U. S. DEPARTMENT OF COMMERCE

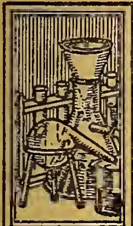
BUILDING MATERIALS AND STRUCTURES

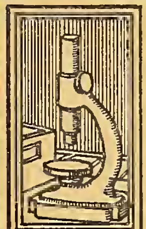
REPORT BMS24

Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute

by

HERBERT L. WHITTEMORE
AMBROSE H. STANG, *and*
CYRUS C. FISHBURN





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by HERBERT L. WHITTEMORE, AMBROSE H. STANG,
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ISSUED AUGUST 24, 1939

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

This report is one of a series issued by the National Bureau of Standards on the structural properties of constructions intended for low-cost houses and apartments. Practically all of these constructions were sponsored by groups within the building industry which advocate and promote the use of such constructions and which have built and submitted representative specimens as outlined in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions. The sponsor is responsible for the representative character of the specimens and for the description given in each report. The Bureau is responsible for the test data.

This report covers only the load-deformation relations and strength of the walls of a house when subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods simulating the loads to which the walls would be subjected in actual service. It may be feasible later to determine the heat transmission at ordinary temperatures and the fire resistance of these constructions and perhaps other properties.

The National Bureau of Standards does not "approve" a construction, nor does it express an opinion as to the merits of a construction, for the reasons given in reports BMS1 and BMS2. The technical facts on these and other constructions provide the basic data from which architects and engineers can determine whether a construction meets desired performance requirements.

Lyman J. Briggs, *Director.*

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CONTENTS

ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Structural Clay Products Institute submitted 9 specimens representing a reinforced-brick wall construction and 18 specimens representing a brick-tile cavity-wall construction.

The reinforced-brick wall specimens were subjected to compressive, transverse, concentrated, and impact loads. The brick-tile cavity-wall specimens were subjected to compressive, transverse, concentrated, impact, and racking loads. The transverse, concentrated, and impact loads were applied to both faces of the brick-tile cavity-wall specimens. For each 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, except for concentrated loads, for which the set only was determined. The results are presented graphically and in tables.

I. INTRODUCTION

In order to provide technical facts on the performance of constructions which might be used in low-cost houses, to discover promising constructions, and ultimately to determine the properties necessary for acceptable performance, the National Bureau of Standards has invited the building industry to cooperate in a program of research on building materials and structures for use in low-cost houses and apartments. The objectives of this program are described in report BMS1, Research on Building Materials and Structures for Use in Low-Cost Housing, and that part of the program relating to structural properties in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions.

As a part of the research on structural properties, six masonry wall constructions have been subjected to a series of standardized laboratory tests to provide data on the properties of some constructions for which the behavior in service is generally known. These data are given in report BMS5, Structural Properties of Six Masonry Wall Constructions. Similar tests have been made on wood-frame constructions by the Forest Products Laboratory of the

United States Department of Agriculture, the results of which will be given in a subsequent report in this series.

The present report describes the structural properties of two wall constructions sponsored by one of the groups in the building industry. The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads, simulating loads to which the elements of a house are subjected. In actual service, compressive loads on a wall are produced by the weight of the roof, second floor and second-story walls, if any, furniture and occupants, wind load on adjoining second-story walls, and snow and wind loads on the roof. Transverse loads on a wall 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 deformation and set under each increment of load were measured because the suitability of a wall construction depends in part on its resistance to deformation under load and whether it returns to its original size and shape when the load is removed.

II. SPONSOR AND PRODUCT

The specimens were submitted by the Structural Clay Products Institute, Washington, D. C., and represented a reinforced and grouted brick wall construction designed to resist transverse loads, such as those caused by high winds and earthquakes, and a brick-tile cavity-wall construction which has been used extensively in Europe.

The reinforced-brick wall specimens were built with a brick facing and backing connected (bonded) by steel wall ties, and reinforced by steel bars set in grout in the vertical collar joint between the facing and backing. The bed joints and the outside of the head joints were cement mortar. The collar joint and the inside of the head joints were filled with grout.

The brick-tile cavity-wall specimens were built with a brick facing and a structural clay-tile backing separated by an air space and connected by steel wall ties. The joints were cement-lime mortar.

III. SPECIMENS AND TESTS

The reinforced-brick wall construction was assigned the symbol *AT*, and the brick-tile cavity wall was assigned the symbol *AU*. The specimens were assigned the designations given in table 1.

Table 1.—*Specimen designations*

Element	Construction symbol	Specimen designation	Load	Load applied
Wall	*AT*	*C1, C2, C3*	Compressive	Upper end.
Do	*AT*	*T1, T2, T3*	Transverse	Either face.
Do	*AT*	*P1, P2, P3* [a]	Concentrated	Do.
Do	*AT*	*I1, I2, I3*	Impact	Do.
Do	*AU*	*C1, C2, C3*	Compressive	Upper end.
Do	*AU*	*T1, T2, T3*	Transverse	Inside face.
Do	*AU*	*T4, T5, T6*	do	Outside face.
Do	*AU*	*P1, P2, P3* [a]	Concentrated	Inside face.
Do	*AU*	*P4, P5, P6* [a]	do	Outside face.
Do	*AU*	*I1, I2, I3*	Impact	Inside face.
Do	*AU*	*I4, I5, I6*	do	Outside face.
Do	*AU*	*R1, R2, R3*	Racking	Near upper end.

[a] These specimens were undamaged portions of the transverse specimens.

No racking specimens were built for the reinforced-brick wall *AT* because for the 8-in. brick walls *AA*, *AB*, and *AC*, reported in BMS5, Structural Properties of Six Masonry Wall Constructions, none of the specimens failed under a racking load of 50 kips, the capacity of the racking equipment, and the deformations and sets for this load were very small. The compressive, transverse, and impact strengths of wall *AT* were greater than those of walls *AB* and *AC*, and it is probable that the racking strength also would have been greater.

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, which also gives the requirements for the specimens and describes the presentation of the results of the tests, particularly the load-deformation graphs.

For the transverse, concentrated, and impact loads, only three specimens of the reinforced-brick wall construction were tested because the wall was symmetrical about a plane midway between the faces, and the results for loads applied to one face of the specimens should be the same as those obtained by applying the loads to the other face.

The tests were begun on March 28, 1938, and completed July 8, 1938. The specimens were tested 28 days after they were built. The sponsor's representative witnessed the tests.

IV. WALL *AT*

1. Sponsor's Statement

(*a*) *Materials*

Brick.—Side-cut clay brick manufactured in Baltimore and furnished by the Baltimore Brick Co. through the Hydraulic Press Brick Co., Washington, D. C. The average dimensions were 8.02 by 3.85 by 2.29 in. (about 8 by 3²⁷⁄₃₂ by 2⁹⁄₃₂ in).

The physical properties of the brick, determined by the Masonry Construction Section of the National Bureau of Standards, are given in table 2. The brick complied with grade *SW* of the American Society for Testing Materials Tentative Standard C 62–37T.

