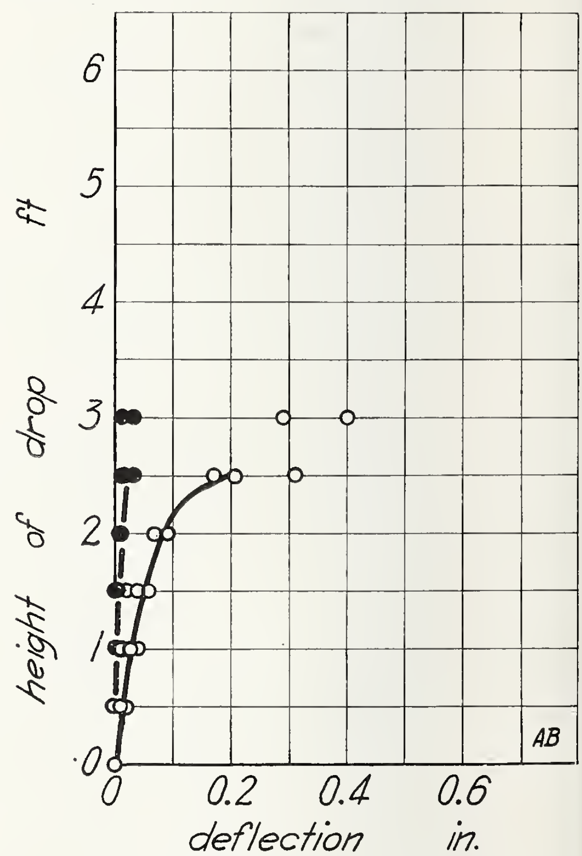


Figure 15.—*Impact load on wall AB.*

Height of drop-deflection and height of drop-set results for specimens *AB–I1, I2,* and *I3* on the span 7 ft 6 in.

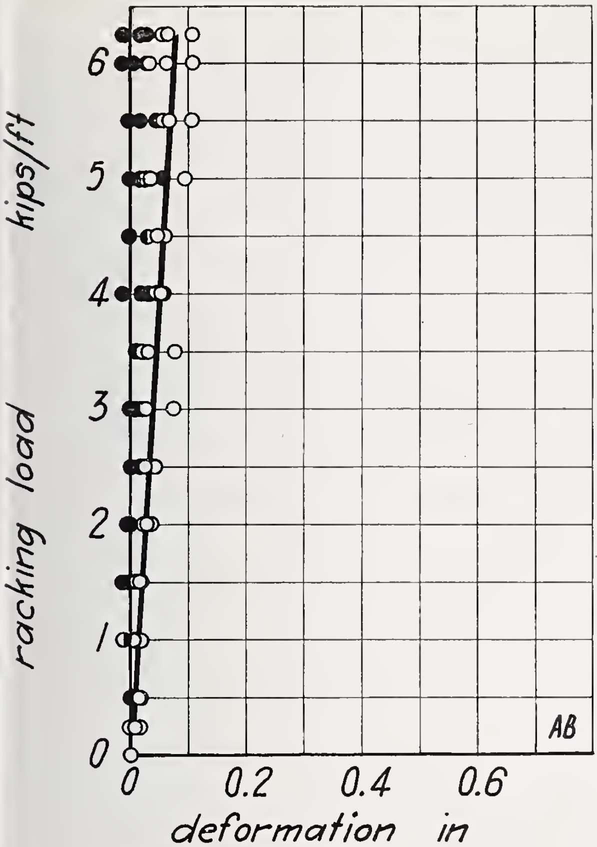


FIGURE 16.—*Racking load on wall AB.*

Load-deformation and load-set results for specimens *AB-R1, R2,* and *R3.* The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 6 ft 0 in.

staggered by using cut stretchers at the ends of alternate courses. The 4-ft wall specimens were 8 ft 4 in. high, 4 ft 2½ in. wide, and 8 1/16 in. thick. The 8-ft wall specimens were 8 ft 4 in. high, 8 ft 4 in. wide, and 8 1/16 in. thick.

All the joints were completely filled with mortar. The bed joints were made by heaping mortar on all shells and webs and the head joints were formed by spreading mortar over the entire side of the tiles before placing. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.32/ft².

2. Compressive Load

The results for wall specimens *AD–C1, C2,* and *C3* are shown in table 9 and in figures 25 and 26.

Each of the specimens failed by crushing of one or more of the bed joints near the inside face. In addition, for specimen *C2* there were two vertical cracks through some of the tiles and joints on the outside face, and for specimen *C3* the shell of one tile broke on the inside face near the upper end of the specimen.

3. Transverse Load

The results for wall specimens *AD–T1, T2,* and *T3* are shown in table 9 and in figure 27.

Each of the specimens failed by rupture of either the mortar or the bond between the tiles and the mortar at a bed joint between the loading rollers.

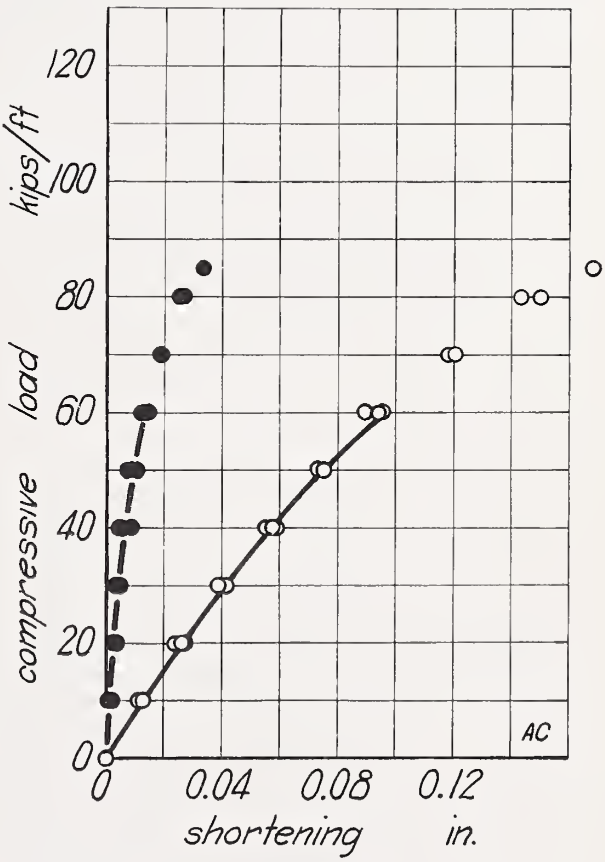


FIGURE 17.—*Compressive load on wall AC.*

Load-shortening and load-set results for specimens *AC-C1, C2,* and *C3.* Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 3 in.

