U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS21

Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association

by

HERBERT L. WHITTEMORE
AMBROSE H. STANG, *and*
DOUGLAS E. PARSONS

NATIONAL
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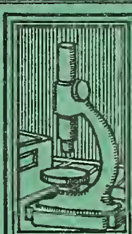

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ISSUED JULY 19, 1939

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 wall of a house when subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods simulating the loads to which the wall would be subjected in actual service. It may be feasible later to determine the heat transmission at ordinary temperatures and the fire resistance of this construction 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 this 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.*

Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association

by Herbert L. Whittemore, Ambrose H. Stang, *and* Douglas E. Parsons

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ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the National Concrete Masonry Association submitted 12 specimens representing a concrete-block cavity-wall construction.

The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads. 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 a table.

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 the 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 a wall construction 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 walls 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 National Concrete Masonry Association, Chicago, Ill., and represented a concrete-block cavity-wall construction. The concrete blocks were manufactured by Mahlstedt Materials, Inc., New Rochelle, N. Y.

III. SPECIMENS AND TESTS

The wall construction was assigned the symbol *AX*, and the specimens were assigned the designations given in table 1.

TABLE 1.—*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 transverse specimens.

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 for each loading 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 June 1, 1938, and completed June 8, 1938. The specimens were tested 28 days after they were built. The sponsor's representative witnessed the tests.

IV. WALL *AX*

1. SPONSOR'S STATEMENT

(a) *Materials*

Blocks.—Hollow concrete blocks made from 1 part of cement and 6 parts of cinders (maximum size ⅜ in.), by volume. The average dimensions were 4.00 by 23.75 by 7.73 in. (about 4 by 1 ft. 11¾ in. by 7¾ in.) for the full-sized blocks and 4.00 by 11.83 by 7.78 (about 4 by 11⅞ by 7¾ in.) for the half-sized blocks. The full-sized block is shown in figure 1. The half-sized blocks were obtained by cutting full-sized blocks through the center core. Mahlstedt Materials, Inc.

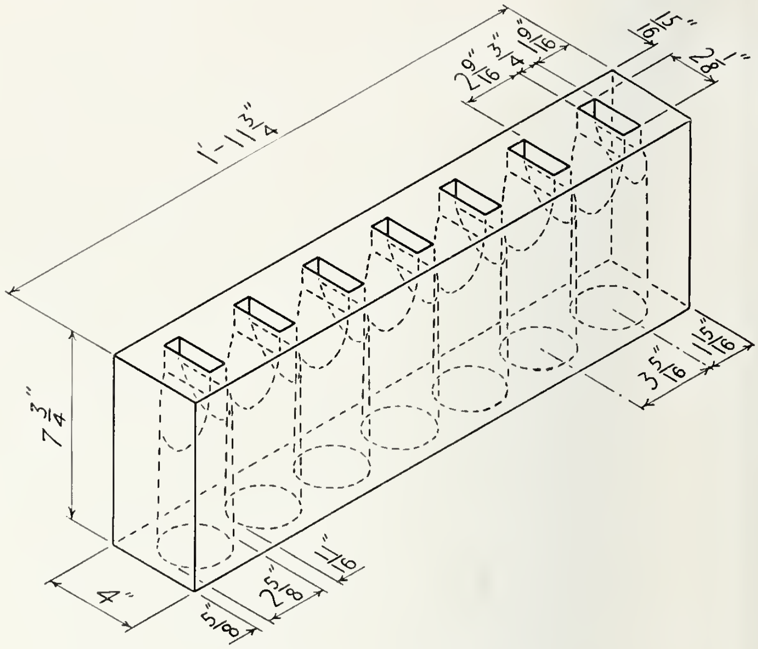

FIGURE 1.—*Concrete block.*

The physical properties of the blocks, determined by the Masonry Construction Section of the National Bureau of Standards, are given in table 2.

TABLE 2.—*Physical properties of the concrete blocks, wall AX*

Size	Thickness of face shell, minimum	Compressive strength		Water absorption, 24-hr. cold immersion		Weight, dry	
		Net area	Gross area	By weight	Per cubic foot of concrete	Per block	Per cubic foot of concrete
	in.	*lb/in.*²	*lb/in.*²	*Percent*	*lb*	*lb*	*lb*
Full-sized	0.50	1,530	900	14.4	12.7	22.7	88.1
Half-sized	.50			15.0	13.1	11.5	87.3

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 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/ft^3, dry hydrated lime 40 lb/ft^3, and 80 lb of dry sand are 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 ⅔ ft^3. 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 40 to 45 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.