Table 2.—*Physical properties of the brick*

Compressive strength	Modulus of rupture	Water absorption					Weight, dry
		5-hr cold	24-hr cold, *C*	5-hr boil, *B*	Saturation coefficient, $\frac{C}{B}$	1-min partial immersion,[a] as laid	
lb/in.²	*lb/in.²*	%	%	%		*g/brick*	*lb/brick*
5,160	830	9.5	10.2	14.7	0.69	19	4.76

[a] Immersed on flat side in ⅛ in. of water.

Mortar.—The materials for the mortar were Medusa Cement Co.'s "Medusa" portland cement, lime putty made by slaking Standard Lime and Stone Co.'s "Washington" powdered quicklime, and Potomac River building sand.

The mortar was 1 part of portland cement, 0.11 part of hydrated lime, and 2.6 parts of dry sand, by weight. The proportions by volume were 1 part of cement, 0.25 part of hydrated lime, and 3 parts of loose damp sand, assuming that portland cement weighs 94 lb/ft³, dry hydrated lime 40 lb/ft³, and 80 lb of dry sand are equivalent to 1 ft³ of loose damp sand. The materials for each batch were measured by weight and mixed in a batch mixer having a capacity of 2/3 ft³. The amount of water added to the mortar was adjusted to the satisfaction of the mason.

The following properties of the mortar materials and the mortar were determined by the Masonry Construction Section. The cement complied with the requirements of Federal Specification SS–C–191a for fineness, soundness, time of setting, and tensile strength. The lime putty contained about 40 percent of dry hydrate, by weight, and had a plasticity of over 600 measured in accordance with Federal Specification SS–L–351. The sieve analysis of the sand is given in table 3.

Table 3.—*Sieve analysis of the sand*

U. S. Standard sieve number	Passing, by weight
	Percent
8	100
16	96
30	82
50	24
100	2

The average water content of the mortar was 19.8 percent, by weight of dry materials. Samples were taken from at least one batch of mortar for each wall specimen, the flow determined in accordance with Federal Specification SS–C–181b, and six 2-in. cubes made. Three cubes were stored in water at 70° F and three stored in air near each specimen. The compressive strength of each cube was determined on the day the corresponding wall specimen was tested. The physical properties of the mortar are given in table 4.

Table 4.—*Physical properties of mortar, wall AT*

Specimen	Flow	Compressive strength	
		Air storage	Water storage
	Percent	*lb/in.²*	*lb/in.²*
C1	126	1,540	3,780
	138	1,660	3,810
C2	135	1,720	3,620
	139	1,530	3,680
C3	132	1,700	3,310
	132	1,670	3,440
T1	123	1,820	3,760
	127	1,740	3,650
T2	131	1,600	3,660
	126	1,780	3,910
T3	126	1,910	3,750
	124	1,650	3,720
I1	123	1,510	3,030
	119	1,690	3,660
I2	130	1,540	3,550
	130	1,620	3,760
I3	128	1,800	3,800
Average	129	1,680	3.640

Grout.—The grout was 1 part of cement, 0.062 part of hydrated lime, 1.45 parts of dry sand, and 0.63 part of water, by weight.

Ties.—Steel, ¼-in. diam, bent to a Z-shape with 90° angles between the outstanding legs and the stem. The length of the stem was 6 in. and of the outstanding legs 3 in.

Reinforcement bars.—Deformed, billet steel, ⅜ in. diam; yield point, 53,200 lb/in.²; tensile strength, 78,400 lb/in.²; weight, 0.375 lb/ft.

(*b*) *Description*

The wall specimens had either 35 or 36 courses of brick. The average height was 8 ft 2 in. for specimens with 35 courses and 8 ft 5 in. for specimens with 36 courses. The width was 4 ft 2½ in. and the thickness 8½ in. The wall was reinforced with two vertical reinforcement bars, *A*, shown in figure 1, and five horizontal reinforcement bars, *B*. The horizontal bars were spaced eight courses apart, the first bar being between the second and third course. In addition, four wall ties, *C*, were placed every fifth course. The ties were spaced 1 ft on centers.

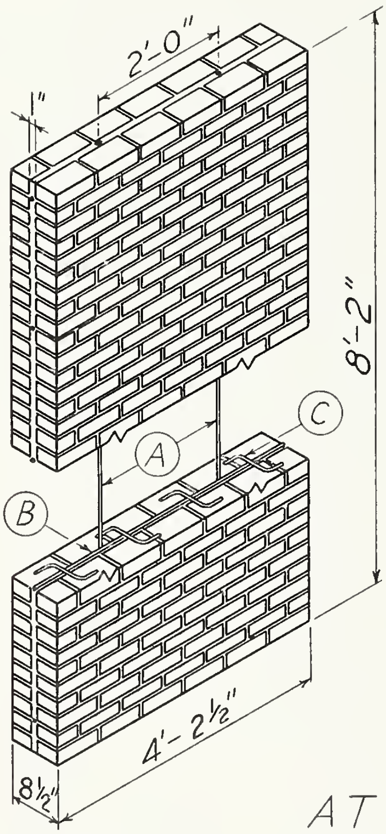

FIGURE 1.—*Four-foot wall specimen AT, having 35 courses.*

A, vertical reinforcement bars; *B*, horizontal reinforcement bars; *C*, wall ties.

The building of each specimen was begun by laying five stretcher courses of the facing. The bed joints were level, and the head joints were buttered on the outside face, leaving the greater portion of these joints open. The first course of the backing was then laid with the same kind of joints as was used in the facing. The collar joint, 1 in. wide, was left open except for a plug of mortar at each end. The vertical reinforcement was supported in position, using a temporary wood support at the top of the bars. The collar joint and the open portions of the head joints in both faces were then filled with grout to the level of the top of the brick in the backing. This operation was then repeated course by course until five courses of the backing were laid. The wall ties, *C*, were then placed in the wall and the next five courses of the facing were laid.

The bed joints were level and were completely filled with mortar. The head joints were filled partly with mortar and partly with grout. The collar joints were completely filled with grout. The joints were cut flush with the faces of the specimen.

The price of this construction in Washington, D. C., as of July 1937 was $0.50/ft².

(*c*) *Fabrication Data*

The fabrication data, determined by the Masonry Construction Section, are given in table 5.

TABLE 5.—*Fabrication data, wall AT*

[The values per square foot were computed using the face area of the specimens]

Thickness of joints		Masonry units	Mortar materials			Mason's time
Bed	Head		Cement	Lime, dry hydrate	Sand, dry	
in.	*in.*	*No./ft²*	*lb/ft²*	*lb/ft²*	*lb/ft²*	*hr/ft²*
0.52	0.51	12.2	9.2	1.0	23.9	0.15

(*d*) *Comments*

Reinforced-brick masonry is used for retaining walls and foundations, and also for walls above grade subjected to high winds and earthquakes. When used as a facing for large concrete structures, such as dams, retaining walls, etc., it may be used as part of the formwork for the concrete.

The horizontal reinforcement bars in spandrel walls (above and below window and door openings) are bent and lapped at the corners to make the building act as a unit under load. The vertical joints between the backing and facing are filled with grout or mortar. Grout-filled walls are strongly preferred because they offer more resistance to moisture penetration.