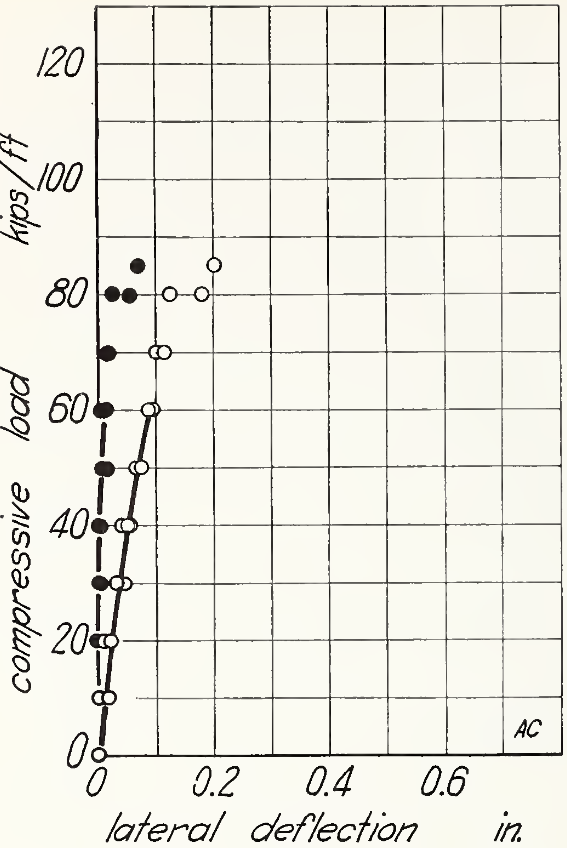
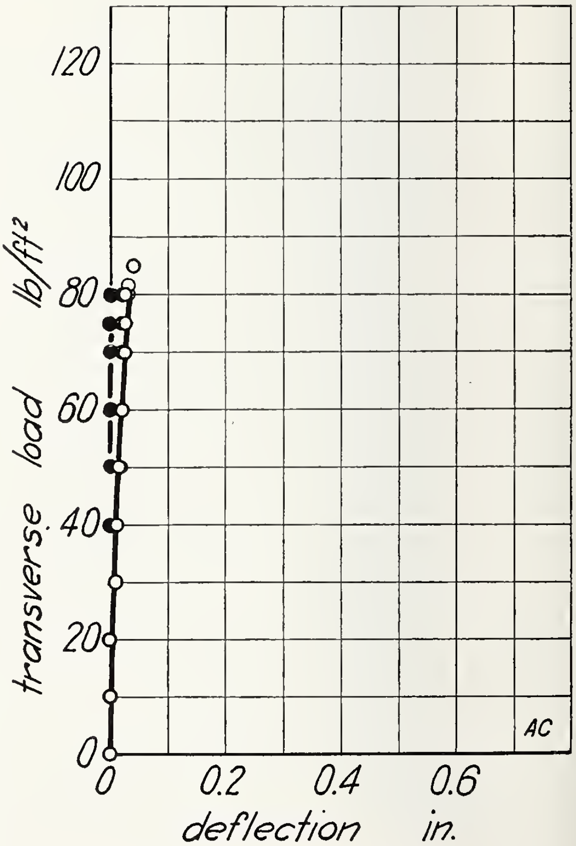


FIGURE 18.—*Compressive load on wall AC.*

Load-lateral deflection and load-lateral set results for specimens *AC–C1, C2,* and *C3.* Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.

FIGURE 19.—*Transverse load on wall AC.*

Load-deflection and load-set results for specimens *AC–T1, T2,* and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.



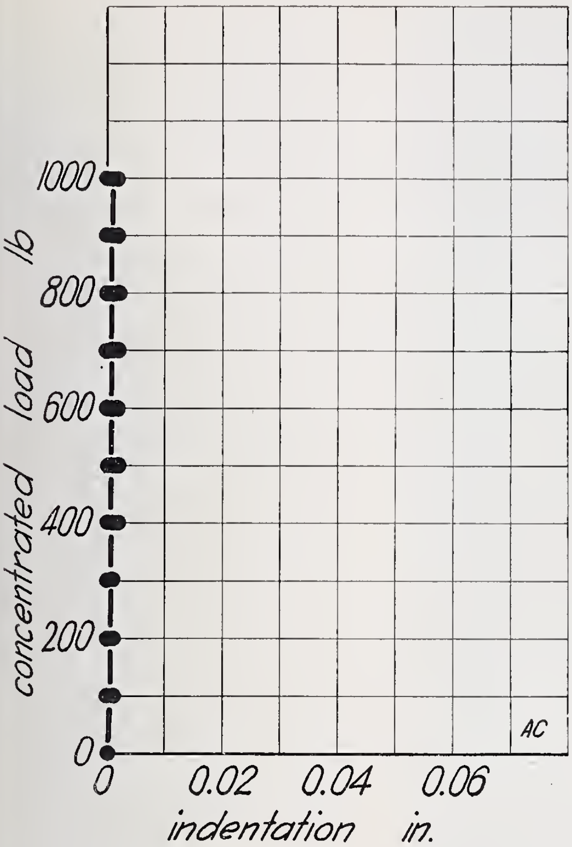


FIGURE 20.—*Concentrated load on wall AC.*

Load-indentation results for specimens *AC-P1, P2,* and *P3.*

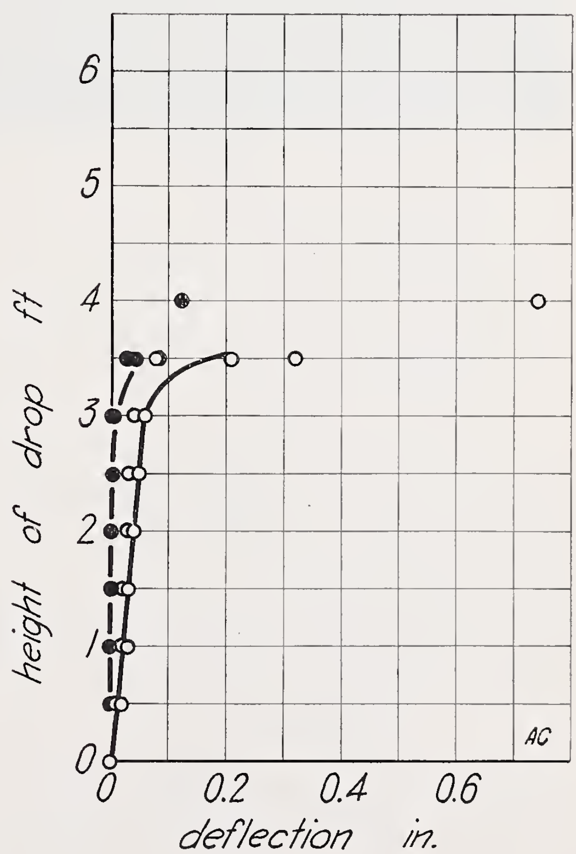


FIGURE 21.—*Impact load on wall AC.*

Height of drop-deflection and height of drop-set results for specimens *AC-I1, I2,* and *I3* on the span 7 ft 6 in.

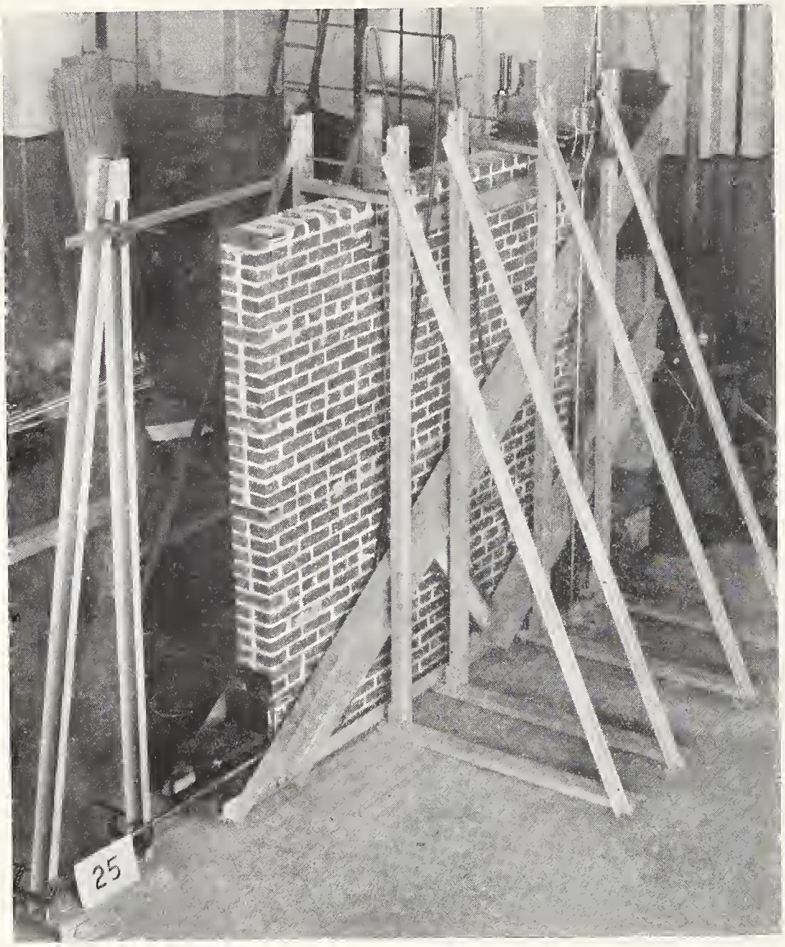


Figure 22.—*Wall specimen AC–R1 under racking load.*

4. Concentrated Load

The results for wall specimens *AD–P1*, *P2*, and *P3* are shown in table 9 and in figure 28.

