Fire Resistance of Walls of Lightweight-Aggregate Concrete Masonry Units

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report BMS117

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Fire Resistance of Walls of Lightweight-Aggregate Concrete Masonry Units

by Harry D. Foster, Earl R. Pinkston, and S. H. Ingberg

Building Materials and Structures Report BMS117

Issued May 1, 1950

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Foreword

This report is one of a series issued by the National Bureau of Standards, dealing with the fire resistance of building constructions and materials. It indicates the fire resistance that can be expected of walls of various thicknesses of lightweight-aggregate concrete masonry units made with cinder, pumice, expanded-slag, or expanded burned-shale aggregates.

As concrete masonry units made with lightweight aggregates are used extensively in both residential and commercial buildings, the information contained in this report is of timely interest to building regulatory bodies in setting up building code requirements pertaining to exits, shaft enclosures, and fire division walls.

E. U. CONDON, *Director.*

Fire Resistance of Walls of Lightweight-Aggregate Concrete Masonry Units

by Harry D. Foster, Earl R. Pinkston, *and* S. H. Ingberg

The results of fire-endurance and hose-stream tests of 16 walls of lightweight-aggregate concrete masonry units are given. The aggregates used in the manufacture of the units were cinders, expanded shale, pumice, or expanded slag. The constructions ranged from 3-in. nonload-bearing partitions to 10-in. load-bearing walls with no framed-in members and included brick-faced exterior bearing walls.

The fire-resistance values indicated by the tests varied with the thickness of the wall, the moisture content at the time of the test, and the kind of aggregate used in the units and ranged from 1 hr 9 min for a 4-in. unplastered partition to 7 hr 3 min for an 8-in. bearing wall faced with brick and backed with 4-in. lightweight-concrete units.

Hose-stream tests conducted at the end of the fire-endurance tests indicated that walls of lightweight-aggregate concrete masonry units met the requirements of this test for their respective fire-resistance values.

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I. Introduction and Scope

Consideration of the fire resistance of walls is of prime importance in the design of buildings. Building regulations usually require fire-resistive walls or partitions for the enclosure of shafts, stairways, and corridors, and also for subdivision into fire areas. The required fire resistance is governed by the type of construction and the amount of combustible material involved in the occupancy of the building. The fire-resistance values of the different types of walls or other building members are based on the results of tests of representative constructions subjected to controlled fire exposures of standardized intensity.

Concrete masonry units made with lightweight aggregates, such as cinders, expanded slag, expanded shale, and similar materials, are extensively used because of their insulating value, ease of cutting, fitting and laying, and lower loading imposed on the supporting members or foundation of the building.

A series of fire tests of walls built of units of the general type mentioned above was undertaken as a part of the Bureau's general program of research on building materials and structures. Sixteen walls, each containing two or more sections of masonry units of the same size but made with different kinds of aggregate, were tested. The thicknesses of the walls were 3, 4, 6, and 10 in. They were constructed of units made with cinders, pumice, expanded slag, and expanded shale. Nine of the walls were not plastered, four were plastered on one side, and three on both sides. One of the walls was of the cavity type and consisted of two 4-in. wythes spaced 2 in. apart. Two of the walls were faced with clay brick as frequently used in exterior wall construction.

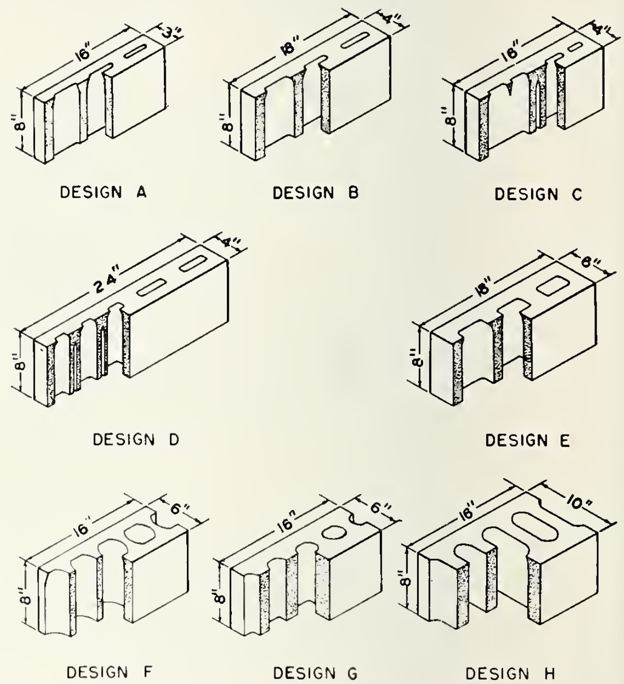

FIGURE 1. *Designs of concrete units used in fire-test walls.*

II. Materials

1. Concrete Masonry Units

The size and design of the units are shown in figure 1. The screen analysis and other physical properties of the aggregates are given in table 1. The nominal size, shell thickness, and percentage of cell area of the units, and the number of blocks obtained per bag of cement are given in table 2.

TABLE 1. *Some physical properties of the aggregates in the lightweight-aggregate concrete units*

Kind of aggregate	Grade	Weight[1]		Moisture content in stock piles	Screen analysis—percentage retained on sieves							Fineness modulus[2]
		Dry (rodded)	Damp (loose)		3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	
		lb/ft³	*lb/ft³*	*Percent*								
Cinder		61.0	65.0	6.4	1	10	30	52	71	84	92	3.40
Pumice		65.0	60.0	32.0		10	26	46	70	90	96	3.40
Expanded slag 1	Fine	48.0	63.5	12.0		1	16	44	68	83	90	3.02
	Coarse	48.0	53.5	6.0	3	86	95	97	98	99	99	5.77
	Combined: 85.5 percent fine and 14.5 percent coarse, by weight					13	28	52	72	85	91	3.41
Expanded slag 11	Fine	62.0	74.0	5.0		1	11	33	64	87	93	2.89
	Coarse	46.0	52.0	4.0	3	72	83	88	92	94	95	5.26
	Combined: 82 percent fine and 18 percent coarse, by weight				1	14	24	43	70	88	93	3.33
Expanded shale	Fine	55.5	65.0	13.0			7	33	52	65	74	2.31
	Coarse	46.5	47.0	12.0	1	68	95	96	100	100	100	5.60
	Combined: 64 percent fine and 36 percent coarse, by weight					20	32	49	66	75	81	3.23

[1] The weights were determined in accordance with the Standard Method of Test for Unit Weight of Aggregate, ASTM Designation: C29–39.

[2] The fineness modulus is an empirical factor obtained by adding the total percentages of sample retained on each of the sieves and dividing the sum by 100. (See Standard Definitions of Terms Relating to Concrete and Concrete Aggregates, ASTM Designation: C125–39).

Table 2. *Batch proportions and yield obtained in the manufacture of lightweight-aggregate concrete units*

Kind of aggregate	Description of units			Cell area	Batch proportions					Yield—units per bag of cement	Test walls in which units were used
	Nominal size	Thickness of shell	Design[1]		Cement	Aggregate[2]			Water		
						Fine	Coarse	Combined			
	in.	*in.*		*Percent*	*lb*	*lb*	*lb*	*lb*	*gal*		
Cinders	4 by 18 by 8	1	B	37	94	--------	--------	653	2.00	33.2	13A
	4 by 24 by 8	1	D	37	(3)	--------	--------	--------	--------	--------	12A
	6 by 18 by 8	$1\frac{1}{8}$	E	50	94	--------	--------	816	3.25	37.2	7A
	6 by 18 by 8	$1\frac{1}{2}$	E	39	94	--------	--------	653	3.20	24.6	8A, 9A, and 15A
	6 by 18 by 8	$1\frac{1}{2}$	E	39	94	--------	--------	653	3.20	24.6	14A
Pumice	4 by 16 by 8	1	C	37	94	--------	--------	560	3.75	35.2	5B and 6A
	10 by 16 by 8	$1\frac{3}{4}$	H	40	94	--------	--------	390	2.75	12.8	11A and 16A
Expanded slag I	3 by 16 by 8	1	A	24	94	500	85	--------	1.25	43.3	2B
	4 by 16 by 8	1	C	37	94	500	85	--------	1.50	34.3	5A
	4 by 16 by 8	1	C	37	94	363	62	--------	1.30	26.2	13B
	4 by 24 by 8	1	D	37	(3)	--------	--------	--------	--------	--------	6B and 12B
	6 by 16 by 8	$1\frac{1}{8}$	F	50	94	500	85	--------	1.50	27.0	7B
	6 by 16 by 8	2	G	24	94	363	62	--------	1.00	16.3	9B and 10A
Expanded slag II	3 by 16 by 8	1	A	24	94	446	97	--------	3.40	41.0	1B
	4 by 16 by 8	$1\frac{5}{16}$	C	24	94	346	75	--------	4.45	24.5	3B
	4 by 16 by 8	1	C	37	94	555	120	--------	3.00	41.5	4A
	6 by 16 by 8	2	G	24	94	346	75	--------	3.75	16.8	10B and 15C
	6 by 16 by 8	$1\frac{3}{8}$	F	39	94	361	75	--------	3.75	20.0	8B and 15D
Expanded shale	3 by 16 by 8	1	A	24	94	485	195	--------	7.40	60.5	1A and 2A
	4 by 16 by 8	$1\frac{5}{16}$	C	24	94	340	187	--------	6.10	32.0	3A
	6 by 16 by 8	$1\frac{3}{8}$	F	39	94	340	137	--------	6.10	25.4	14B and 15B
	10 by 16 by 8	$1\frac{3}{4}$	H	40	94	340	137	--------	5.00	15.9	11B and 16B