The average water content of the mortar was 20 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 wall 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.

Wall ties.—Basic-steel wire, 3/16-in. diam bent to the shape of a rectangle, outside dimensions 6 by 3 7/8 in., with ends butted (not welded) at the center of a 3 7/8-in. side. Precast Concrete Joist Accessories Co.

(b) *Description*

(1) *Four-foot wall specimens.*—The 4-ft wall specimens were 8 ft 3 in. high, 4 ft 0 in. wide, and 10 in. thick. The specimens were built with a concrete-block facing, *A*, and backing, *B*, as shown in figure 2, separated by an air space, *C*, and connected by steel wall ties, *D*.

Table 3.—*Sieve analysis of the sand, wall AX*

U. S. Standard Sieve No.	Passing, by weight
	Percent
8	100
16	96
30	81
50	25
100	2

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

Specimen	Flow	Compressive strength: Air storage	Compressive strength: Water storage
	Percent	*lb/in.*²	*lb/in.*²
C1	109	1, 440	3, 240
C2	105	1, 470	2, 880
C3	119	1, 400	3, 300
T1	122	1, 810	2, 950
T2	120	1, 570	3, 150
T3	125	2, 180	3, 160
I1	112	1, 330	3, 300
I2	124	1, 240	2, 990
I3	124	1, 590	3, 190
R1	119	1, 780	3, 400
	116	1, 550	3, 230
R2	109	1, 600	3, 340
	112	1, 400	3, 310
R3	115	1, 370	3, 350
	111	1, 370	3, 500
Average	116	1, 540	3, 220

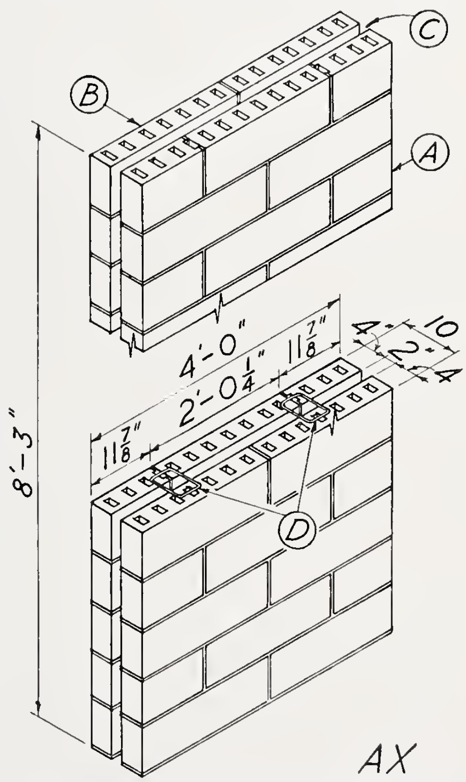

Figure 2.—*Four-foot wall specimen AX.*
A, facing; *B*, backing; *C*, air space; *D*, wall ties.

There were 12 courses in the facing and 12 in the backing. The first course in the facing had two full-sized blocks. The first course in the backing had a full-sized block and two half-sized blocks. There were two wall ties, located as shown in figure 2, in each alternate bed joint starting with the joint above the first course.

The bed joints were furrowed and only the outer edges of the head joints were buttered with mortar.

The price of this construction in Washington, D. C., as of July 1937, was \$0.46/ft^2.

(2) *Eight-foot wall specimens.*—The 8-ft wall specimens were 8 ft 3 in. high, 8 ft 1/2 in. wide, and 10 in. thick. The specimens were similar to the 4-ft specimens. There were four wall ties, spaced 2 ft 0 in. on centers, in each alternate bed joint, starting with the joint above the first course.

(c) *Fabrication Data*

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

TABLE 5.—*Fabrication data, wall AX*

[The valves 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*	*Number/ft²*	*lb/ft²*	*lb/ft²*	*lb/ft²*	*hr/ft²*
0.52	0.47	1.45	2.71	0.30	7.05	0.083

(d) *Comments*

Cavity walls have been used for several years and there are many concrete houses with cavity walls in the United States. On March 1, 1939, there were about 40 houses having walls of construction *AX* at Alden Estates, Port Chester, N. Y., and more were being built.