The indentations after a load of 1,000 lb had been applied were 0.001, 0.000, and 0.000 in. for specimens *P1*, *P2*, and *P3*, respectively, and no other effect was observed.

5. Impact Load

Wall specimen *AD–I1* during the impact test is shown in figure 29. The results for wall specimens *AD–I1*, *I2*, and *I3* are shown in table 9 and in figure 30.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint near midspan.

6. Racking Load

The results for wall specimens *AD–R1*, *R2*, and *R3* are shown in table 9 and in figure 31.

Each of the specimens failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of the load and the stop. In addition, for specimen *R3* the bed joint under the top course broke across the entire width of the specimen.

Specimen *R1* after the racking test is shown in figure 32. The failure by stepwise cracks through the joints is typical of the failure for both the *AD* and the *AE* racking wall specimens.

X. WALL *AE*

1. Description

The specimens were built with structural clay tiles laid on side, as shown in figure 33, and cement-lime mortar. The head joints were staggered by using cut stretchers at the ends of alternate courses. The 4-ft wall specimens were 8 ft 4 in. high, 4 ft 2 in. wide, and 8 in. thick. The 8-ft wall specimens were 8 ft 4 in. high, 8 ft 4 in. wide, and 8 in. thick.

Figure 23.—*Racking load on wall AC.*

Load-deformation and load-set results for specimens *AC-R1* and *R2*. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizoutal measuring device was 5 ft 10 in.

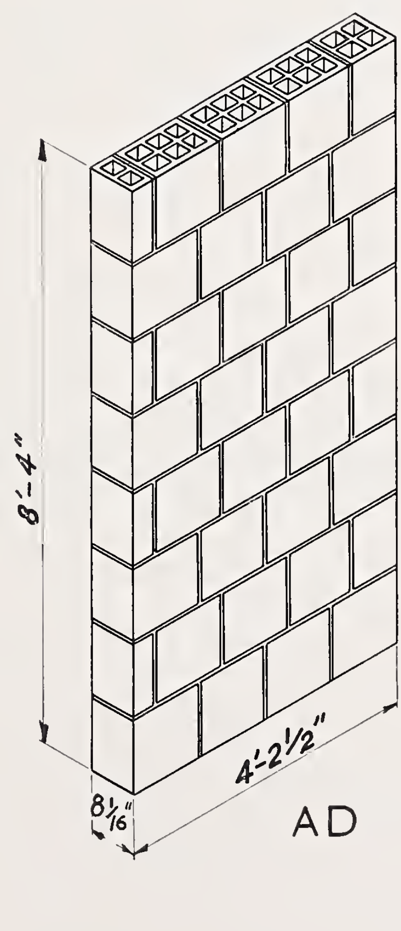


Figure 24.—*Four-foot structural clay tile-wall specimen AD.*

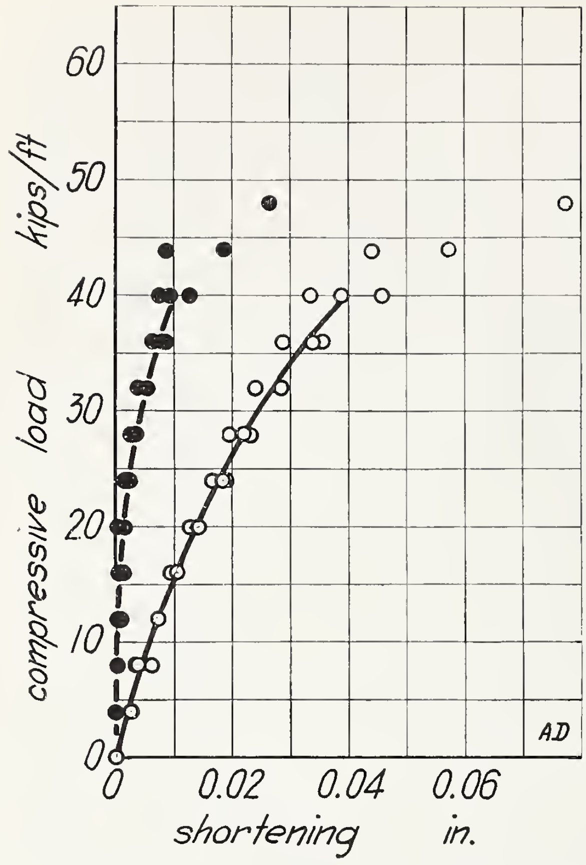


FIGURE 25.—*Compressive load on wall AD.*

Load-shortening and load-set results for specimens *AD–C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 3 in.

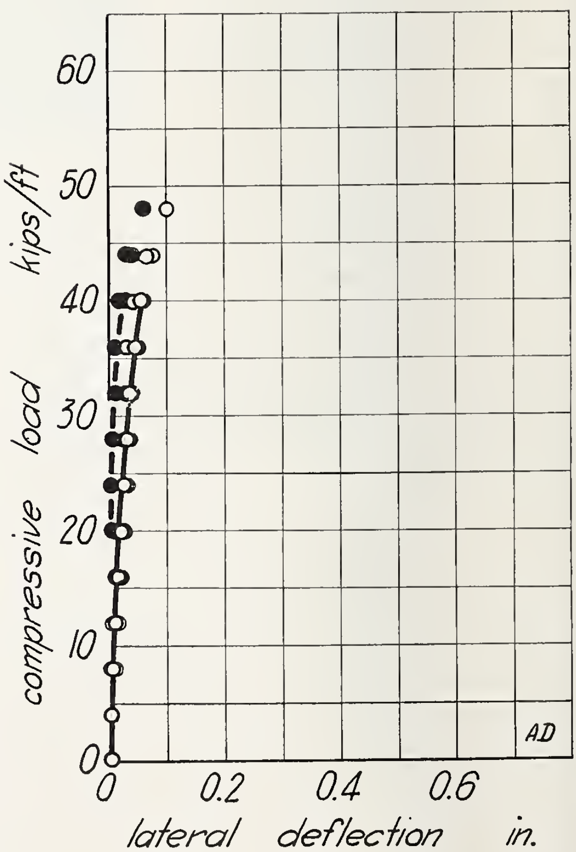


FIGURE 26.—*Compressive load on wall AD.*

Load-lateral deflection and load-lateral set results for specimens *AD–C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.