[1] The designs of the units in cutaway sections are indicated in figure 1, page 2.
[2] The aggregates were taken directly from the stock piles and had moisture contents approximating those given in table 1.
[3] Batch proportions were not determined.

(a) Cinder Concrete Units

The cinders were taken from stock piles where they had weathered to permit any lime they might contain to slake and any sulfur or iron rust to be washed out. Unslaked lime, sulfur, or iron in cinders may cause "popping" or staining of the finished walls. After weathering and washing, the cinders were crushed, graded, and recombined in the proportions required to give a fineness modulus of approximately 3.50. After approximately one-half of the required water had been added to the aggregate, each batch was mixed in a spiral-blade mixer for 3 min before the portland cement and remaining water were added. The batches were mixed for 5 additional min after adding the cement.

The 4- by 24- by 8-in. units were molded by the vibration process in the vicinity of New York City. All other cinder concrete units were molded in the Chicago district by the tamping process. They were cured in a saturated atmosphere for approximately 24 hr at temperatures ranging from 90° to 110°F and then stored in the open stock yard for about 6 weeks before being shipped to the Bureau for test.

(b) Pumice Concrete Units

The pumice aggregate was prepared by crushing a natural vesicular volcanic lava to ½-in. particles or smaller. Particles passing a No. 8 sieve tend to break down to a fine powder unsuited for use as a fine aggregate. Consequently, siliceous sand was used for this purpose.

The pumice aggregate, sand, cement, and water were proportioned and mixed in the same manner used for the cinder concrete units. The units were molded by the tamping process in a plant in Chicago. They were cured in the same manner and for approximately the same time as the cinder concrete units.

(c) Expanded-Slag Concrete Units

The aggregates were prepared from molten slag brought in contact with water by two methods differing in the amount of water and the mechanical treatment. The expansion of slag I was accomplished by pouring molten blast-furnace slag into water and entrapping some of the steam thus generated. The expansion of slag II was accomplished by a combination of water and mechanical treatments that entrapped vapor, air, and gas. The two types of expanded slag were crushed and graded, as indicated in table 1.

The expanded-slag aggregates, cement, and water were proportioned and mixed in the same manner used for the cinder masonry units. The units were molded by the tamping process and cured in the same plant and in the same manner as were the pumice concrete units.

(d) Expanded-Shale Concrete Units

The shale aggregate was produced by passing freshly mined lumps of shale through rotary kilns. As the lumps passed through the kiln they were expanded by thermochemical reactions. The resulting cellular clinker was chilled, crushed, and graded as indicated in table 1.

The expanded-shale aggregates, cement, and water were proportioned and mixed in the same manner as used for the cinder concrete units. The units were molded by the tamping process and cured in the same plant and in the same manner as were the pumice concrete units.

2. Mortar and Plaster

The mortar consisted of 1 part of portland cement, 1 part of hydrated lime, and 6 parts of sand, by volume. Proper proportions were actually obtained by weight, assuming that portland cement weighs 94 lb/ft^3, hydrated lime 40 lb/ft^3, and that a cubic foot of loose damp sand would, after drying, weigh 80 lbs. The portland cement and hydrated lime were of well-known brands obtained from local dealers. The sand was Potomac River building sand, about 95 percent of which was a mixture of siliceous minerals and the remainder was largely mica, calcite, pyroxenes, and feldspar. The plaster was sisal-fibered gypsum obtained from local dealers. One part of the gypsum plaster was mixed with three parts of sand, by weight.

3. Tests of Materials

Units representative of each design and kind of aggregate were tested for compressive strength and absorption in accordance with Standard Methods of Sampling and Testing Concrete Masonry Units, ASTM Designation: C 140-39. The results are given in table 3.

TABLE 3. *Some physical properties of the units used in test walls*

Kind of aggregate used in units	Average size	Shell thickness	Design[1]	Cell area	Weight: As delivered	Weight: After drying		Tests[2]: Moisture content[3]	Tests[2]: Absorption		Tests[2]: Compressive strength based on gross area	Tests[2]: Test walls in which units were used
	in.	*in.*		*Percent*	*lb/unit*	*lb/unit*	*lb/ft^3*	*Percent*	*Percent*	*lb/ft^3*	*lb/in.^{2}*	
Cinders	4.00 by 17.71 by 7.80	1.04	B	37	20.6	20.0	87.9	20.0	13.9	12.2	1,015	13A
	3.92 by 23.76 by 7.70	0.84	D	37	26.0	25.2	92.2	23.1	13.6	12.5	820	12A
	5.76 by 17.70 by 7.72	1.03	E	50	23.0	22.6	87.0	14.1	14.7	12.8	705	7A
	5.78 by 17.70 by 7.76	1.57	E	39	29.1	28.1	88.0	25.1	14.4	12.6	1,145	8A, 9A and 15A
	5.80 by 17.70 by 7.76	1.48	E	39	29.5	28.2	88.2	29.2	11.5	13.0	1,205	14A
Pumice	3.98 by 15.70 by 7.66	0.98	C	37	16.4	14.8	77.0	48.0	22.0	16.9	665	5B and 6A
	10.00 by 15.69 by 7.78	1.82	H	40	35.7	31.6	76.9	59.8	22.3	17.1	700	11A and 16A
Expanded slag I	2.92 by 15.70 by 7.86	0.90	A	24	14.4	14.1	99.1	17.4	13.9	13.8	640	2B
	3.99 by 15.76 by 7.76	1.00	C	37	18.1	17.4	95.2	22.2	15.5	14.7	645	5A
	3.92 by 23.72 by 7.94	0.84	D	37	31.5	30.7	108.4	20.5	10.2	11.1	895	6B and 12B
	4.00 by 15.80 by 7.70	1.00	C	37	19.4	18.3	101.3	41.6	13.2	13.4	990	13B
	6.00 by 15.78 by 7.71	1.31	F	50	23.9	22.9	99.4	24.9	13.1	13.0	800	7B
	6.00 by 15.71 by 7.59	2.00	G	24	30.0	28.7	99.4	30.1	13.0	13.1	1,075	9B and 10A
Expanded slag II	2.98 by 15.73 by 7.92	0.94	A	24	15.8	15.2	97.8	31.8	13.4	13.1	935	1B
	4.00 by 15.79 by 7.76	1.29	C	24	21.4	20.8	100.4	22.5	11.6	11.6	1,090	3B
	4.00 by 15.79 by 7.80	1.00	C	37	18.5	18.2	100.2	15.1	14.0	14.0	550	4A
	6.00 by 15.73 by 7.70	1.48	F	39	27.1	26.3	104.1	30.8	10.2	10.6	1,315	8B and 15D
	6.00 by 15.71 by 7.69	1.99	G	24	31.9	30.8	99.4	29.7	12.0	12.0	1,420	10B and 15C
Expanded shale	2.92 by 15.71 by 7.76	0.93	A	24	12.5	11.8	78.7	30.1	18.1	14.3	985	1A and 2A
	4.00 by 15.70 by 7.66	1.22	C	24	17.6	16.8	81.0	26.9	16.4	13.3	1,280	3A
	5.98 by 15.70 by 7.68	1.38	F	39	21.9	21.2	82.2	22.4	15.3	12.6	1,380	14B and 15B
	10.00 by 15.70 by 7.72	1.80	H	40	35.4	33.2	82.6	43.9	15.2	12.6	1,395	11B and 16B

[1] The designs of the units, in cutaway sections, are indicated in figure 1, page 2.