The outside of foundation walls should be waterproofed under all conditions where waterproofing is recommended for other types of foundation walls. However, for grout-filled walls, flashings around openings may be omitted.

The outside mortar joints should be concave, tooled with a round jointing tool to compress firmly the mortar against the brick. The inside face may be used without decoration or may be finished with paint or plaster applied directly to the brick.

2. Compressive Load

Wall specimen *AT–C3* under compressive load is shown in figure 2. The results for wall specimens *AT–C1*, *C2*, and *C3* are shown in table 6 and in figures 3 and 4.

Table 6.—*Structural properties, wall AT*

[Weight, 88.7 lb/ft²]

Load	Load applied	Specimen designation	Maximum height of drop	Maximum load
			ft	[a]*kips/ft*
Compressive	Upper end, 2.83 in. from the inside face.	*C1*		154
		C2		142
		C3		191
	Average			162
				lb/ft²
Transverse	One face; span, 7 ft 6 in	*T1*		218
		T2		184
		T3		206
	Average			203
				lb
Concentrated	One face	*P1*		[b] 1,000
		P2		[b] 1,000
		P3		[b] 1,000
	Average			[b] 1,000
Impact	One face; span 7 ft 6 in	*I1*	[b] 10.0	
		I2	[b] 10.0	
		I3	[b] 10.0	
	Average		[b] 10.0	

[a] A kip is 1,000 lb.
[b] Specimen did not fail. Test discontinued.

Figure 2.—*Wall specimen AT–C3 under compressive load*

The compressive loads were applied 2.83 in. from the inside face. The shortenings and sets shown in figure 3 for a height of 8 ft were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 3 in.

Specimens *C1* and *C2* failed by rupture of the collar joints at both edges of the specimens and crushing of bricks in several courses on the inside face. For specimen *C3* the lower third of the specimen completely collapsed.

3. Transverse Load

The results for wall specimens *AT–T1*, *T2*, and *T3* are shown in table 6 and in figure 5.

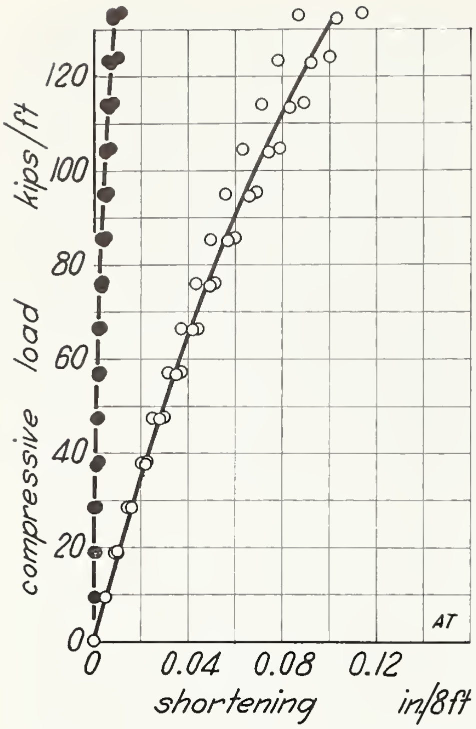

FIGURE 3.—*Compressive load on wall AT.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *AT-C1*, *C2*, and *C3*. The load was applied 2.83 in. from the inside face. The loads are in kips per foot of actual width of specimen.

At loads of 190, 142, and 166 lb/ft^2 for specimens *T1*, *T2*, and *T3*, respectively, the bond between the brick and the mortar ruptured at one or more bed joints between the loading rollers. At the maximum loads these cracks opened further and new cracks developed. Each of the specimens failed by deflecting continuously under constant load.

4. CONCENTRATED LOAD

Wall specimen *AT-P2* under concentrated load is shown in figure 6. The results for wall specimens *AT-P1*, *P2*, and *P3* are shown in table 6 and in figure 7.

The indentations after a load of 1,000 lb had been applied were 0.006, 0.002, 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 *AT-I1*, *I2*, and *I3* are shown in table 6 and in figure 8.

The set after a drop of 10 ft was 0.020 in. for specimen *I1*, and there was a crack about 2 in. long between a brick and the mortar at one edge of the specimen in a bed joint near midspan. The sets after a drop of 10 ft were 0.007 and 0.015 in. for specimens *I2* and *I3*, respectively, and no other effect was observed.

V. WALL *AU*

1. SPONSOR'S STATEMENT

(a) *Materials*

Brick.—The brick were the same as for wall *AT*. The water absorption for 1-min partial immersion, as laid, was 19 grams/brick.

Tile.—The structural clay tile were obtained from the National Fireproofing Company and were made in Magnolia, Ohio. The tile had four cells, as shown in figure 9. The average dimensions were 3.76 by 4.95 by 11.95 in. (about 3¾ by 4$^{15}/_{16}$ by 12 in).

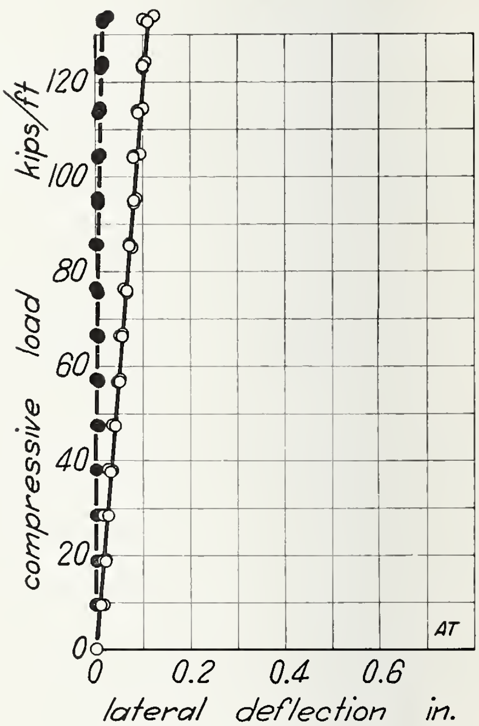

FIGURE 4.—*Compressive load on wall AT.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *AT-C1*, *C2*, and *C3*. The load was applied 2.83 in. 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 3 in., the gage length of the deflectometers.

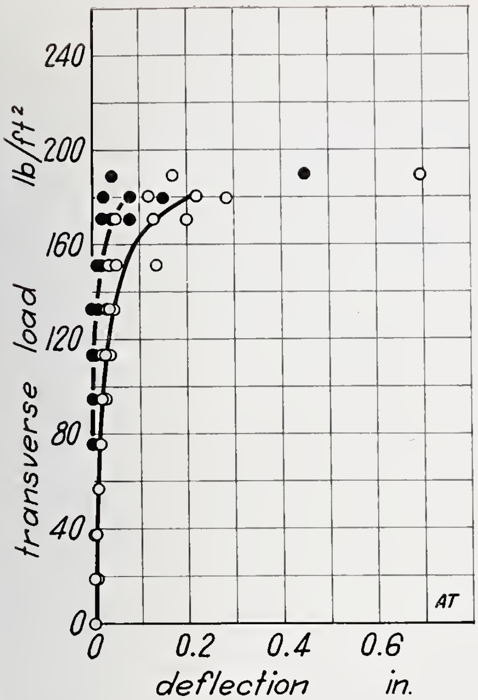

Figure 5.—*Transverse load on wall AT.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *AT–T1, T2,* and *T3* on the span 7 ft 6 in.