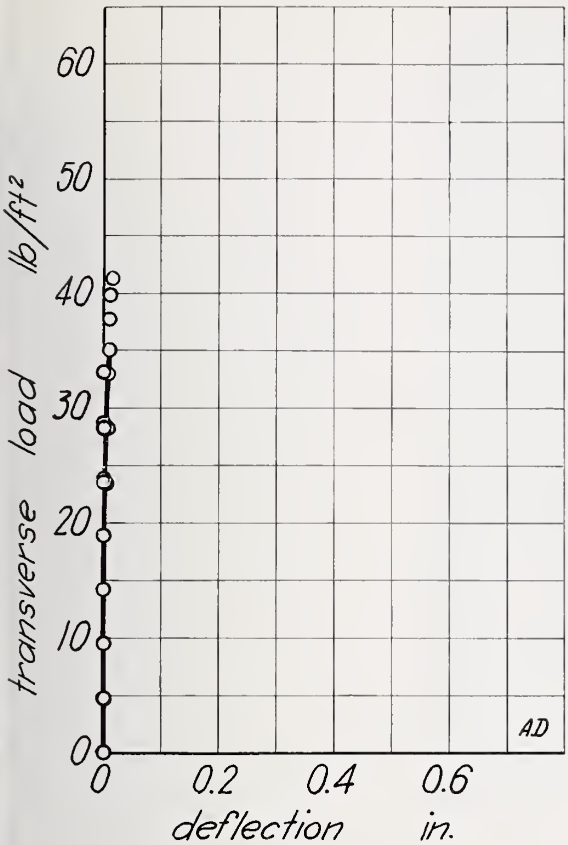


FIGURE 27.—*Transverse load on wall AD.*

Load-deflection and load-set results for specimens *AD-T1, T2,* and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.

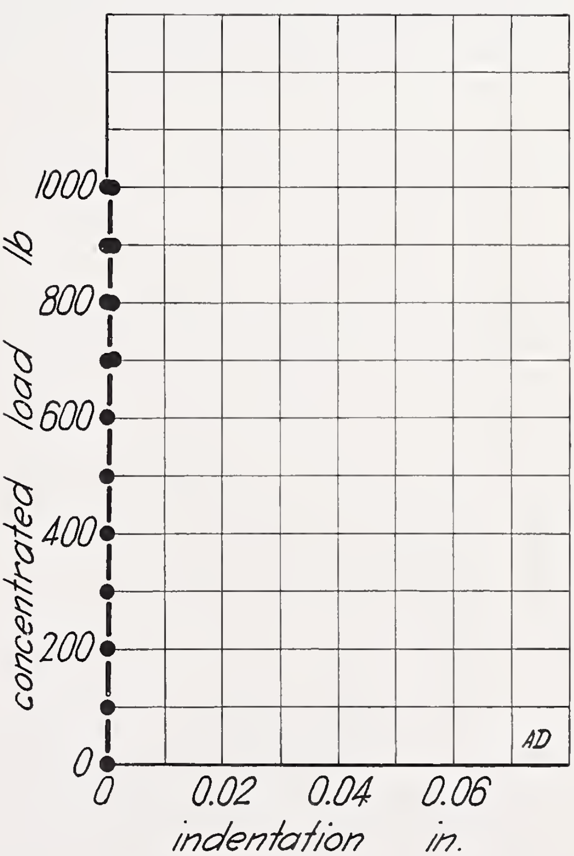


FIGURE 28.—*Concentrated load on wall AD.*

Load-indentation results for specimens *AD-P1, P2,* and *P3.*

FIGURE 29.—*Wall specimen AD–I1 during the impact test.*

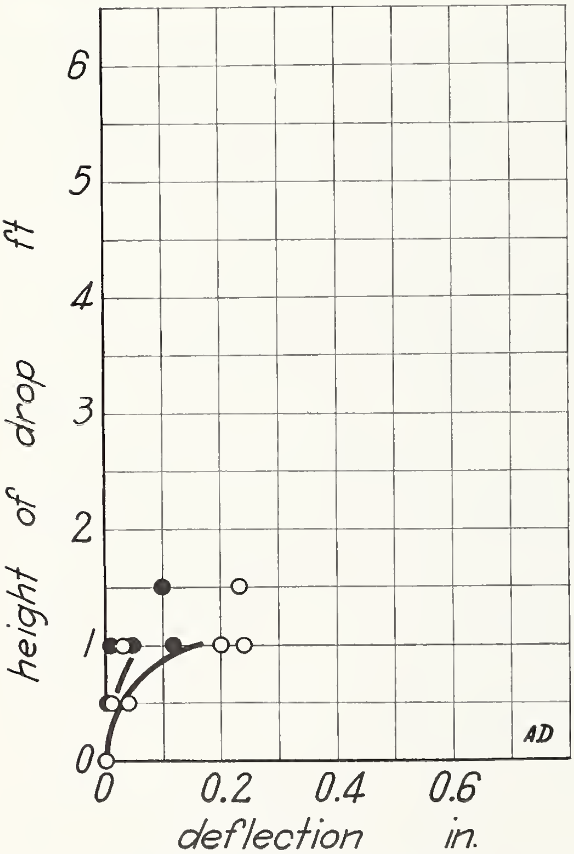


FIGURE 30.—*Impact load on wall AD.*

Height of drop-deflection and height of drop-set results for specimens *AD–I1, I2,* and *I3* on the span 7 ft 6 in.

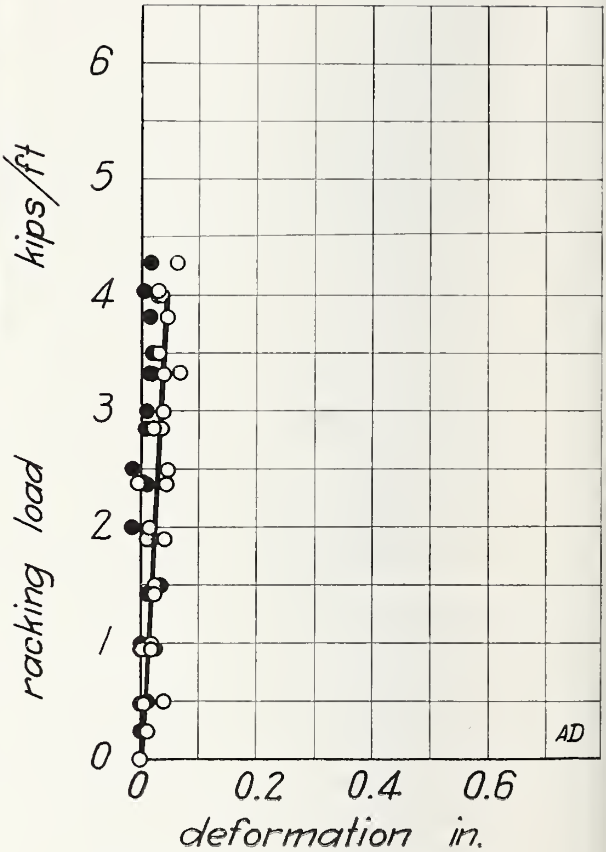


FIGURE 31.—*Racking load on wall AD.*

Load-deformation and load-set results for specimens *AD–R1, R2,* and *R3.* The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 6 ft 0 in.

FIGURE 32.—*Wall specimen AD–R1 after the racking test.*

The load was applied to the right edge near the upper end of the specimen.

All the joints were completely filled with mortar. The bed joints were level. The head joints were made by buttering the ends of all shells and webs. To prevent mortar from dropping off the shells when placing, the tiles were buttered and then tapped lightly against the mortar board with the cells in a vertical position. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.31/ft^2.

2. COMPRESSIVE LOAD

The results for wall specimens *AE–C1*, *C2*, and *C3* are shown in table 9 and in figures 34 and 35.

Each of the specimens failed by breaking of the tiles in the two courses at the upper end of the specimen. In addition, for specimen *C3* the inside face of the tiles in a third course broke.

3. TRANSVERSE LOAD

The results for wall specimens *AE–T1*, *T2*, and *T3* are shown in table 9 and in figure 36.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint between or near one of the loading rollers.