[2] All tests were made in accordance with Standard Methods of Sampling and Testing Concrete Masonry Units, ASTM Designation: C 140-39.

[3] The moisture contents were determined at approximately the same time that the compressive strength tests were made. They were expressed as a percentage of the total absorptions.

The time of set, consistency, and tensile strength of the gypsum plaster were determined in accordance with Standard Methods of Testing Gypsum and Gypsum Products, ASTM Designation: C 26–33. The results are given in table 4. The compressive strengths of the mortars and plasters are also given in table 4. The compressive-strength values were obtained by testing three 2-in. cubes that were made from each batch of mortar or plaster and aged 28 days in locations adjacent to the walls for which they were used.

The wide range in the strength of the mortars and plasters used for the walls is due in part to the use of different shipments of portland cement and plaster which were obtained as needed over a period of nearly 3 years. The seasonal variation in the uncontrolled aging conditions for the walls with which the test cubes were stored is also reflected in their strength values.

Table 4. *Tests of mortar and plaster*

Mortar[1]	Plaster					
Compressive strength[2]	Consistency[3]	Time of set[3]	Tensile strength, neat[3]	Mix dry-weight proportion	Compressive strength, sanded[2]	Test walls in which used
lb/in.²		*hr*	*lb/in.²*		*lb/in.²*	
613	50	13	245	1:3	598	1A and 1B
855	45	12	330	1:3	486	2A and 2B
444	45	12	330	1:3	538	3A and 3B
691	49	8	275	1:3	558	4A
692	-----	-----	-----	-----	-----	5A and 5B
928	-----	-----	-----	-----	-----	6A and 6B
-----	49	8	275	1:3	488	7A and 7B
615	49	8	275	1:3	348	8A and 8B
880	-----	-----	-----	-----	-----	9A and 9B
407	-----	-----	-----	-----	-----	10A and 10B
812	-----	-----	-----	-----	-----	11A and 11B
649	-----	-----	-----	-----	-----	12A and 12B
360	49	8	275	1:3	348	13A and 13B
719	-----	-----	-----	-----	-----	14A and 14B
887	-----	-----	-----	-----	-----	15A, 15B, 15C, and 15D
(4)	-----	-----	-----	-----	-----	16A and 1oB

[1] The mortar was proportioned, by volume, of 1 part of portland cement to 1 part of hydrated lime to 6 parts of sand.
[2] The compressive strengths of the mortar and plaster were obtained from tests of three 2-in. cubes of each batch and were determined after curing 28 days in locations adjacent to the partitions.
[3] The time of set, consistency, and tensile strength of the plaster were determined in accordance with Standard Methods of Testing Gypsum and Gypsum Products, ASTM Designation: C 26-33.
[4] Not determined.

III. Test walls

1. Construction

The construction is indicated in figures 2 and 3. All except three walls were built of 3-, 4-, 6-, or 10-in. units laid with cells vertical in common bond. Walls 13 and 14 were faced with brick that were bonded and tied with brick header ties above every second course of concrete units. The bricks used for facing wall 13 were laid flat and those for wall 14, on the 2¼- by 8-in. edge. The cavity-type wall, 12, consisted of two 4-in. walls spaced 2 in. apart and tied together at points 24 in. apart in every second bed joint. The ties were of 3/16-in. steel wire bent to a 3⅞- by 6-in. rectangle, with ends butted (not welded) at the center of one short side.

2. Size

The walls were built in fireproofed test frames of 20-in. 140-lb steel-girder beams, bolted or riveted at the corners, and having openings for test specimens 16 ft long and 8 to 11 ft high. They were built in two sections, each being 8 ft long and bonded together along the vertical center line except where it was desired to load each section independently. With the exception

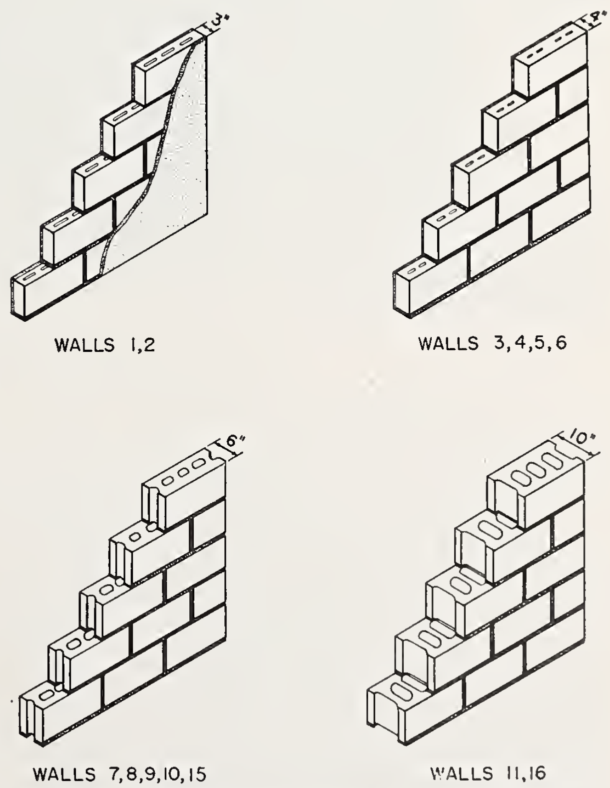

Figure 2. *Construction used in 3-, 4-, 6- and 10-in. test walls.*

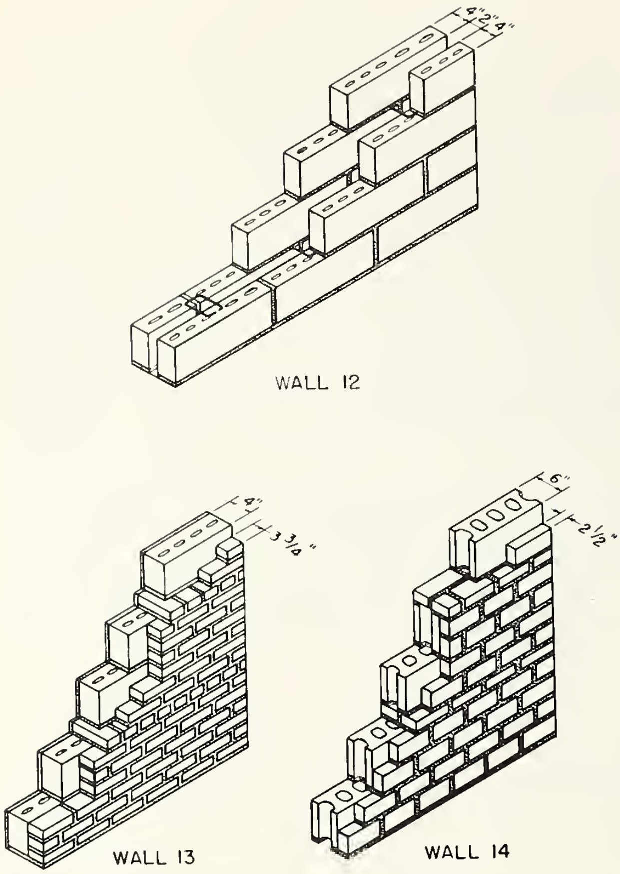

FIGURE 3. *Construction of cavity-type and of brick-faced test walls.*

of wall 4, the two sections of each wall were built of units of the same or similar design but made with different kinds of lightweight aggregate. Section B of wall 4 was built of units with sand and gravel aggregate and is not considered in this report.

3. Restraint and Loading

The nonload-bearing walls were built solidly within the frames to give a condition of restraint representative of that at the borders of partitions in buildings. The load-bearing walls were built in frames equipped with hydraulic jacks, figure 4, so that loads could be applied throughout the fire-endurance tests. They were centered on 8-ft loading beams resting on the pistons of the hydraulic jacks. They were bedded with mortar against the frames at the top but not at the ends. Openings approximately 1 in. wide were left between the ends of the walls and the frames. Similar openings were left between the two sections of wall 4 and of the cavity-type wall, 12. These openings were filled with loosely packed mineral wool, and the two sections of walls 4 and 12 were loaded independently during the fire-endurance tests.