The physical properties of the tile, determined by the Masonry Construction Section, are given in table 7.

Table 7.—*Physical properties of the tile, wall AU*

Thickness of face shell, minimum	Ratio of width of cell to over-all thickness of bearing shell	Compressive strength, load applied to side		Water absorption		Weight, dry
		Net area	Gross area	24-hr cold	1-hr boil	
in.		*lb/in.*²	*lb/in.*²	*Percent*	*Percent*	*lb/tile*
0.40	2.1	4,610	1,720	4.0	5.9	9.48

The tile complied with the American Society for Testing Materials Standard C34–36, except for the water absorption determined by the 1-hr boil test. The average value of 5.9 percent complied with the Standard, but the individual values for four of the ten specimens were less than the specified minimum value of 4 percent. These values were 2.9, 2.9, 3.0, and 3.6 percent.

Mortar.—The materials for the mortar were the same as for wall *AT*.

The mortar was 1 part of cement, 0.42 part of hydrated lime, and 5.1 parts of dry sand,

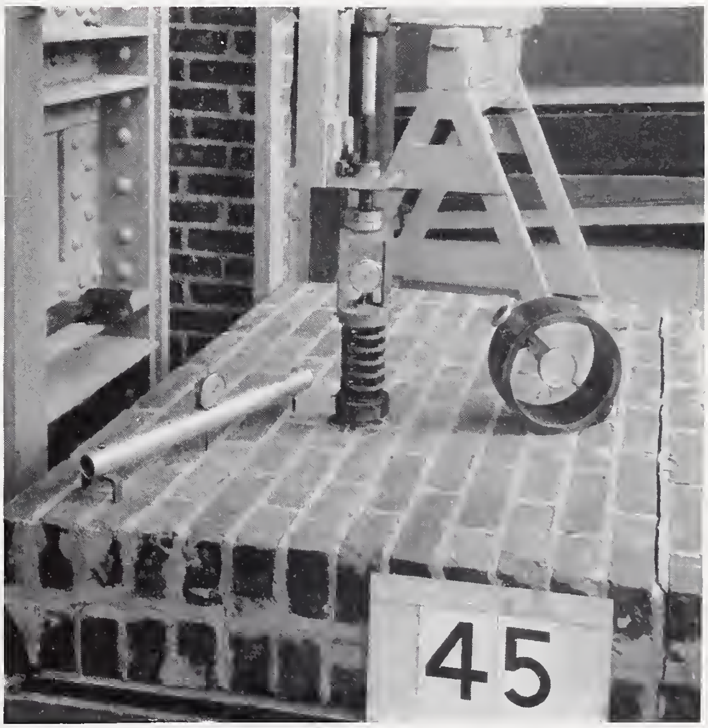

Figure 6.—*Wall specimen AT–P2 under concentrated load.*

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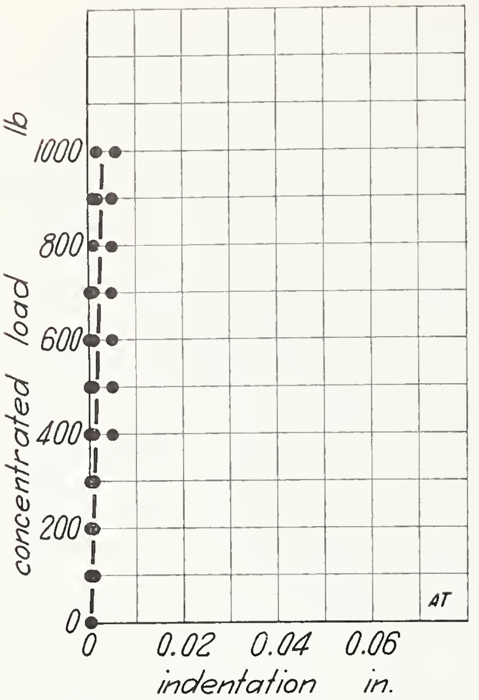

Figure 7.—*Concentrated load on wall AT.*

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

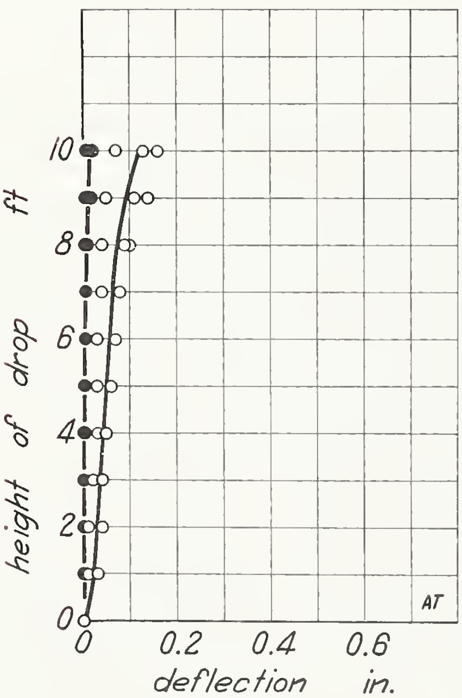

Figure 8.—*Impact load on wall AT.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *AT-I1*, *I2*, and *I3* on the span 7 ft 6 in.

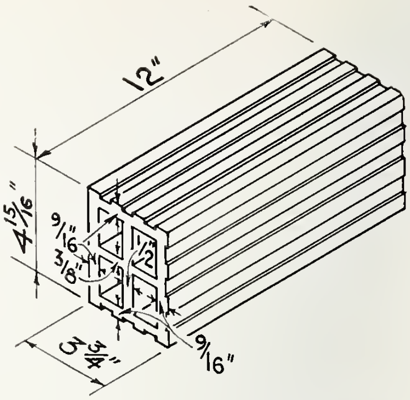

Figure 9.—*Structural clay tile.*

by weight. The proportions by volume were 1 part of cement, 1 part of hydrated lime, and 6 parts of 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. The materials for each batch were measured by weight and mixed in a batch mixer having a capacity of 2/3 ft^3. The amount of water added to the mortar was adjusted to the satisfaction of the mason.

Table 8.—*Physical properties of mortar, wall AU*

Specimen	Flow	Compressive strength	
		Air storage	Water storage
	Percent	*lb/in.*^{2}	*lb/in.*^{2}
C1	118	362	656
	115	361	636
C2	116	417	647
C3	116	388	685
T1	119	382	687
T2	118	307	597
T3	120	280	658
T4	121	398	675
T5	114	360	654
T6	112	379	620
I1	112	466	676
I2	111	450	663
I3	110	356	651
I4	108	533	663
I5	111	371	631
I6	113	604	607
R1	110	528	596
	112	452	591
R2	81	421	685
R3	109	469	722
Average	112	414	650

The physical properties of the mortar were determined by the Masonry Construction Section. The average water content of the mortar was 23.2 percent, by weight of dry materials. Samples were taken from at least one batch of mortar for each wall specimen, the flow determined in accordance with Federal Specification SS-C-181b, and six 2-in. cubes made. Three cubes were stored in water at 70° F and three stored in air near each specimen. The compressive strength of each cube was determined on the day the corresponding wall specimen was tested. The physical properties of the mortar are given in table 8.