4. CONCENTRATED LOAD

The results for wall specimens *AE–P1*, *P2*, and *P3* are shown in table 9 and in figure 37.

For specimen *P1*, the indentation after a load of 1,000 lb had been applied was 0.004 in. and the tile was slightly spalled where the load was applied. For specimens *P2* and *P3*, the indentations after a load of 1,000 lb had been applied were 0.001 and 0.000 in., respectively, and no other effect was observed.

5. IMPACT LOAD

The results for wall specimens *AE–I1*, *I2*, and *I3* are shown in table 9 and in figure 38.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint near midspan.

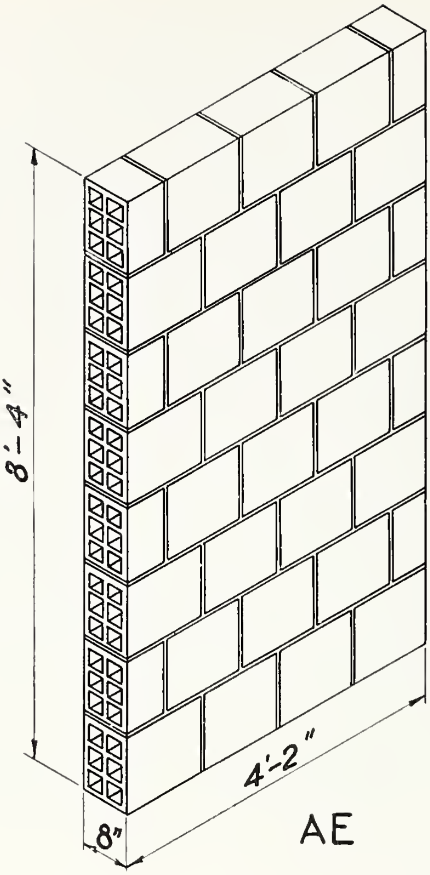


Figure 33.—*Four-foot structural clay tile wall-specimen AE.*

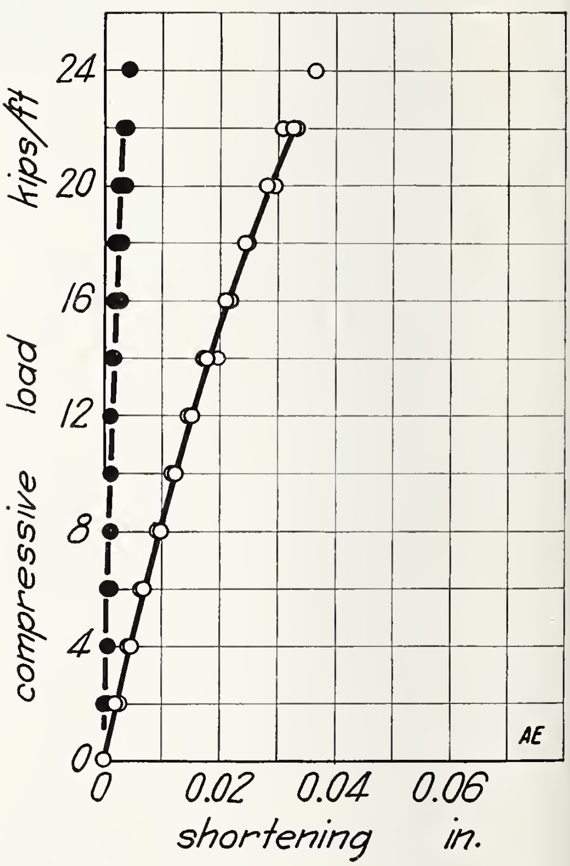


Figure 34.—*Compressive load on wall AE.*

Load-shortening and load-set results for specimens *AE-C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 3 in.

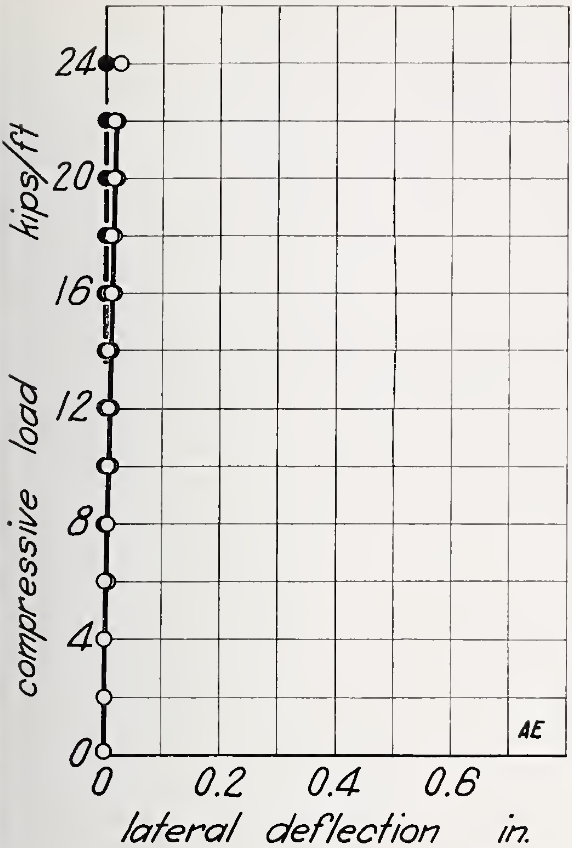
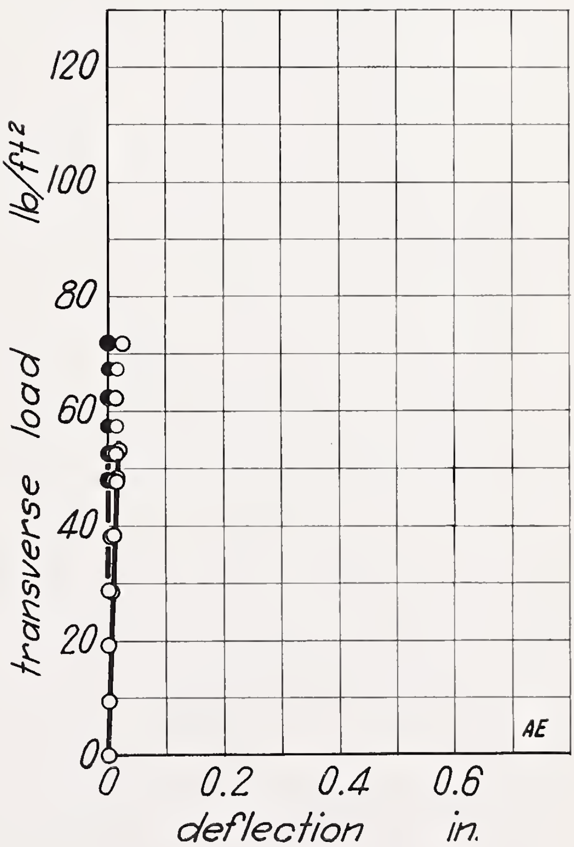


Figure 35.—*Compressive load on wall AE.*

Load-lateral deflection and load-lateral set results for specimens *AE–C1, C2,* and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.

Figure 36.—*Transverse load on wall AE.*

Load-deflection and load-set results for specimens *AE–T1, T2,* and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.