4. Workmanship

The walls were built and plastered by skilled craftsmen working under contract. The workmanship was representative of local commercial jobs.

Full horizontal mortar beds were obtained for the 3- and 4-in. walls. Only the face shells of the blocks in the 6- and 10-in. walls were bedded. The vertical mortar joints were formed with mortar applied to the outside edges of the units before shoving them into place. No attempt was made to point the joints in the walls that were to be plastered. However, the walls that were to be tested without plaster finish were carefully pointed.

5. Wall Finish

Some of the walls were finished with 1:3 gypsum plaster on one or both sides. The plaster was applied a few days after the walls were built. Its total thickness was ½ in. A white-coat finish was not used. Instead, both the scratch and brown coats were applied the same day and given a float-finish. Wood baseboards were used on both sides of all of the plastered walls. They were attached by nailing into wood plugs set in the joints of the masonry.

6. Storing and Aging

After the mortar and plaster had taken its initial set, the frames containing the walls were moved to storage tracks for seasoning. Some of the plastered walls were covered with wet burlap for a few days in order to prevent excessive drying until after the plaster had set. All of the walls, except one, were aged for 28 to 40 days before being tested. That one, wall 16, being of units that had aged for a long time, was tested 14 days after it was built. The approximate moisture contents of the walls were taken as the same as those of unplastered control units like those used in the walls and seasoned with them. These values were found by determining the loss in drying the control units to constant weight at 220° F. They are given, in pounds per cubic foot of concrete material, in table 5 to indicate the condition of the walls at the time of test.

FIGURE 4. *Cavity-type load-bearing wall, 12, prepared for fire-endurance test.*

The section of the wall in the foreground was of expanded-slag I concrete units, and that, in the background, of cinder concrete units. The test frame, the hydraulic jacks for loading the wall, and the asbestos pads for protecting the thermocouples are shown

IV. Method of Testing and Equipment

The tests were conducted in accordance with the Standard Methods of Fire Tests of Building Construction and Materials of the American Standard Association, ASA No.: A2–1934, (ASTM Designation: C 19–33).

1. Wall-Testing Furnace

The tests were made in a furnace built of reinforced concrete and lined with firebrick to form a combustion chamber $2\frac{1}{2}$ ft deep and 16 ft long. The combustion chamber extended 6 ft below the burners in order to provide room for debris that might fall from the test wall and obstruct them. The details of the construction of the furnace are shown in figure 5. The walls were exposed on one side to furnace fires that were controlled to have average temperatures of approximately:

1,000° F at 5 min
1,300° F at 10 min
1,550° F at 30 min
1,700° F at 1 hr
1,850° F at 2 hr
2,000° F at 4 hr
2,300° F at 8 hr or more.

The test fire was produced by 92 gas burners (B, fig. 5) that were controlled with $\frac{3}{4}$-in. gas cocks, K, on each burner and also with one large valve, L, on the main gas supply. The

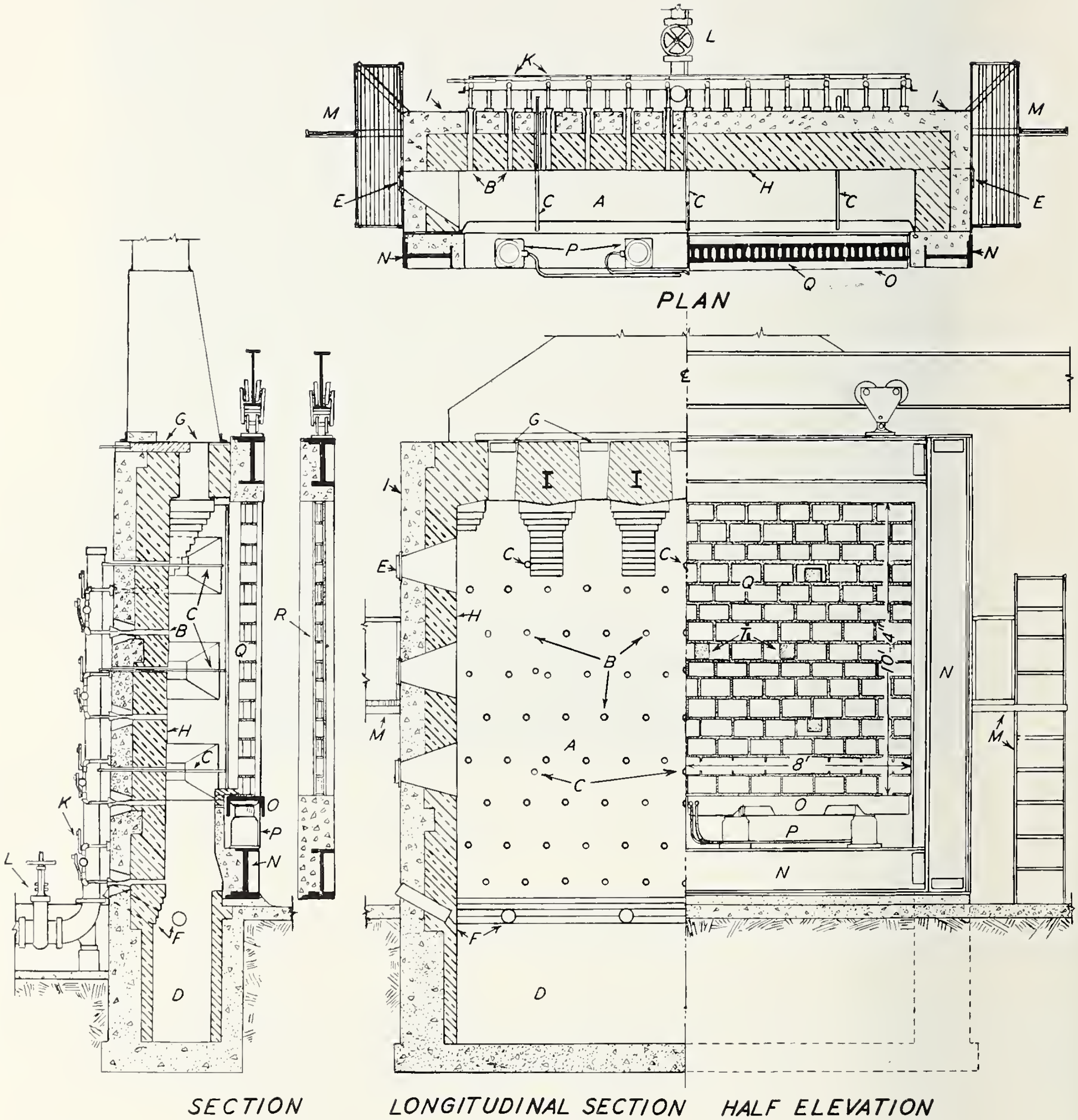

FIGURE 5. *Wall-testing furnace.*

A, Furnace chamber; B, burners; C, thermocouple protection tubes; D, pit for debris; E, mica-glazed observation windows; F, auxiliary air inlets; G, flue outlets and dampers; H, firebrick furnace-lining; I, reinforced-concrete furnace shell; K, gas cocks; L, gas-control valve; M, ladders and platforms to upper observation windows; N, movable fire-proofed test frame; O, loading beams; P, hydraulic loading jacks; Q, load-bearing test wall; R, nonbearing test partition; T, asbestos pads covering thermocouples on unexposed surface of test wall.

burners were of the induction type with venturi mixing tubes, part of the air for combustion being drawn in around the gas jet. Additional air was supplied to the combustion chamber through six 4-in. diameter inlets, F. The natural flow through these inlets was accelerated by means of jets of compressed air.

The fire exposure was continued in each test until one of the following criteria that limit the fire resistance was obtained: (a) Fire damage sufficient to allow the passage of flame or gas hot enough to ignite cotton waste, (b) failure under the applied load, or (c) the transmission of heat through the wall sufficient to raise the average temperature on its unexposed surface 250 deg or 325 deg F at any thermocouple location.

2. Temperatures

The temperatures of the furnace, on the unexposed side of the walls, and in the cells of some of the walls were measured at 5- to 10-min intervals during the fire tests. The temperatures in the furnace were measured with nine 18-gage chromel-alumel thermocouples, C, figure 5. The thermocouples and their leads, which were within porcelain insulators, were protected by $\frac{3}{4}$-in. wrought-iron pipes that were sealed at one end and symmetrically distributed in the furnace chamber.