Ties.—Steel, ¼-in. diam, bent to a Z-shape with 90° angles between the outstanding legs and the stems. The length of the stem was 6 in. and of the outstanding legs, 3 in.

(*b*) *Description*

(1) *Four-foot wall specimens.*—The 4-ft wall specimens were 8 ft 3 in. high, 4 ft 1 in. wide, and 9¾ in. thick. The specimens were built with a brick facing, *A*, as shown in figure 10, and a structural clay-tile backing, *B*, separated by an air space, *C*, and connected by wall ties, *D*. There were 36 courses of brick and 18 courses of tile. The ties were placed every sixth brick course starting with the fourth course from the lower end. The ties were spaced as shown in the figure, at least ½ in. from the nearest head joint.

The bed joints under both the brick and the tile were furrowed. The head joints of the brick were completely filled with mortar by heavily buttering the end of each brick before placing. When necessary, additional mortar was slushed into the joint from above. The head joints in the tile were made by buttering the outside edges of the tile, leaving the inside of the cross joint open. The nominal thickness of the joints was ½ in., and the joints were cut flush with the faces of the masonry units.

The price of this construction in Washington, D. C., as of July 1937 was \$0.50/ft².

(2) *Eight-foot wall specimens.*—The 8-ft wall specimens were 8 ft 3 in. high, 8 ft 3 in. wide, and 9¾ in. thick. The specimens were similar to the 4-ft specimens. There were four wall ties, spaced 2 ft 0 in. on centers, in every sixth brick course starting with the fourth course from the lower end.

(*c*) *Fabrication Data*

The fabrication data, determined by the Masonry Construction Section, are given in table 9.

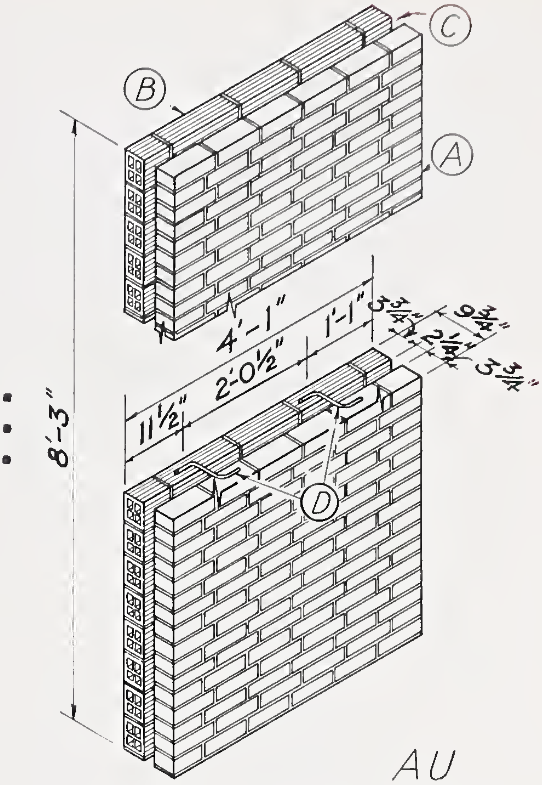

FIGURE 10.—*Four-foot wall specimen AU.*

A, facing; *B*, backing; *C*, air space; *D*, wall ties.

TABLE 9.—*Fabrication data, wall AU*

[The values per square foot were computed using the face area of the specimens]

Thickness of joints		Masonry units	Mortar materials			Mason's time
Bed	Head		Cement	Lime, dry hydrate	Sand, dry	
in.	*in.*	*No./ft²*	*lb/ft²*	*lb/ft²*	*lb/ft²*	*hr/ft²*
0.46 (brick) .56 (tile)	0.58 (brick) .39 (tile)	6.1 (brick) 2.1 (tile)	2.0	0.8	10.2	0.15

(*d*) *Comments*

Cavity walls with brick ties have been used in this country for at least 50 years in all types of buildings. In the last 20 years many buildings have been erected with All-Rolok and Rolok-Bak walls, two types of cavity walls with brick ties.

Cavity walls with metal ties have been used in England for several decades; and almost all the masonry structures built during the past 15 years have been of this type. This construction was introduced into the United States many years ago, and the number of buildings built with cavity walls has increased greatly during the past 5 years. About 300 houses of this construction were built in 1938.

In a house, the cavity wall extends from the top of the foundation wall to the eaves or to the base of the parapet wall. The bottom of the cavity should be below the damp-proofed course, but above ground level. Weep holes should be provided at intervals in the head joints in the facing at the bottom of the cavity. These holes should slope down from the bottom of the cavity to the outside of the wall.

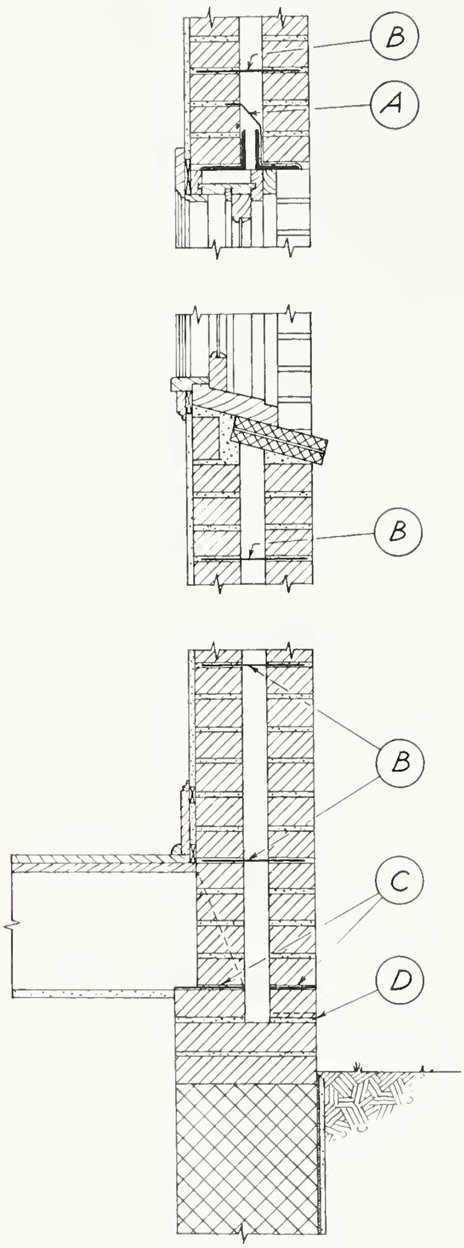

FIGURE 11.—*Lintel flashing and damp check for cavity walls.*

A, flashing; *B*, wall ties; *C*, damp check; and *D*, weep hole.

The cavity may be either closed (except for weep holes) or ventilated. If closed, the upper and lower ends are sealed. If ventilated, the entire wall or only the upper or lower portion may be ventilated. The closed cavity has better thermal insulation, while the ventilated cavity will allow moisture to evaporate more quickly, if any penetrates the facing.