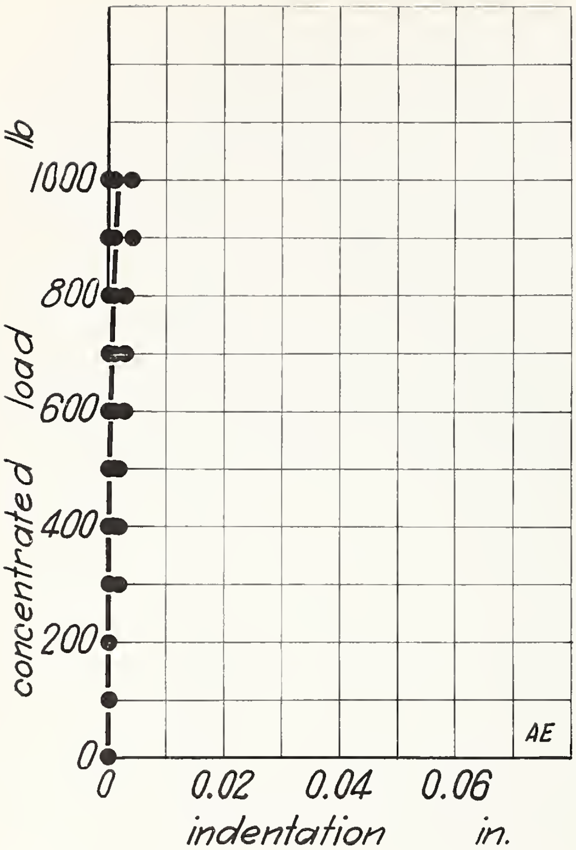


FIGURE 37.—*Concentrated load on wall AE.*

Load-indentation results for specimens *AE-P1*, *P2*, and *P3*.

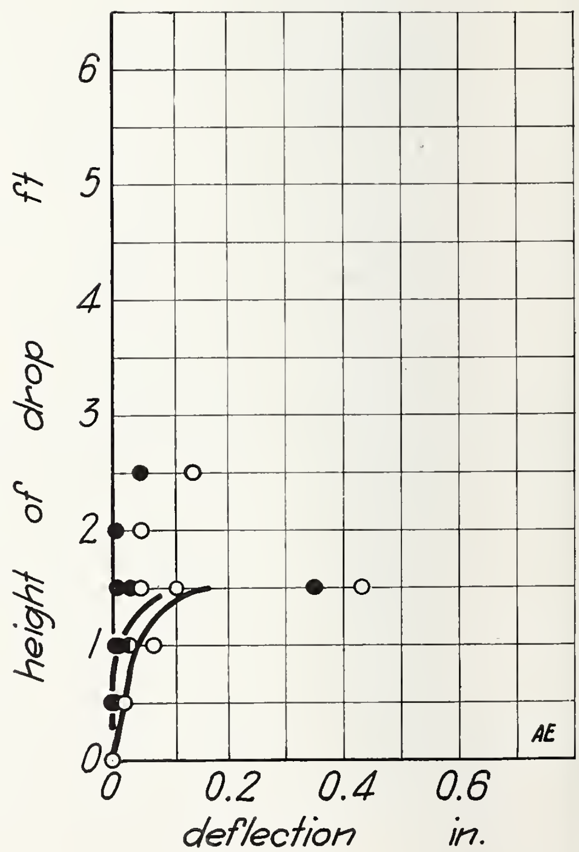


FIGURE 38.—*Impact load on wall AE.*

Height of drop-deflection and height of drop-set results for specimens *AE-I1*, *I2*, and *I3* on the span 7 ft 6 in.

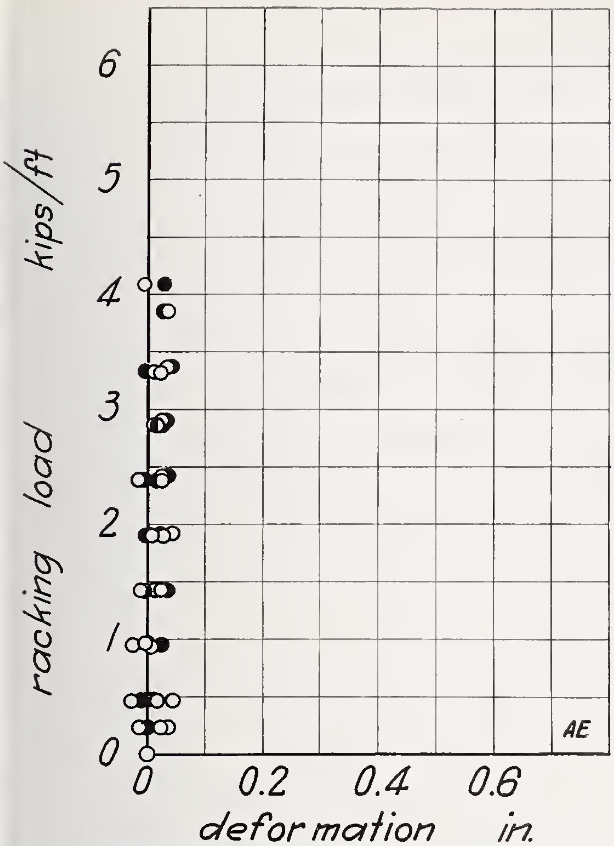


FIGURE 39.—*Racking load on wall AE.*

Load-deformation and load-set results for specimens *AE–R1*, *R2*, and *R3*. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 6 ft 0 in.

6. Racking Load

The results for wall specimens *AE–R1*, *R2*, and *R3* are shown in table 9 and in figure 39. Each of the specimens failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of load and the stop. In addition, for specimen *R1*, several tiles broke.

XI. WALL *AF*

1. Description

The specimens were built with stone concrete blocks and cement-lime mortar as shown in figure 40. The head joints were staggered by using cut stretchers at the ends of alternate courses. The 4-ft wall specimens were 8 ft 1 in. high, 4 ft 0 in. wide, and 7$^{13}/_{16}$ in. thick, except for specimens *T1*, *T2*, *T3*, and *I3*, which were 8 ft 9 in. high. The 8-ft wall specimens were 8 ft 1 in. high, 8 ft 0 in. wide, and 7$^{13}/_{16}$ in. thick.

All the joints were completely filled with mortar. The bed joints were made by heaping mortar over all shells and webs and the head joints were formed by spreading mortar over the entire end of the block before placing. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was \$0.30/ft^2.

2. Compressive Load

Wall specimen *AF–C1* under compressive load is shown in figure 41. The results for wall specimens *AF–C1*, *C2*, and *C3* are shown in table 9 and in figures 42 and 43.