The temperatures of the unexposed surface of the walls were measured with 22-gage chromel-alumel thermocouples, the leads of which were insulated with asbestos sleeving, except for a short length near the junctions. They were coiled under flexible, oven-dry, felted-asbestos pads, 6 in. square and 0.4 in. thick, held firmly against the partition. Extra thermocouples and a supply of dry cotton waste were provided for use over cracks or other places on the surface of the walls where high temperatures developed. The arrangement of the thermocouples on the surface of a wall is shown in figures 4 and 7.

The leads from all of the thermocouples were assembled in an insulated junction box, from which a compensating thermocouple was connected to a cold junction maintained at the temperature of melting ice. The ends of the alumel and chromel lead wires in the insulated junction box were connected to the copper wires of a lead-sheathed cable leading to selector switches in the instrument room. These switches were connected to portable potentiometers for measuring the electromotive force of the thermocouples. The readings of the potentials were subsequently converted to temperatures.

3. Deflections

The deflections were measured during the tests at nine locations on the unexposed surface of the walls. They were obtained by measuring from the surface of the wall to weighted wires fastened to the top of the test frame and extending downward in front of and a few inches from the test wall. One of the wires was opposite the vertical center line of the test specimen and one opposite the quarter points on each side of the center line.

4. Hose Stream

Fire-test walls that withstand a fire-endurance test of 1 hr or more are required to be subjected to a hose-stream test. This test is ordinarily made by subjecting a duplicate wall to a fire exposure of a duration equal to half of the desired fire-resistance rating but not for more than 1 hr. It is permissible, however, to apply the hose stream to the fire-endurance test walls immediately after their test. This optional method was used for the present tests. The water for the hose-stream tests was delivered through a $2\frac{1}{2}$-in. cotton, rubber-lined, fire hose and discharged through a National Standard Playpipe equipped with a $1\frac{1}{8}$-in. discharge tip. The water was discharged against the wall from a position at 19 ft (20 less 1 ft for its upward inclination) in front of the fire exposed side and at pressures of 30 to 45 lb/in^2. The water pressures were controlled by the adjustment of a valve in the supply line. They were measured by means of a gage connected to the base of the playpipe. The hose stream was applied at 30 lb/in.^{2} for 1 min for each 100 ft^2 of exposed area for all walls that had a fire endurance of 1 to $1\frac{1}{2}$ hr; for $1\frac{1}{2}$ min, for walls having a fire endurance of $1\frac{1}{2}$ to 2 hr; for $2\frac{1}{2}$ min, for walls having a fire endurance of 2 to 4 hr; and at 45 lb/in.^{2} for 5 min, for walls having a fire endurance of over 4 hr.

V. Results

The results of the fire-endurance and hosestream tests are given in table 5 and in the logs of the individual tests.

TABLE 5. *Description of walls and results of fire-endurance and hose-stream tests*

Wall		Description of walls												Tests[4]				
									Wall finish			Age at time of fire-endurance test		Fire endurance				
No.	Section	Nominal thickness	Size[1]	Restraint or load during fire test (on gross area)	Kind of aggregate used in units	Nominal dimensions of units	Cell area of units	Design of units[2]	On fire-exposed side	On unexposed side	Moisture content of control units at time of fire-endurance test[3]	Unit	Wall	Severity of exposure	Time		Determining factor	Results of hose stream with water on fire-exposed side
		in.	*ft*	*lb/in.²*		*in.*	*Percent*				*lb/ft³*	*days*	*days*	*Percent*	*hr*	*min*		
1	A	3	8 by 10	Restrained	Expanded shale	3 by 16 by 8	24	A	Plaster[5]	Plaster[5]	6.2	74	40	105	2	02	Temp max	Met requirements.
	B	3	8 by 10	do	Expanded slag II	3 by 16 by 8	24	A	do	do	1.1	74	40	105	2	08	do	Do.
2	A	3	8 by 10	do	Expanded shale	3 by 16 by 8	24	A	do	do	3.9	153	39	102	1	54	Temp avg	Do.
	B	3	8 by 10	do	Expanded slag I	3 by 16 by 8	24	A	do	do	1.8	153	39	102	2	08	do	Do.
3	A	4	8 by 10	do	Expanded shale	4 by 16 by 8	24	C	do	None	4.5	156	40	102	2	42	do	Do.
	B	4	8 by 10	do	Expanded slag II	4 by 16 by 8	24	C	do	do	2.5	156	40	102	2	24	do	Do.
4	A	4	8 by 10	do	Expanded slag II	4 by 16 by 8	37	C	do	do	1.4	112	30	100	1	30	do	Do.
5	A	4	8 by 9	do	Expanded slag I	4 by 16 by 8	37	C	None	do	3.2	155	35	93	[6]1	36	Temp max	Do.
	B	4	8 by 9	do	Pumice	4 by 16 by 8	37	C	do	do	6.6	155	35	93	[6]2	03	do	Do.
6	A	4	8 by 8	do	Pumice	4 by 16 by 8	37	C	do	do	1.8	512	29	100	1	16	Temp avg	
	B	4	8 by 8	do	Expanded slag I	4 by 24 by 8	37	D	do	do	1.4	242	29	100	1	09	do	
7	A	6	8 by 10	do	Cinders	6 by 18 by 8	50	E	Plaster[5]	Plaster[5]	1.8	222	40	100	2	06	Temp max	Met requirements.
	B	6	8 by 10	do	Expanded slag I	6 by 16 by 8	50	F	do	None	2.2	237	40	100	2	28	Temp avg	Do.
8	A	6	8 by 10	do	Cinders	6 by 18 by 8	39	E	do	do	2.7	221	38	100	2	12	do	Do.
	B	6	8 by 10	do	Expanded slag II	6 by 16 by 8	39	F	do	do	3.0	237	38	100	2	54	do	Do.
9	A	6	8 by 10	do	Cinders	6 by 18 by 8	39	E	None	None	2.7	359	28	100	1	36	do	
	B	6	8 by 10	do	Expanded slag I	6 by 16 by 8	24	G	do	do	2.6	377	28	100	3	20	do	
10	A	6	8 by 10	175	Expanded slag I	6 by 16 by 8	24	G	do	do	3.8	153	35	101	3	54	Temp max	Met requirements.
	B	6	8 by 10	175	Expanded slag II	6 by 16 by 8	24	G	do	do	3.0	152	35	101	3	55	do	Do.
11	A	10	8 by 10	70	Pumice	10 by 16 by 8	40	H	do	do	11.8	74	37	100	5	20	Ignition of waste	
	B	10	8 by 10	70	Expanded shale	10 by 16 by 8	40	H	do	do	5.9	74	37	100	4	42	Temp avg	
12	A	[7]10	8 by 10	80	Cinders	4 by 24 by 8	37	D	do	do	1.8	148	28	100	3	45	do	Collapsed at 4½ min.[8]
	B	[7]10	8 by 10	80	Expanded slag I	4 by 24 by 8	37	D	do	do	1.8	168	28	100	4	43	do	
13	A	8	8 by 10	80	Cinders	4 by 18 by 8	37	B	Plaster[5]	Brick[9]	2.1	223	40	100	6	26	do	
	B	8	8 by 10	80	Expanded slag I	4 by 16 by 8	37	C	do	do	2.4	242	40	100	7	03	do	
14	A	8½	8 by 10	80	Cinders	6 by 18 by 8	39	E	None	Brick[10]	3.3	174	32	99	4	54	do	Met requirements.
	B	8½	8 by 10	80	Expanded shale	6 by 16 by 8	39	F	do	do	4.0	190	32	99	5	26	do	Do.
15	A	6		Restrained	Cinders	6 by 18 by 8	39	E	None	None	2.7	496	30	100	1	37	do	
	B	6		do	Expanded shale	6 by 16 by 8	39	F	do	do	2.3	512	30	100	1	54	do	
	C	6		do	Expanded slag II	6 by 16 by 8	24	G	do	do	1.9	511	30	100	3	29	do	
	D	6		do	Expanded slag II	6 by 16 by 8	39	F	do	do	2.6	512	30	100	2	25	do	
16	A	10		do	Pumice	10 by 16 by 8	40	H	do	do	6.3	475	14	100	4	33	do	
	B	10		do	Expanded shale	10 by 16 by 8	40	H	do	do	3.2	475	14	100	4	19	do	

[1] All but 2 of the walls consisted of 2 sections of the same or similar designs of units with different kinds of aggregates. Walls 15 and 16, tested to determine effect of moisture content, had 4 and 2 sections, respectively, each with an area of approximately 40 ft².