It is not necessary to apply a finish to either face of the walls. However, the outside face is usually waterproofed with two coats of cement paint. Probably the best outside finish for this and other types of concrete masonry walls is portland-cement stucco. A brick facing may be used instead of the concrete-block facing.

The most economical inside finish is cement paint. However, the usual inside finish is plaster applied directly to the concrete blocks. The plaster may be decorated with paint or wallpaper.

2. COMPRESSIVE LOAD

Wall specimen *AX–C1* under compressive load is shown in figure 3. The results for wall specimens *AX–C1*, *C2*, and *C3* are shown in table 6 and in figures 4 and 5.

TABLE 6.—*Structural properties, wall AX*

[Weight, 44.1 lb/ft²]

Load	Load applied	Specimen designation	Maximum height of drop	Maximum load
			ft	[a] *kips/ft*
Compressive	Upper end, 3.33 in. from inside face.	*C1*		36.0
		C2		39.5
		C3		37.9
	Average			37.8
				lb/ft²
Transverse	One face; span 7 ft 6 in	*T1*		50.5
		T2		52.3
		T3		46.5
	Average			49.8
				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*	2.5	
		I2	3.0	
		I3	3.5	
	Average		3.0	
				[a] *kips/ft*
Racking	Near upper end	*R1*		5.94
		R2		6.20
		R3		5.89
	Average			6.01

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

The compressive loads were applied to both the facing and the backing, 3.33 in. from the inside face. The shortenings and sets shown in figure 4 for a height of 8 ft were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 11 in. The lateral deflections shown in figure 5 were measured on the backing. The facing deflected the same amount as the backing within 0.01 in., the estimated error of measurement.

Each of the specimens failed by crushing of blocks in the backing in one or more courses near the upper end of the specimen.