Flashings, extending at least 6 in. beyond the jambs, must be used over all openings for doors and windows, as shown in figure 11. Parapet walls used above cavity walls should have watertight copings and should be adequately flashed.

Cavity walls have somewhat higher insulating value than solid masonry walls because of the air space between the backing and the facing. This space also provides a barrier against moisture penetration when the wall is properly flashed.

Paint or plaster may be applied directly to the inside face, or the wall may be used without any finish. If greater thermal insulation is desired, for example in northern latitudes, the inside face may be furred and plastered.

2. Compressive Load

The results for wall specimens *AU–C1*, *C2*, and *C3* are shown in table 10 and in figures 12 and 13.

The compressive loads were applied to both the facing and the backing, 3.25 in. from the inside face. The shortenings and sets shown in figure 11 for a height of 8 ft were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 4 in.

Each of the specimens failed by breaking of the tile in the upper two or three courses. No failure of the brick facing was observed.

3. Transverse Load

Wall specimen *AU–T3* under transverse load is shown in figure 14. The results are shown in table 10 and in figure 15 for wall specimens *AU–T1*, *T2*, and *T3*, loaded on the inside face, and in figure 16 for wall specimens *AU–T4*, *T5*, and *T6*, loaded on the outside face.

TABLE 10.—*Structural properties, wall AU*

[Weight, 62.3 lb/ft²]

Load	Load applied	Specimen designation	Failure of loaded face, height of drop	Failure of opposite face, height of drop	Maximum height of drop	Maximum load
			ft	*ft*	*ft*	[a] *Kips/ft*
Compressive	Upper end, 3.25 in. from the inside face.	*C1*				27.1
		C2				26.4
		C3				29.8
	Average					27.8
						lb/ft²
Transverse	Inside face; span, 7 ft 6 in.	*T1*				17.0
		T2				23.8
		T3				23.7
	Average					21.5
Do	Outside face; span, 7 ft 6 in.	*T4*				30.0
		T5				26.2
		T6				31.2
	Average					29.1
						lb
Concentrated	Inside face	*P1*				[b] 1,000
		P2				[b] 1,000
		P3				[b] 1,000
	Average					[b] 1,000
Do	Outside face	*P4*				[b] 1,000
		P5				[b] 1,000
		P6				[b] 1,000
	Average					[b] 1,000
Impact	Inside face; span, 7 ft 6 in.	*I1*	3.0	3.5	3.5	
		I2	3.5	3.5	3.5	
		I3	3.5	4.0	4.0	
	Average		3.3	3.7	3.7	
Do	Outside face; span, 7 ft 6 in.	*I4*	2.5	2.5	2.5	
		I5	3.0	2.5	3.0	
		I6	3.0	3.5	3.5	
	Average		2.8	2.8	3.0	
						[a] *Kips/ft*
Racking	Near upper end	*R1*				5.34
		R2				5.11
		R3				5.03
	Average					5.16

[a] A kip is 1,000 lb.
[b] Specimen did not fail. Test discontinued.

Each of the specimens *T1*, *T2*, and *T3* failed by rupture of the bond between the brick and the mortar at a bed joint at midspan in the facing, and rupture of the bond between the tile and the mortar at one or two bed joints at or between the loading rollers in the backing. In each case the failures in the tile backing occurred at joints having ties.

For specimens *T4*, *T5*, and *T6* at loads of 27.5, 17.2, and 15 lb/ft², respectively, the bond between the tile and the mortar ruptured at a bed joint near midspan in the backing. At the maximum load each of the specimens failed by

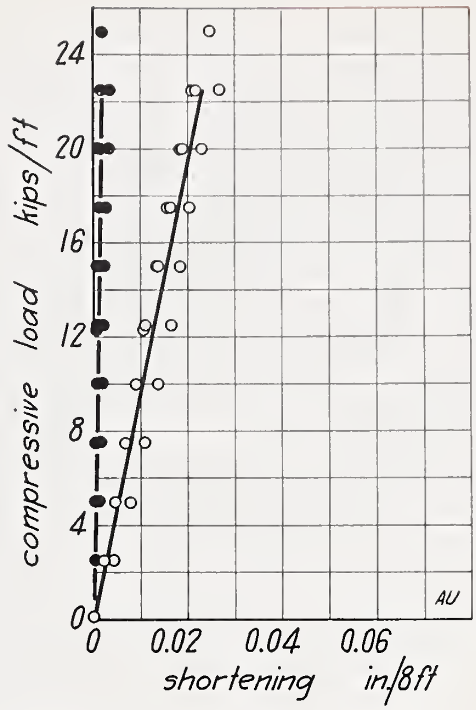

FIGURE 12.—*Compressive load on wall AU.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *AU–C1*, *C2*, and *C3*. The load was applied 3.25 in. from the inside face. The loads are in kips per foot of actual width of specimen.

rupture of the bond between the brick and the mortar at a bed joint between the loading rollers in the facing. For specimens *T4* and *T5* the failure of the brick facing occurred at joints having ties.

4. Concentrated Load

The results are shown in table 10 and in figure 17 for wall specimens *AU–P1*, *P2*, and *P3*, loaded on the inside face, and in figure 18 for wall specimens *AU–P4*, *P5*, and *P6*, loaded on the outside face.

The concentrated loads were applied to the faces of the specimens at midwidth and midway between ties. The indentations after a load of 1,000 lb had been applied were 0.002, 0.018, 0.002, 0.001, 0.001, and 0.004 in. for specimens *P1*, *P2*, *P3*, *P4*, *P5*, and *P6*, respectively, and no other effect was observed.

5. Impact Load

Wall specimen *AU–I2* during the impact test is shown in figure 19. The results are

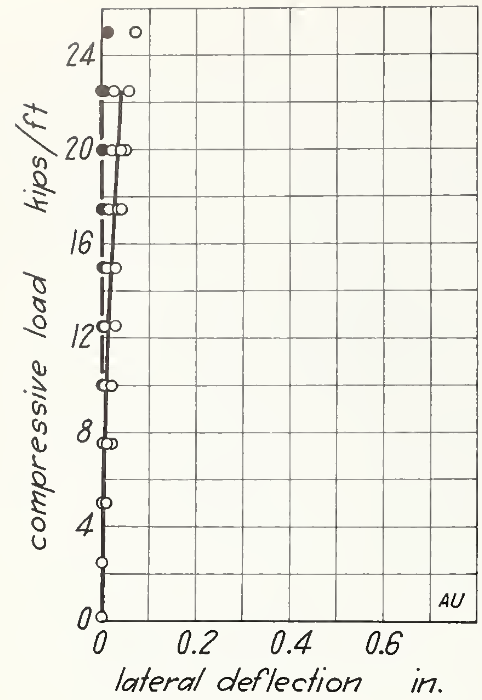

FIGURE 13.—*Compressive load on wall AU.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *AU–C1*, *C2*, and *C3*. The load was applied 3.25 in. 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 4 in., the gage length of the deflectometers.