[2] The designs of the units are indicated in figure 1, page 2.

[3] The moisture content was determined by drying at 220°F control units that had seasoned with the fire-test walls.

[4] All fire-endurance and hose-stream tests were made in accordance with Standard Specifications for Fire Tests of Building Constructions and Materials, ASTM Designation: C 19–33 (ASA No.: A2–1934).

[5] The plaster consisted of 1 part of fibered gypsum to 3 parts of sand, by volume, and was applied to a total thickness of ½ in.

[6] The fire-endurance time should be decreased from 1 hr 36 min to 1 hr 27 min, and from 2 hr 3 min to 1 hr 54 min, respectively, to correct for the low severity of fire exposure as per Sec. 5(b) of ASTM Standard, Designation: E 119–47.

[7] This wall was of the cavity type and consisted of two 4-in. wythes spaced 2 in. apart.

[8] See section VI, 6, page 15, for evaluation of this result.

[9] The bricks were laid on the 3¾- by 7¾-in. face.

[10] The bricks were laid on edge.

1. Log of Tests

The log of tests gives the description of the walls, the important observations that were made during each test, the duration of the tests, the factors which determined the fire endurance of each wall, and the results of the hose-stream tests. Reference is made to figure 6 showing the deflections, toward (+) and away (—) from the fire, at the center of the walls; to figures 7 to 9 showing the condition of some of the walls after test, and to figures 10 to 18 giving the temperatures of the furnace and the test wall.

Test 1.—Three-inch nonbearing plastered partition; expanded-shale concrete units, 24 percent of cell area, in section A; and expanded slag II concrete units, 24 percent cell area, in section B.

The first effects of the fire exposure were noted at 12 min when dull cracking sounds were heard. At 25 min, wet spots began to show in the plaster on the unexposed side of the wall, as indicated in figure 7. Fine diagonal cracks appeared across the lower corners of the unexposed surface at 1 hr 6 min. No further changes in the appearance of either side of the partition were observable when the gas was turned off at 2 hr 11 min.

The fire endurance of section A was limited by a temperature rise of 325 deg F at one place on the unexposed surface at 2 hr 2 min; and of section B, in the same manner, at 2 hr 8 min. The deflection and temperature curves are given in figures 6 and 10.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2} for 2½ min for each 100 ft^2 of exposed area. The exposed-side plaster was washed away, but the partition met the requirements of the test.

Test 2.—Three-inch nonbearing plastered partition; expanded-shale concrete units, 24 percent of cell area, in section A; and expanded slag I concrete units, 24 percent cell area, in section B.

The early effects of the fire exposure, noted at 5 and 7 min, consisted of dull cracking sounds and the appearance of fine cracks across the corners of the unexposed side. Steam was observed at these cracks at 14 min. At 48 min, vertical cracks near the ends of the partition, and a long horizontal crack near the top, were noted. No further fire effects were noted when the gas was turned off at 2 hr 13 min.

The fire endurance of section A was limited by an average temperature rise of 250 deg F on the unexposed surface at 1 hr 54 min: and of section B in the same manner at 2 hr 8 min. The deflection and temperature curves are given in figures 6 and 10.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2}, for 2½ min for each 100 ft^2 of exposed area. The exposed-side plaster was washed away, but the partition met the requirements of the test.

Test 3.—Four-inch nonbearing partition plastered on the exposed side; expanded-shale concrete units, 24 percent of cell area, in section A: and expanded slag II concrete units, 24 percent of cell area, in section B.

The first effects, noted at 9 min, were fine vertical cracks near the middle of the unexposed side and in a horizontal mortar joint at the midheight of section B. Cracks in two other horizontal mortar joints were observed at 1 hr 35 min. Some of the mortar joints in both sections of the partition showed wet spots at 12½ min. Soon after this, steam issued from some of the cracks. This steaming had ceased at 1 hr 40 min. No further fire effects were noted on either side of the partition when the gas was turned off at 2 hr 47 min.

The fire endurance of the partition was limited by an average temperature rise of 250 deg F at 2 hr 42 min for section A; and for section B, at 2 hr 24 min. The deflection and temperature curves are given in figures 6 and 10.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2}, for 2½ min for each 100 ft^2 of exposed area and met the requirements of the test.

Test 4.—Four-inch nonbearing partition plastered on the exposed side; expanded-slag II concrete units, 37 percent of cell area, in section A. (Section B was of gravel concrete units and is not included in this report.)

Neither wet spots on the unexposed surface nor steam appeared during the fire exposure, nor did the appearance of the exposed plaster change. The gas was turned off at 1 hr 55 min.

The fire endurance of this partition was limited by an average temperature rise of 250 deg F on the unexposed surface at 1 hr 30 min. The deflection and temperature curves are given in figures 6 and 11.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2} for 1½ min for each 100 ft^2 of exposed area and met the requirements of the test.

Test 5.—Four-inch nonbearing unplastered partition; expanded-slag I concrete units, 37 percent of cell area, in section A; and pumice concrete units, 37 percent of cell area, in section B.

Cracking sounds, first heard at 1 min after the beginning of the fire exposure, continued intermittently throughout the test. At 15 min, wet spots began to appear on the unexposed side of section B of the partition. Nearly all of these had disappeared at 2 hr. The gas was turned off at 2 hr 12 min.

The fire endurance of section A was limited by a temperature rise of 325 deg F at one place on the unexposed surface at 1 hr 36 min; and of section B, in the same manner, at 2 hr 3 min. The deflection and temperature curves are given in figures 6 and 11.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2}, for 2½ min for each 100 ft^2 of exposed area and met the requirements of the test.

Test 6.—Four-inch nonbearing unplastered partition; pumice concrete units, 37 percent of cell area, in section A; and expanded-slag I concrete units, 37 percent of cell area, in section B.

Wet spots were noted at a number of places on the unexposed surface at 12½ min. At 30 min, a considerable amount of steam was coming from section A and a smaller amount, from section B. At 1 hr 15 min, the steaming had ceased. Diagonal cracks across the corners of the unexposed surface were noted at 21 and 30 min. The gas was turned off at 1 hr 30 min.

The fire endurance of the partition was limited by an average temperature rise of 250 deg F at 1 hr 16 min for section A; and at 1 hr 9 min for section B. The deflection and the temperature curves are given in figures 6 and 11.

This partition was not subjected to the hose-stream test.

Test 7.—Six-inch nonbearing partition; cinder concrete units, 50 percent of cell area, in section A, plastered on both sides; and expanded-slag I concrete units, 50 percent of cell area, in section B, plastered only on the exposed side.

The fire effects consisted of wet spots and steam, first noticed for section B at 16 min, and, for section A at 30 min. The steaming had stopped at 1 hr 18 min and nearly all of the wet spots had disappeared at 1 hr 55 min. Other fire effects consisted of a horizontal crack in the unexposed plaster, near the top of section A, at 1 hr 15 min. The gas was turned off at 2 hr 30 min.

The fire endurance of section A was limited by a maximum temperature rise of 325 deg F at one point on the unexposed surface at 2 hr 6 min; and of section B, by an average temperature rise of 250 deg F at 2 hr 28 min. The deflection and temperature curves are given in figures 6 and 12.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2}, for 2½ min for each 100 ft^2 of exposed area and met the requirements of the test.

Test 8.—Six-inch nonbearing partition plastered only on the exposed side; cinder concrete units, 39 percent of cell area, in section A; and expanded-slag II concrete units, 39 percent of cell area, in section B.

The fire effects consisted of wet spots on the unexposed surface of section A, which appeared at 32 min and disappeared at approximately 2 hr. The gas was turned off at 3 hr.

The fire endurance of section A was limited by an average temperature rise of 250 deg F on the unexposed surface at 2 hr 12 min; and of section B, in the same manner, at 2 hr 54 min. The deflection and temperature curves are given in figures 6 and 12.

The partition was subjected to the hose stream at a pressure of 30 lb/in.^{2}, for 2½ min for each 100 ft^2 of exposed area. The water washed away the plaster and some of the vertical mortar joints, figure 8. As water did not pass through the partition, it met the requirements of the test.