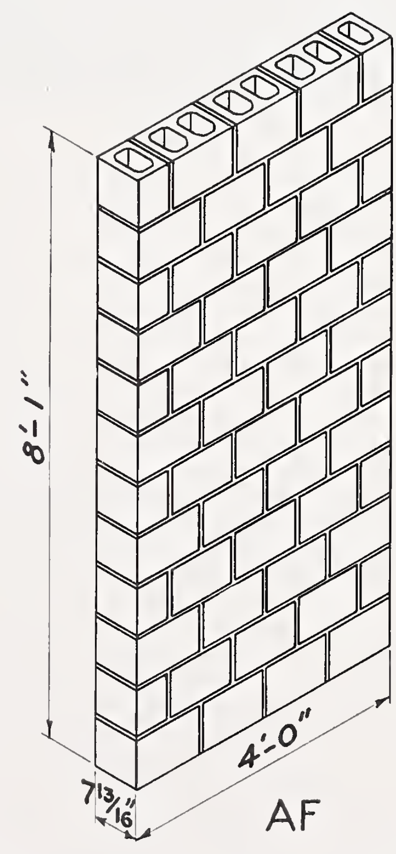


FIGURE 40.—*Four-foot stone-concrete block wall specimen AF.*

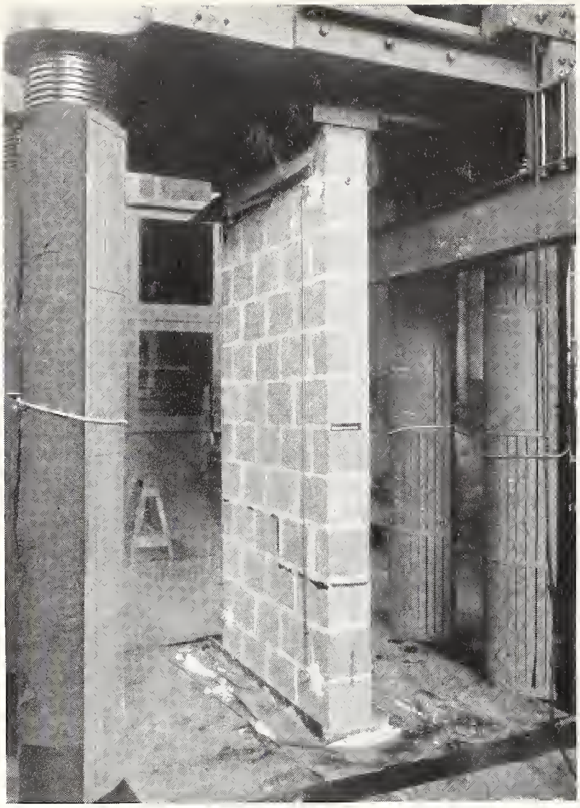
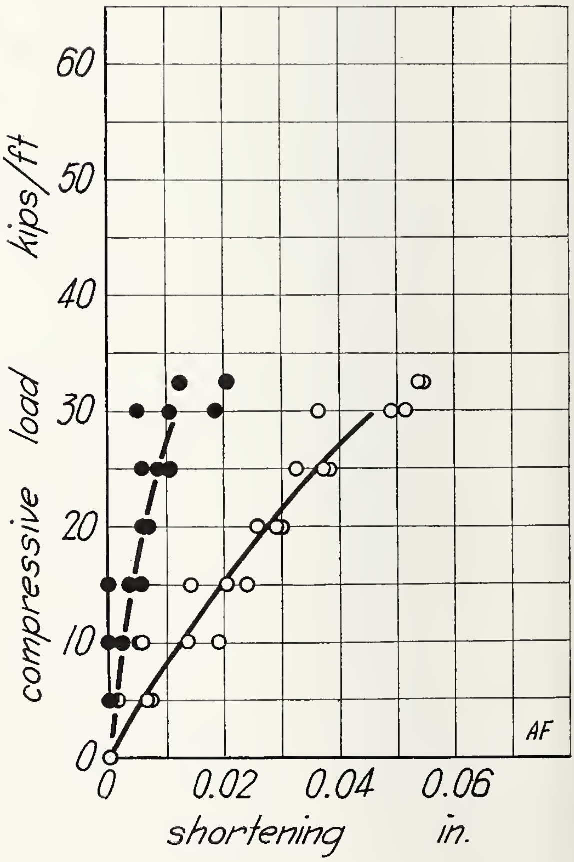


FIGURE 41.—*Wall specimen AF–C1 under compressive load.*

FIGURE 42.—*Compressive load on wall AF.*

Load-shortening and load-set results for specimens *AF–C1*, *C2*, and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 9 in.



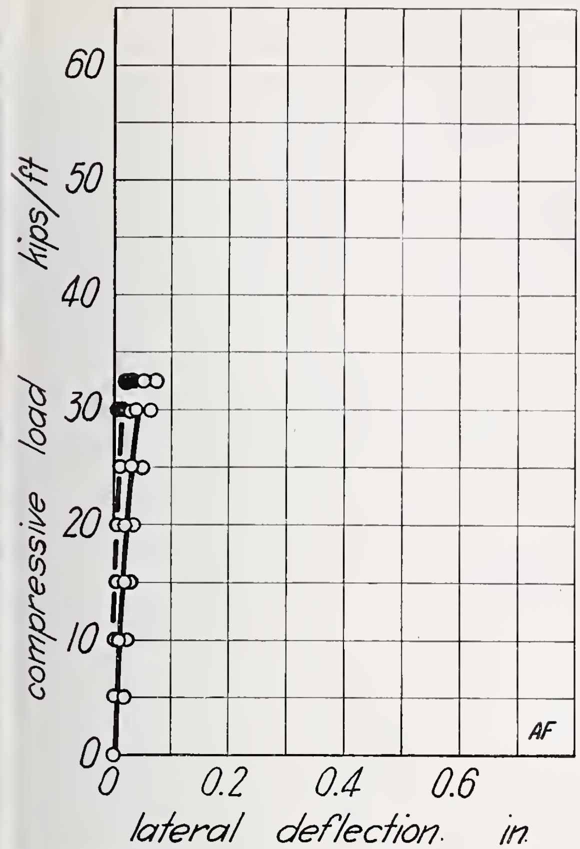


FIGURE 43.—*Compressive load on wall AF.*

Load-lateral deflection and load-lateral set results for specimens *AF–C1, C2,* and *C3*. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 9 in., the gage length of the deflectometers.

Specimens *C1* and *C3* failed by cracking of the blocks near the upper end of the specimens. The cracks occurred on one edge and on the inside face of the specimens. Specimen *C2* failed by cracking of the blocks on one edge, crushing of a bed joint, and breaking of the inside face of the blocks in one course near the upper end of the specimen.

3. Transverse Load

The results for wall specimens *AF–T1, T2,* and *T3* are shown in table 9 and in figure 44.

Specimen *T1* failed by rupture of both the mortar and the bond between the blocks and the mortar at a bed joint near one of the loading rollers. Specimen *T2* failed by rupture of the bond between the blocks and the mortar at a bed joint near one of the loading rollers, and specimen *T3* failed by rupture of the bond between the blocks and the mortar at a bed joint between the loading rollers.

4. Concentrated Load

The results for wall specimens *AF–P1, P2,* and *P3* are shown in table 9 and in figure 45.

The indentations after a load of 1,000 lb had been applied were 0.000, 0.004, and 0.002 in. for specimens *P1, P2,* and *P3*, respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens *AF–I1, I2,* and *I3* are shown in table 9 and in figure 46.

Each of the specimens failed by rupture of the mortar at a bed joint in the middle half of the specimen.

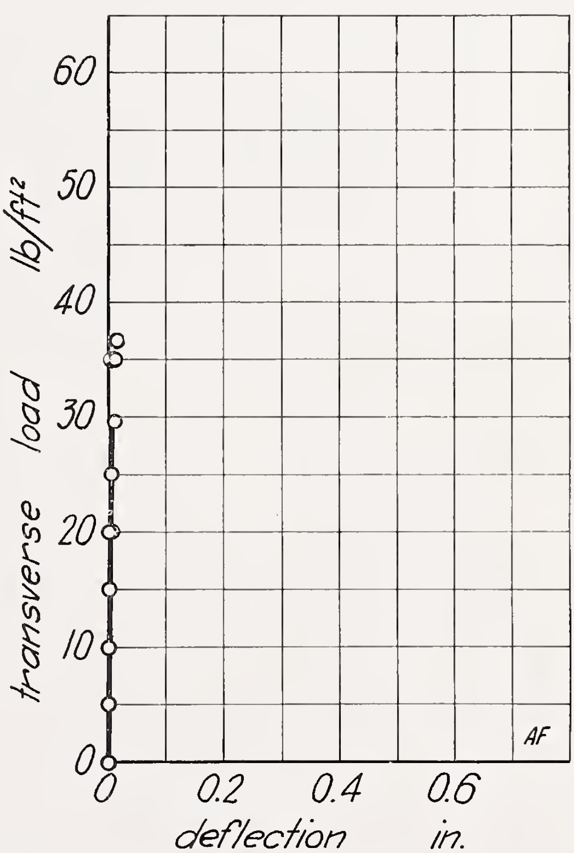


FIGURE 44.—*Transverse load on wall AF.*

Load-deflection and load-set results for specimens *AF–T1, T2,* and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 5 in., the gage length of the deflectometers.