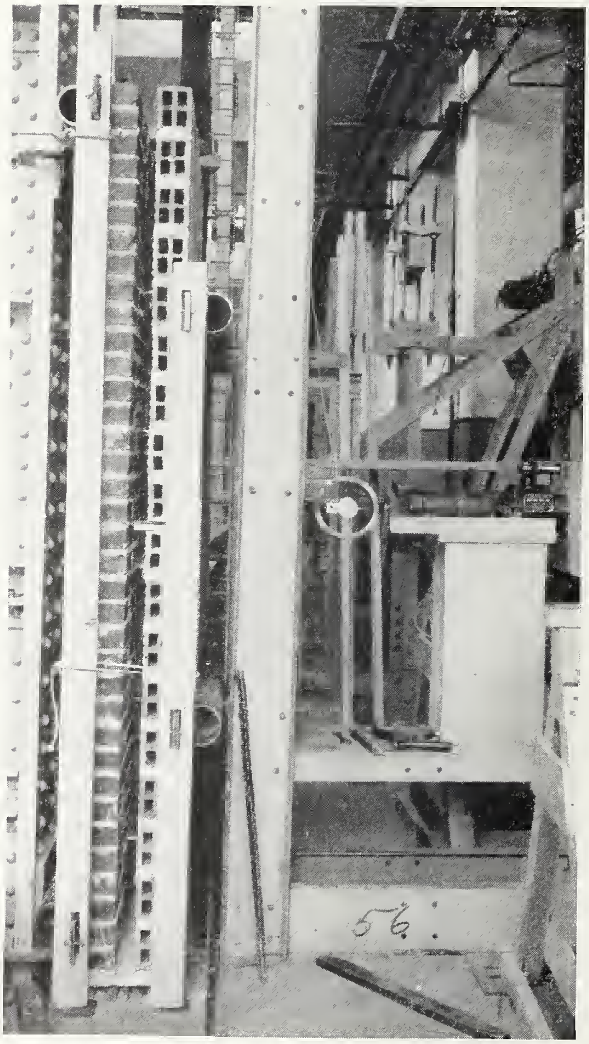

FIGURE 14.—*Wall specimen AU–T3 under transverse load.*

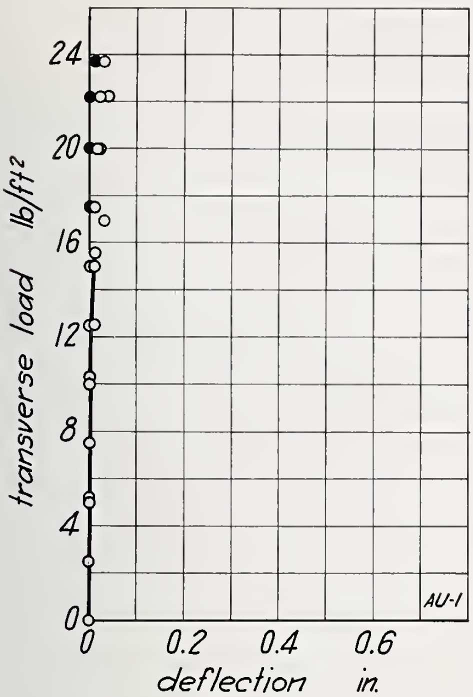

FIGURE 15.—*Transverse load on wall AU, load applied to inside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *AU–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.

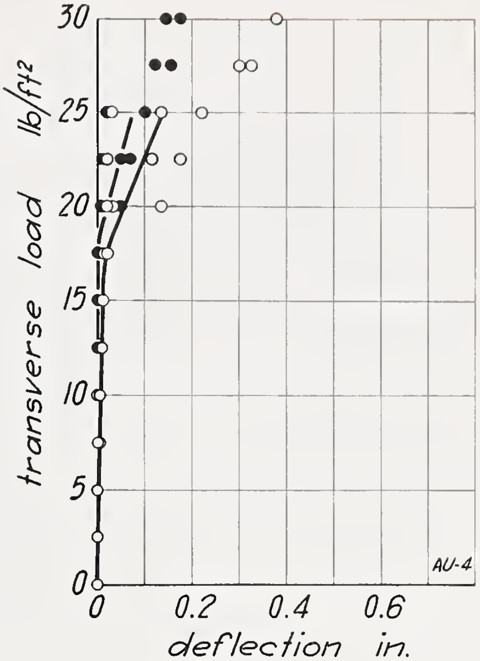

FIGURE 16.—*Transverse load on wall AU, load applied to outside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *AU–T4*, *T5*, and *T6* 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.

shown in table 10 and in figure 20 for wall specimens *AU–I1*, *I2*, and *I3*, loaded on the inside face, and in figure 21 for wall specimens *AU–I4*, *I5*, and *I6*, loaded on the outside face.

The impact loads were applied to the center of the inside face of specimens *I1*, *I2*, and *I3*, the sandbag striking the tile backing at midspan, one tile course below the nearest joint with ties. For each of the specimens *I1*, *I2*, and *I3* at drops of 2, 2, and 3 ft, respectively, the bond between the brick and the mortar in the facing ruptured transversely (across the specimen) near midspan. For specimens *I1* and *I3* the breaks occurred at joints with ties. At drops of 2, 2.5, and 3 ft for specimens *I1*, *I2*, and *I3*, respectively, the bond between the tile and the mortar in the backing ruptured transversely (across the specimen) near midspan. The rupture in specimen *I1* occurred at a joint with ties. At higher drops both the backing and the facing failed by opening of these cracks or by the formation of new cracks. In all cases the tile backing failed first, followed by the failure of the brick facing at the next drop.