Test 9.—Six-inch nonbearing unplastered partition; cinder concrete units, 39 percent of cell area, in section A; and expanded-slag I concrete units, 24 percent of cell area, in section B.

The effects of the fire exposure were confined to steam and the formation of wet spots on the unexposed surface. At 30 min, wet spots were appearing at a number of places. They predominated on section B. The gas was turned off at 3 hr 30 min.

The fire endurance of section A was limited by an average temperature rise of 250 deg F on the unexposed surface at 1 hr 36 min; and of section B, in the same manner, at 3 hr 20 min. The deflection and temperature curves are given in figures 6 and 13.

This partition was not subjected to the hose-stream test.

Test 10.—Six-inch unplastered bearing wall; 175-lb/in.^{2} load; expanded-slag I concrete units, 24 percent of cell area, in section A; and expanded-slag II concrete units, 24 percent of cell area, in section B.

A number of fine vertical cracks extending nearly the full height of the wall formed in the unexposed surface. The first two of the cracks appeared at 7 and 10 min. Steam began to issue from the wall at 25 min and caused wet spots which first appeared on the unexposed surface at 42½ min. After 3 hr, the wall surface began to dry and the wet spots disappeared. The gas was turned off at 4 hr 4 min.

The fire endurance of the wall was limited by a temperature rise of 325 deg F at one place on the unexposed surface, at 3 hr 54 min, for section A; and at 3 hr 55 min, for section B. The deflection and temperature curves are given in figures 6 and 13.

The partition was subjected to the hose stream at a pressure of 45 lb/in.^{2}, for 5 min for each 100 ft^2 of exposed area and met the requirements of the test.

Test 11.—Ten-inch unplastered bearing wall; 70 lb/in.^{2} load; pumice concrete units, 40 percent of cell area, in section A; and expanded-shale concrete units, 40 percent of cell area, in section B.

During the first 10 min, a number of cracking sounds were heard. A number of fine vertical cracks, some extending from the top to the bottom of the wall, appeared in section A of the wall during the first part of the test. The first of these cracks was observed at 12 min. These cracks widened as the test progressed, with one of them opening to ⅛ in. at 1 hr 30 min. The first wet spots appeared on section A at 40 min, and on section B at 51 min. At 1 hr 30 min, nearly all of the unexposed surface of section A was wet. At 2 hr 15 min, cotton waste was put over one of the larger cracks in section A. It soon became wet from the condensation of steam. However, at 4 hr 55 min, the wet waste was replaced with dry waste. At 5 hr 20 min, the waste ignited. The fire exposure was continued for 6 hr 22 min. At that time a 2½-in. outward deflection, at the middle of section A, made it unsafe to continue the test.

The fire endurance of section A was limited by the ignition of cotton waste over a crack in the unexposed surface, at 5 hr 20 min; and that of section B, by an average temperature rise of 250 deg F on the unexposed surface, at 4 hr 42 min. The deflection and temperature curves are given in figures 6 and 14.

This wall was not subjected to a hose-stream test.

Test 12.—Ten-inch unplastered cavity-type bearing wall made up of two 4-in. walls, spaced 2 in. apart, tied together with metal ties; 80-lb/in.^{2} load; cinder concrete units, 37 percent of cell area, in section A; and expanded-slag I concrete units, 37 percent of cell area, in section B.

At 46 min, a fine vertical crack extending from the top to the bottom of section B was observed. Steam issued from the edge of the wall at 26 min. Wet spots first appeared at 46 min on the unexposed surface of section B and began to disappear at 3 hr. They did not form on section A. When the gas was turned off at 5 hr 15 min, there were no visible cracks or other effects of the fire on the exposed surface.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F on the unexposed surface at 3 hr 45 min for section A; and at 4 hr 43 min, for section B. The deflection and temperature curves are given in figures 6 and 15.

The wall was subjected to the hose stream at a pressure of 45 lb/in.^{2} for each 100 sq ft of exposed area. After 4½ min of water application, section A collapsed. This section should have withstood the hose stream for 4 min at a pressure of 30 lb/in.^{2} to have met the requirements of the test. Section B, with a fire endurance of 4 hr 43 min, was required to withstand the hose stream, at a pressure of 45 lb/in.^{2}, for 8 min.

Test 13.—Eight-inch plastered bearing wall veneered with brick laid on side; 80-lb/in.^{2} load; cinder concrete units, 37 percent of cell area, in section A; and expanded-slag I concrete units, 37 percent of cell area, in section B.

At 45 min, steam was issuing from the borders of the walls and wet spots were appearing on some of the unexposed side mortar joints. At 1 hr 45 min, a small area of the exposed plaster was loose and had curled out slightly. Cracking sounds, which were believed to be from the breaking of the brick header ties, were heard between 2 hr and 2 hr 30 min. There was no further change in the appearance of the wall when the gas was turned off at 7 hr 7 min.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F on the unexposed surface at 6 hr 26 min for section A; and at 7 hr 3 min, for section B. The deflection and temperature curves are given in figures 6 and 16.

This wall was not subjected to the hose-stream test.

Test 14. — Eight and one-half-inch unplastered bearing wall, veneered with brick on edge; 80-lb/in.[2] load; cinder concrete units, 39 percent of cell area, in section A; and expanded-shale concrete units, 39 percent of cell area, in section B.

At 50 min, steam was issuing from the top of the wall, and at 1 hr 5 min, wet spots appeared on the unexposed side mortar joints. These began to disappear at 2 hr 10 min. There was no further change in the appearance of the wall up to 5 hr 35 min when the gas was turned off.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F on the unexposed surface at 4 hr 54 min for section A; and at 5 hr 26 min, for section B. The deflection and temperature curves are given in figures 6 and 17.

The wall was subjected to the hose stream at a pressure of 45 lb/in.[2] for 4 min for each 100 ft[2] of exposed area. The water washed out nearly all of the vertical mortar joints and pitted the surface of the cinder concrete blocks (fig. 9). After the wall cooled it was loaded to 160 lb/in.[2] without showing further damage. The wall met the requirements of the hose-stream test.

Test 15.—Six-inch nonbearing unplastered wall; cinder concrete units, 39 percent of cell area, in section A; expanded-shale concrete units, 39 percent of cell area, in section B; expanded-slag II concrete units, 24 percent of cell area, in section C; and expanded-slag II concrete units, 39 percent of cell area, in section D.

Cracking sounds were heard at frequent intervals during the test. Steam issued from the borders and unexposed surface of the wall from 20 min to 1 hr 45 min. A diagonal crack, across one of the lower corners of the wall and following the mortar joints, was observed at 32 min. There had been no further change in the appearance of the wall when the gas was turned off at 3 hr 32 min.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F at 1 hr 37 min for section A; at 1 hr 54 min for section B; at 3 hr 29 min for section C; and at 2 hr 25 min for section D. The deflection and temperature curves are given in figures 6 and 18.

This wall was not subjected to the hose-stream test.

Test 16.—Ten-inch nonbearing unplastered wall; pumice concrete units, 40 percent of cell area, in section A; and expanded-shale concrete units, 40 percent of cell area, in section B.

At 30 min, a small amount of steam was issuing from the borders of the wall. At 1 hr 50 min, a vertical crack, extending from top to bottom, was formed at the midlength of the wall. At 3 hr 5 min cracking sounds were heard but no cracks were visible. There had been no further change in the appearance of the wall when the gas was turned off at 5 hr.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F at 4 hr 33 min for section A; and at 4 hr 19 min for section B.

This wall was not subjected to the hose-stream test.

VI. Discussion of Results

The fire endurance of all but one of the walls of this series was determined by the limiting temperature rise on the unexposed surface. For that one, it was determined by the ignition of waste at a crack in the unexposed surface.

Damage to the construction as a whole or to its several constituent parts, is not taken as a criterion of the performance in the fire-endurance test. However, observations of such damage were made. Some of the exposed shells were loosened by the cracking of the transverse webs, but none of them fell during the fire-endurance tests. A number of the units, particularly in the bearing walls, were cracked through both the exposed and unexposed shells and broke into two parts as they were removed from the wall. The fire exposures, particularly those of the longer durations, weakened the cement binder in the blocks and mortar, and caused minor and variable disintegration. There was no noticeable fusion on the surface of any of the walls.