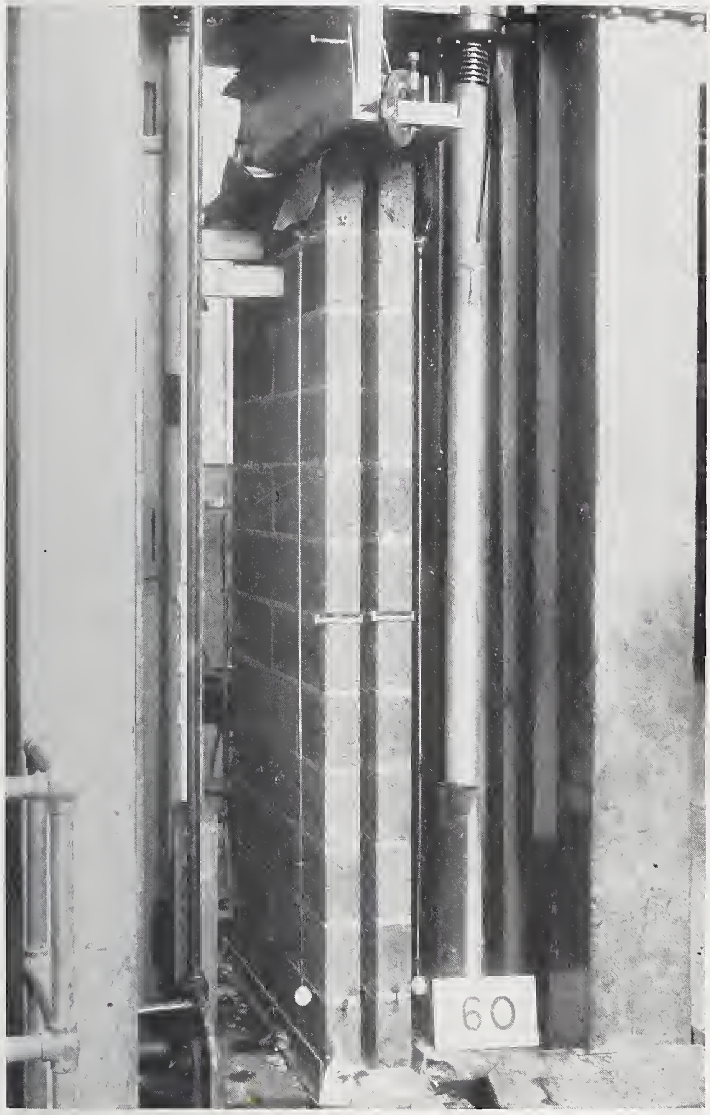

Figure 3.—*Wall specimen AX–C1 under compressive load.*

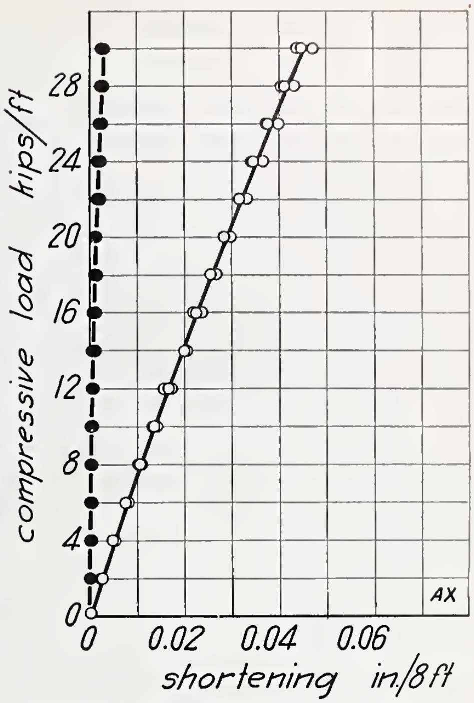

Figure 4.—*Compressive load on wall AX.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *AX–C1, C2,* and *C3.* The load was applied 3.33 in. from the inside face. The loads are in kips per foot of actual width of specimen.

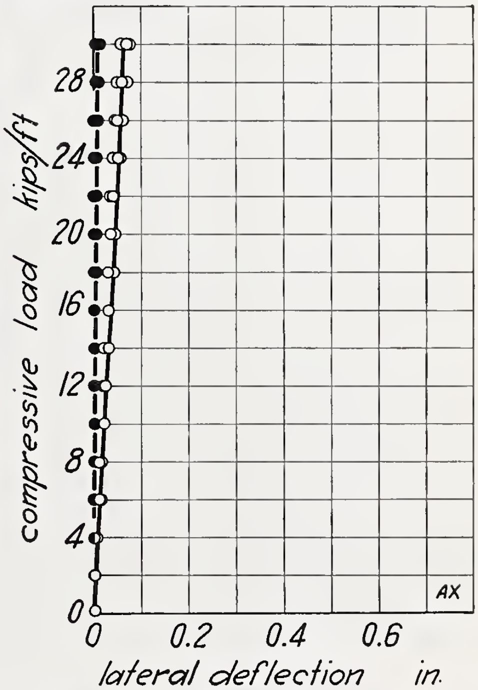

Figure 5.—*Compressive load on wall AX.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *AX–C1, C2,* and *C3.* The load was applied 3.33 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 1 in., the gage length of the deflectometers.

3. Transverse Load

Wall specimen *AX–T1* under transverse load is shown in figure 6. The results for wall specimens *AX–T1*, *T2*, and *T3* are shown in table 6 and in figure 7.

The lateral deflections shown in figure 7 were measured on the backing. The facing deflected the same amount as the backing within 0.01 in., the estimated error of measurement.

Each of the specimens failed by rupture of the bond between the blocks and the mortar in both the facing and the backing at bed joints at or between the loading rollers. For specimens *T1* and *T3* the failure occurred at joints having no ties and the ruptured joints in the facing and backing were at the same height. For specimen *T2* the failure in the facing occurred at a joint having no ties, whereas the failure in the backing occurred at a joint having ties.

Figure 6.—*Wall specimen AX–T1 under transverse load.*

4. Concentrated Load

Wall specimen *AX–P3* under concentrated load is shown in figure 8. The results for wall specimens *AX–P1*, *P2*, and *P3* are shown in table 6 and in figure 9.

The concentrated loads were applied to one face of each specimen at midwidth. For specimen *P1* the load was applied on a head joint, for specimen *P2* at the intersection of a head joint and a bed joint having no ties, and for specimen *P3* at the center of a concrete block.

The indentations shown in figure 9 to the left of the vertical axis and the decrease in the indentation for one specimen for loads greater than 700 lb were caused by the difficulty of obtaining readings on the rough surfaces of the specimens. The indentations after a load of 1,000 lb had been applied were less than 0.015 in. for each of the specimens, and no other effect was observed.