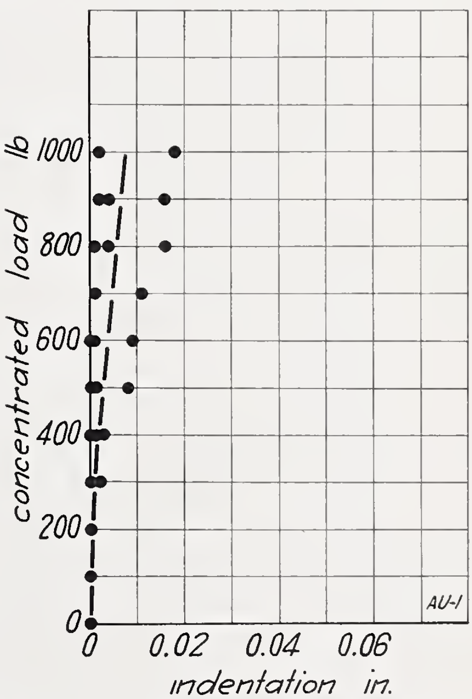

FIGURE 17.—*Concentrated load on wall AU, load applied to inside face.*

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

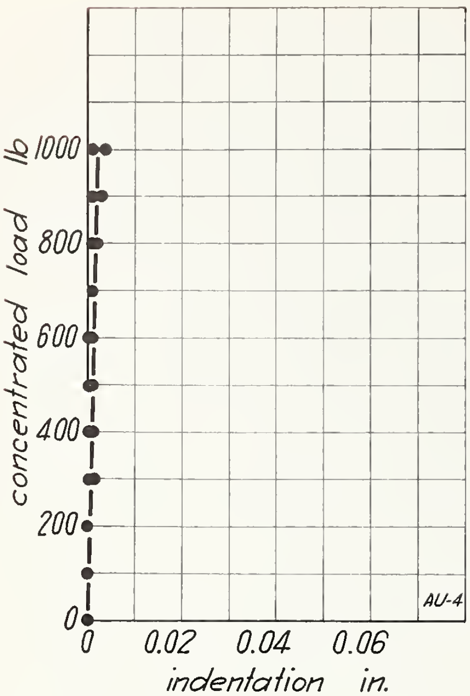

FIGURE 18.—*Concentrated load on wall AU, load applied to outside face.*

Load-indentation results for specimens *AU-P4, P5,* and *P6.*

FIGURE 19.—*Wall specimen AU-12 during the impact test.*

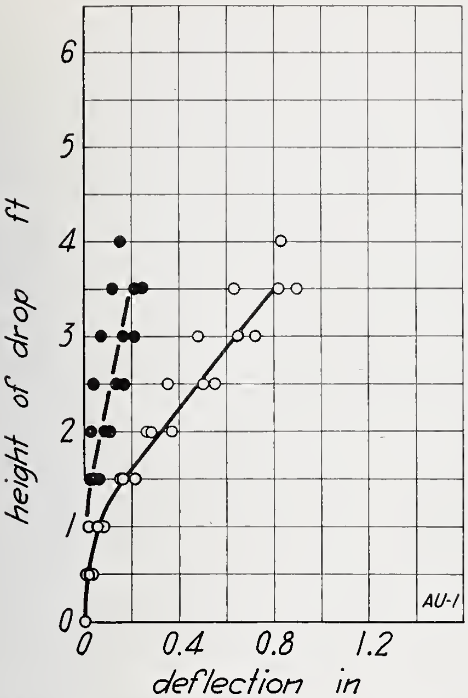

FIGURE 20.—*Impact load on wall AU, load applied to inside face.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *AU–I1*, *I2*, and *I3* on the span 7 ft 6 in.

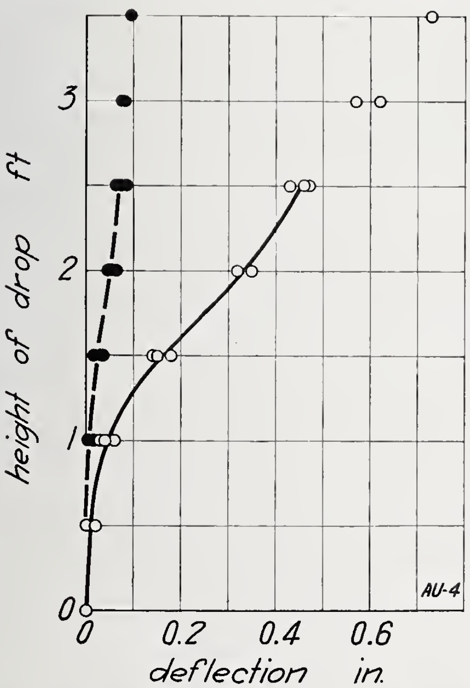

FIGURE 21.—*Impact load on wall AU, load applied to outside face.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *AU–I4*, *I5*, and *I6* on the span 7 ft 6 in.

The impact loads were applied to the center of the outside face of specimens *I4*, *I5*, and *I6*, the sandbag striking the brick facing at midspan, between joints with ties. For each of the specimens *I4*, *I5*, and *I6* at drops of 1.5, 2, and 2 ft, respectively, the bond between the tile and the mortar in the backing ruptured transversely (across the specimen) at or above midspan. For specimen *I6* the break occurred at a joint with ties. At drops of 2, 2, and 3 ft for specimens *I4*, *I5*, and *I6*, respectively, the bond between the brick and the mortar in the facing ruptured transversely (across the specimen) at or above midspan. The breaks in specimens *I4* and *I5* occurred at joints with ties. At higher drops both the backing and the facing failed by opening of these cracks or by the formation of a new crack in the tile backing. For specimens *I4* and *I6* both the backing and the facing failed at the same drop. For specimen *I5* the tile backing failed first, followed by failure of the brick facing at the next drop.

6. Racking Load

Wall specimen *AU–R1* under racking load is shown in figure 22. The results for wall specimens *AU–R1*, *R2*, and *R3* are shown in table 10 and in figure 23.

The racking loads were applied near the upper end of each specimen to a bearing plate covering both the facing and the backing, and the stop was also in contact with both. The deformations and sets shown in figure 23 for a height of 8 ft were computed from the values obtained by the measuring-device readings. The gage length of the vertical measuring device was 6 ft 5 in. for specimen *R1* and 6 ft 0 in. for specimen *R3*. The gage length of the horizontal measuring device was 5 ft 0 in. for both specimens. The deformations and sets for specimen *R2* are not given in figure 23 because there was relative motion between the facing and backing which caused errors in the readings.

At loads of 2.92, 4.75, and 3.75 kips/ft for specimens *R1*, *R2*, and *R3*, respectively, the tile backing of each specimen cracked in the bed and head joints, along the diagonal from the load to the stop. In addition a few tile were broken. At the maximum load the facing and the backing of specimen *R1* and the backing of specimens *R2* and *R3* failed by rupture of

FIGURE 22.—*Wall specimen AU–R1 under racking load.*

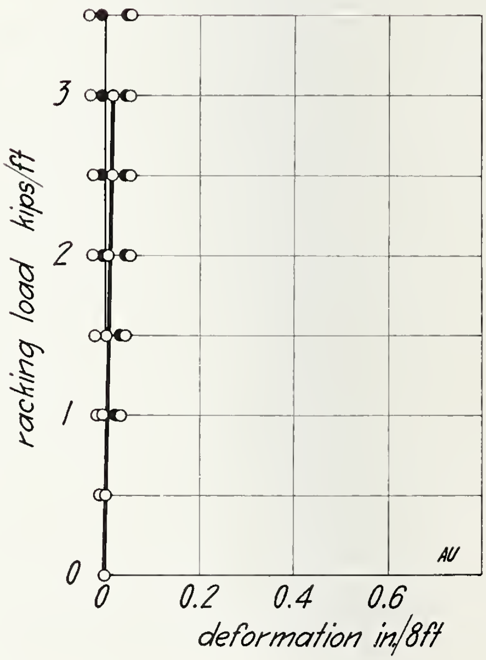

FIGURE 23.—*Racking load on wall AU.*

Load-deformation (open circles) and load-set (solid circles) results for specimens *AU–R1* and *R3*. The loads are in kips per foot of actual width of specimen.

the bond between the masonry units and the mortar in the bed and head joints, along the diagonal from the load to the stop. The facings of specimens *R2* and *R3* did not fail.

The drawings of the specimens were prepared by E. J. Schell, G. W. Shaw, and T. J. Hanley of the Bureau's Building Practice and Specifications Section, under the supervision of V. B. Phelan.

The structural properties were determined 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, with the assistance of the following members of the professional staff: C. C. Fishburn, F. Cardile, R. C. Carter, H. Dollar, M. Dubin, A. H. Easton, A. S. Endler, C. D. Johnson, P. H. Petersen, A. J. Sussman, and L. R. Sweetman.

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