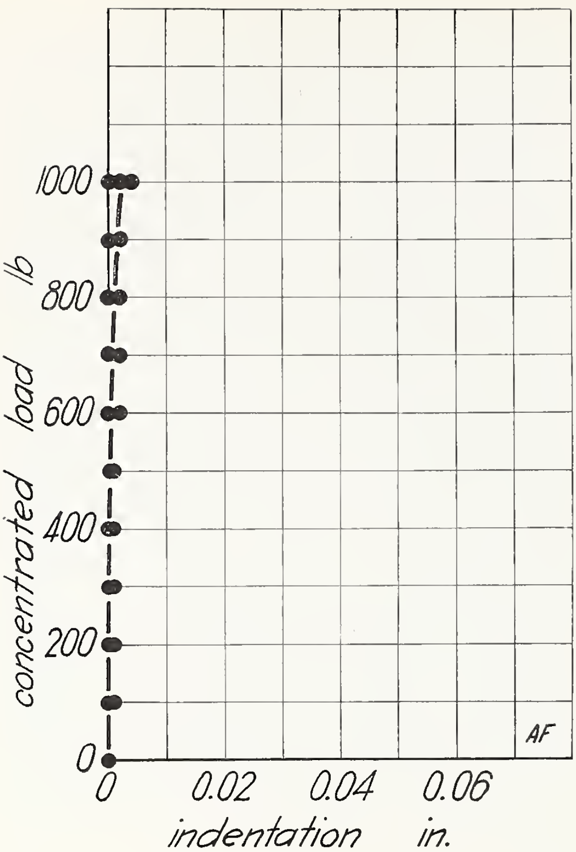


Figure 45.—*Concentrated load on wall AF.*

Load-indentation results for specimens *AF–P1*, *P2*, and *P3*.

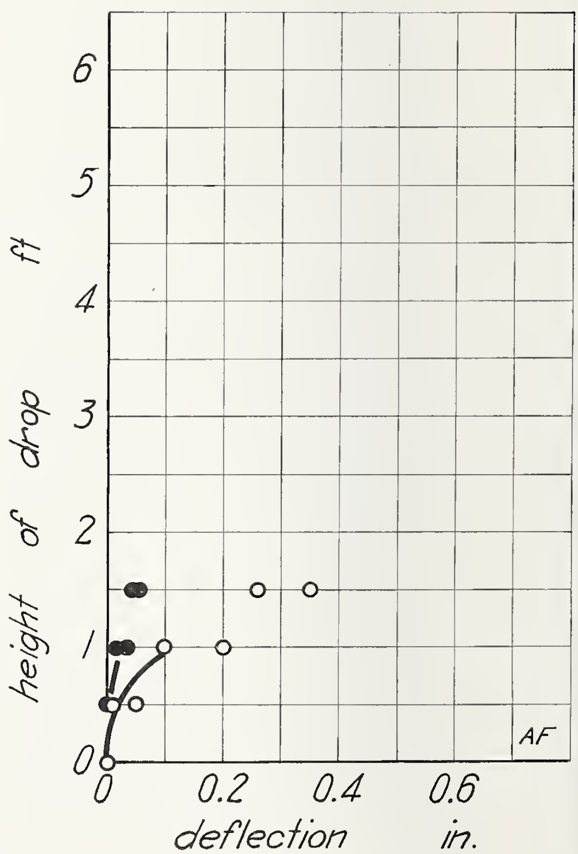


Figure 46.—*Impact load on wall AF.*

Height of drop-deflection and height of drop-set results for specimens *AF–I1*, *I2*, and *I3* on the span 7 ft 6 in.

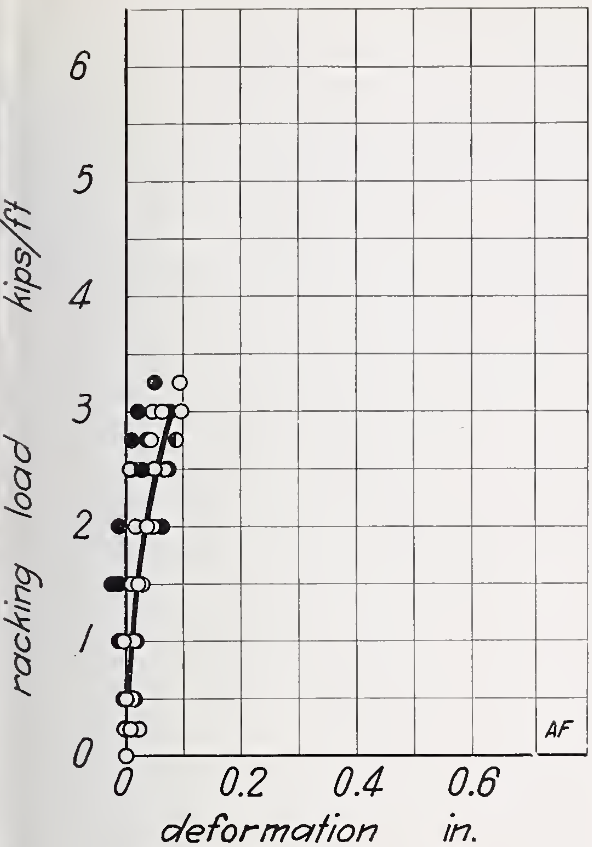


FIGURE 47.—*Racking load on wall AF.*

Load-deformation and load-set results for specimens *AF–R1*, *R2*, and *R3*. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 6 ft 0 in.

6. Racking Load

The results for wall specimens *AF–R1*, *R2*, and *R3* are shown in table 9 and in figure 47.

Specimen *R1* failed by rupture of the bond between the blocks and the mortar in stepwise cracks through the bed and head joints approximately along a diagonal between the point of application of load and the stop. Two blocks were broken at the lower end of the specimen near the edge at the stop. Specimens *R2* and *R3* failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of load and the stop. In addition, a few blocks near the point of application of load cracked.

XII. COMMENTS

It Is Customary when building houses of these constructions to finish the inside face of the walls either by applying wood furring strips, lath, and plaster, or by applying the plaster directly to the wall. These specimens were not finished in either of these ways; therefore, the structural properties given in this report may not be exactly the same as the structural properties of the corresponding construction as customarily finished in a house. It is believed that the difference, if any, is so small, except for concentrated loads and possibly impact loads, that the structural properties given in this report may be considered as the structural properties for the corresponding construction whatever the finish on the inside face.

The experimental data in this report were obtained from tests made by the Engineering Mechanics Section, under the supervision of H. L. Whittemore and A. H. Stang, and the Masonry Construction Section, under the supervision of D. E. Parsons. The following members of the professional staff participated in the work: C. C. Fishburn, F. Cardile, R. C. Carter, H. Dollar, M. Dubin, A. H. Easton, A. S. Endler, C. D. Johnson, T. M. Kelly, P. H. Petersen, A. J. Sussman, and L. R. Sweetman.

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1885	*Compression of common, hardburnt, and face brick* (used in pier tests of 1886 and 1891), Watertown Arsenal Tests of Metals, etc., 1138–1161.
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Year	Transverse Strength of Masonry Walls
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WASHINGTON, June 15, 1938.

The *National Bureau of Standards* was established by act of Congress, approved March 3, 1901, continuing the duties of the old Office of Standard Weights and Measures of the United States Coast and Geodetic Survey. In addition, new scientific functions were assigned to the new Bureau. Originally under the Treasury Department, the Bureau was transferred in 1903 to the Department of Commerce and Labor (now the United States Department of Commerce). It is charged with the development, construction, custody, and maintenance of reference and working standards, and their intercomparison, improvement, and application in science, engineering, industry, and commerce.

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