5. Impact Load

Wall specimen *AX–I2* during the impact test is shown in figure 10. The results for wall specimens *AX–I1*, *I2*, and *I3* are shown in table 6 and in figure 11.

The impact loads were applied to the center of one face of each specimen, the sandbag striking the face about midway, between wall ties. At drops of 1.5, 2.5, and 2 ft for specimens *I1*, *I2*, and *I3*, respectively, a bed joint near midheight in both the facing and the backing cracked. At the maximum drop each specimen failed by rupture of the bond between the blocks and the mortar at the cracked bed joints. For specimens *I2* and *I3* the failures occurred at joints having ties.

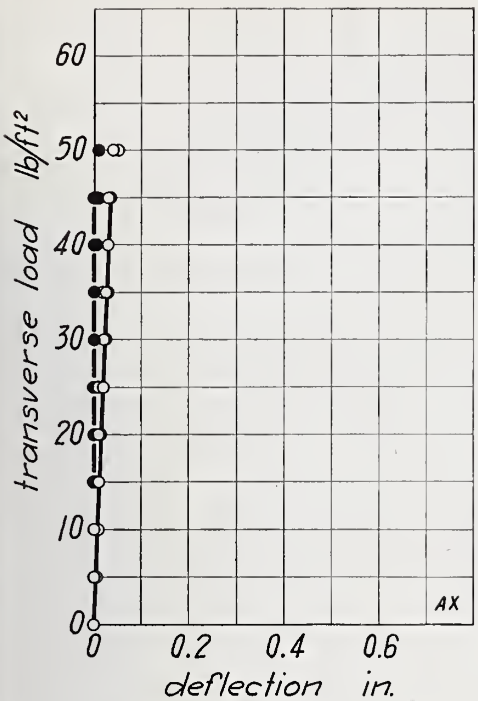

FIGURE 7.—*Transverse load on wall AX.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *AX–T1*, *T2*, and *T3* on the span 7 ft 6 in. The deflections and sets are for the gage lengths of the deflectometers. For specimen *T1* the gage length was 7 ft 1 in., and for specimens *T2* and *T3* the gage length was 7 ft 6 in.

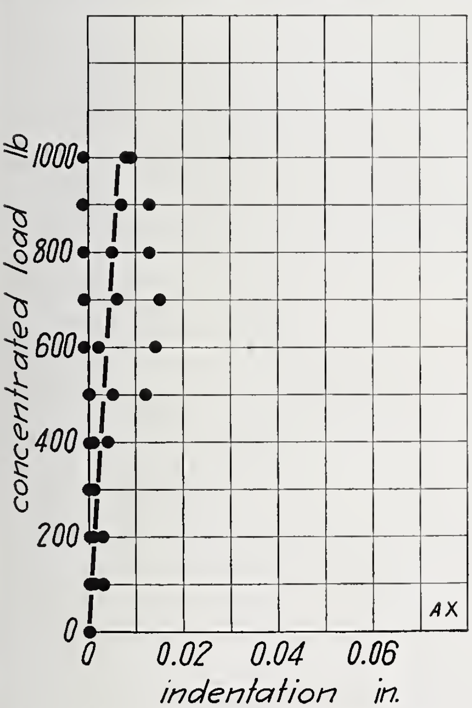

FIGURE 9.—*Concentrated load on wall AX.*

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

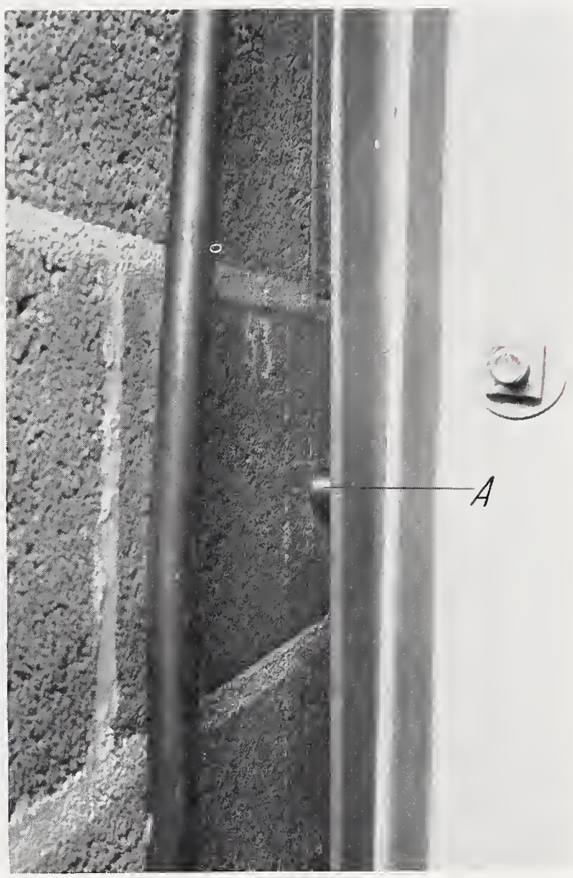

FIGURE 8.—*Wall specimen AX–P3 under concentrated load.*

A, loading disk.

FIGURE 10.—*Wall specimen AX-I2 during the impact test.*

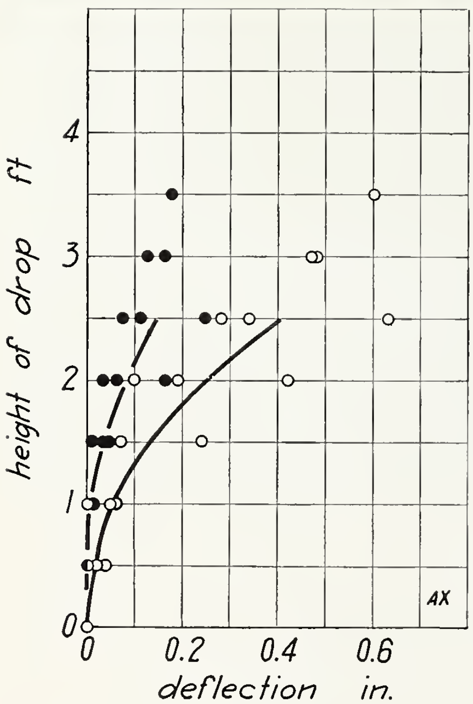

FIGURE 11.—*Impact load on wall AX.*

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

FIGURE 13.—*Racking load on wall AX.*

Load-deformation (open circles) and load-set (solid circles) results for specimens *AX-R1*, *R2*, and *R3*. The loads are in kips per foot of actual width of specimen.

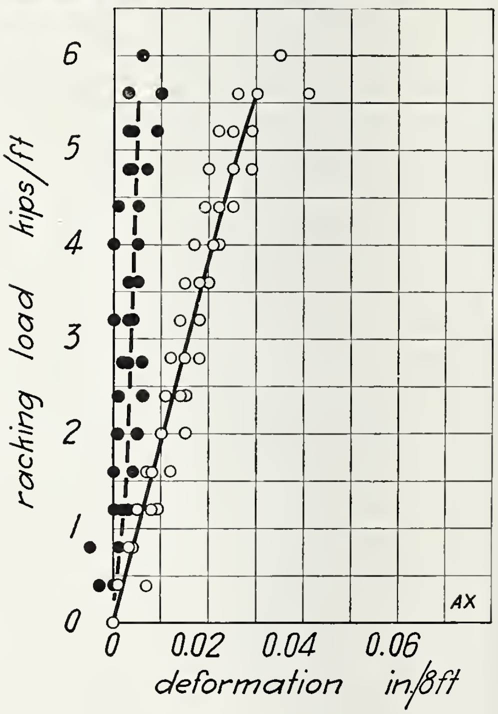

FIGURE 12.—*Wall specimen AX–R1 under racking load.*

6. Racking Load

Wall specimen *AX–R1* under racking load is shown in figure 12. The results for wall specimens *AX–R1*, *R2*, and *R3* are shown in table 6 and in figure 13.

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 13 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 6 in. for specimen *R1* and 6 ft 1 in. for specimens *R2* and *R3*. The gage length of the horizontal measuring device was 5 ft 0 in. for all three specimens.

Specimen *R1* failed by crushing of blocks in both the facing and the backing at the loaded corner. Specimens *R2* and *R3*, failed by rupture of both the facing and the backing approximately along a diagonal between the point of application of load and the stop. The cracks did not follow the mortar joints but went directly through the blocks. In addition, for specimen *R3* two blocks at the stop crushed.

The sponsor supplied the information contained in the sponsor's statement. The drawings of the specimens were prepared by E. J. Schell and G. W. Shaw 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.

WASHINGTON, March 27, 1939.

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