1. Effect of Wall Thickness

When the moisture content, the kind of aggregate, and other conditions are the same in two or more walls, the fire resistance of solid walls has been found to be nearly proportional to the 1.7 power of the wall thickness.[1] For walls of hollow units of similar design the relation holds approximately for the "effective thickness," which is obtained by multiplying the over-all thickness of the wall by the percentage of solid material in the units. A comparison showing the above relation can be had between the test results with section B of 4-in. wall 6 and that of section B of 6-in. wall 9. Both were of units made with expanded-slag aggregate I. The effective thickness for the former was 2.5 in. and for the latter, 4.6 in., and the respective fire endurance, 1 hr 9 min and 3 hr 20 min, which conforms closely with the theoretical relation. A second comparison can be had from the test results of the two sections of wall 15, both of 6-in. units made with expanded-slag aggregate II but differing in cell area. With respective effective thicknesses of 4.56 and 3.66 in., the fire-resistance values were 3 hr 29 min and 2 hr 25 min. A third comparison can be had with section B of 4-in. wall 6, and section B of the cavity-type wall, 12,

[1] National Bureau of Standards BMS92, "Fire Resistance Classifications of Building Constructions," Appendix B.

which consisted of two 4-in. wythes of the same type of unit. The calculated fire endurance of the latter, based on the test results of the former, was 4 hr 40 min. The fire endurance obtained in the test was only 3 min greater than the calculated value.

2. Effect of Type of Aggregate

There was little difference in the test results that could be attributed to differences between expanded-slag I units and expanded-slag II units, as shown by section B of walls 1 and 2, and by section B of walls 7 and 8. There was some difference in the performance of walls made of units of expanded slag, expanded clay, and pumice, but it may have been due to incidental variations. However, the limiting temperature rise on the unexposed-side surface of walls of cinder concrete units was reached earlier than with walls of pumice, expanded-slag, or expanded-shale concrete units. The limit for a 6-in. wall of cinder concrete units, plastered on the exposed side, was reached in 2 hr 12 min, and for a similar wall of expanded-slag units, in 2 hr 54 min, (wall 8). For an unplastered 6-in. wall of cinder concrete units, it was reached in 1 hr 37 min; for one of the expanded-shale concrete units, in 1 hr 54 min; and for one of expanded-slag concrete units, in 2 hr 25 min, (wall 15). For a 10-in. unplastered cavity-type wall, 12, the limiting temperature rise was reached in 3 hr 45 min, for the section built of cinder concrete units, and in 4 hr 43 min for the section built of expanded-slag units.

3. Effect of Moisture Content

Consideration should be given to the moisture content of the test specimens when evaluating the results of fire tests. All of the lightweight aggregates are moisture retentive, particularly so for those having very small pores like those in pumice aggregate. Units made with such aggregates require prolonged drying in a heated building before they attain constant weight.

The effect of moisture in walls of pumice concrete units is shown by the results of tests of section A of walls 11 and 16, both of which were 10 in. thick and not plastered. The moisture in the units of the first wall at the time of the test was 11.8 lb/ft^3 and the average temperature rise on the unexposed surface was 160 deg F when the test was stopped at 6 hr 22 min. The moisture in the units of the second wall was 6.3 lb/ft^3 and an average temperature rise of 250 deg F was reached at 4 hr 33 min. The difference in test results, due to differences in moisture content of expanded-shale concrete units, is indicated for sections B of walls 11 and 16, and for expanded-slag concrete units by section B of wall 10 and section C of wall 15. The higher moisture content consistently increased the time required for attaining the limiting temperature rise on the unexposed surface.

The aggregates used in the units for the walls tested in the present series were more retentive of moisture than most materials used in building constructions. The specimens that were tested after the normal seasoning period of 30 to 90 days gave results that were relatively higher than would be obtained for otherwise comparable constructions built of less moisture retentive materials. The moisture contents of the specimens that were seasoned 250 to 500 days were lower than usual for fire-test specimens, and consequently, the fire-endurance values obtained in the tests were lower than would be generally obtained. Fire-endurance values from walls seasoned for periods intermediate to the above might be more applicable in making comparisons with established values for other materials.

4. Effect of Combustible Framed-in Members

When combustible members are framed into a bearing wall, the fire resistance is limited by an average temperature rise of 325 deg F at positions 3½ to 4 in. from the surface into which the combustible members are framed. Hence, the time at which the above-mentioned limiting temperature was reached between the two wythes of the cavity-type wall, 12, determined the resistance to be used when combustible members are framed into the wall. These times were 1 hr 30 min for section A of cinder concrete units, and 1 hr 54 min for section B of expanded-slag I concrete units. Temperature measurements for the determination of the fire resistance of the walls with combustible framed-in members were not made in the other bearing walls of this series. However, the results of a large number of other fire tests have indicated that the fire resistance of 8-in. bearing walls with combustible framing set in 4 in. from the unexposed side and embedded on at least three sides in solid masonry or incombustible material will be about two-fifths of that for the same walls with incombustible or no framing members bedded in them.[2]

5. Effect of Loading

All of the bearing walls sustained the applied working loads during the fire exposures, although subject to qualification in the case of section A of wall 11 of pumice concrete blocks. The fire exposure of this wall was continued to 6 hr 20 min, even though the fire endurance was limited by ignition of waste at 5 hr 20 min. The curves given in figure 6 indicate a considerably greater outward deflection for section A of wall 11 of pumice concrete units than for section B of expanded-shale concrete units. In-

[2] National Bureau of Standards BMS92, "Fire Resistance Classifications of Building Constructions," page 27.

asmuch as the two sections were bonded together, the deflection indicated for the former was, without doubt, less than would have been obtained if it had been tested as an independent wall. It is probable, however, that load failure of a separate wall of the pumice concrete units would not have occurred before 5 hr 20 min of fire exposure, since, at that time, the deflection of the wall, as bonded with the other section of expanded-shale concrete units, was only 1¾ in.

6. Resistance to the Hose Stream

Ten of the test walls were subjected to the hose-stream tests at the end of the fire-endurance tests. Three of the remaining walls, 6, 9, and 15, were of the same kind of units as in other walls that had been subjected to both the fire-endurance and hose-stream tests. A hose-stream test of the brick-faced wall 13 was not considered necessary, since brick-faced wall 14, with the bricks set on edge, easily met the requirements of such a test.

The 10-in. walls, 11 and 16, were not subjected to the hose-stream test, but considering the performance in the tests of unplastered 4-in. wall 5, and of 6-in. wall 10, after a 4-hr fire exposure, it can be assumed that these 10-in. walls would have withstood easily the hose stream after 1 hr of fire exposure. This is the requirement of the test specifications when a duplicate wall is used.

For wall 10, the load was not applied after the hose-stream test, which was conducted at the end of the fire-endurance test. It appears probable, considering the low deflection of the wall, that the load would have been sustained subsequent to a hose-stream test conducted after a 1-hr fire exposure.

The cinder concrete unit section, A, of the 10-in. cavity-type wall, 12, collapsed after 4½ min of water application at 45-lb/in.^{2} pressure following 5¼ hr of fire exposure. A part of the exposed wythe of the expanded-slag I concrete unit, section B, collapsed after 4¾ min of hose-stream application. Section A of this wall, having given a fire endurance of 3 hr 45 min, was required to withstand the hose stream at 30-lb/in.^{2} pressure for 4 min. It more than met the requirements. Section B, having given a fire endurance of 4 hr 43 min, was required to withstand the hose stream at 45-lb/in.^{2} pressure for 8 min after a fire exposure of 1 hr. Its condition after 1 hr of the fire-endurance test was sufficiently good in comparison to what it was after 5¼ hr of fire exposure, to indicate that a duplicate wall after 1 hr of fire exposure would have met the hose-stream requirements.

VII. Summary

The fire-resistance values of the constructions in the present series are given in Table 6, grouped according to aggregates. The agreement in values for the walls of comparable constructions was close. The results differed by only 1 min for two walls of 6-in. cinder concrete units and also for two 6-in. bearing walls of units made with expanded-slag aggregates. The difference for two 3-in. plastered walls of units of expanded-shale aggregate was 8 min. This difference may have been due in part to the small difference in moisture content of the two walls.

Three-inch and four-inch plastered walls of units having 24 percent cell area and made with expanded-slag or expanded-shale aggregate gave fire-resistance values ranging from 1 hr 54 min to 2 hr 8 min. Four-inch unplastered walls of units having 37 percent cell area and made with the same general type of aggregate gave values ranging from 1 hr 9 min to 1 hr 30 min. Six-inch unplastered walls of units having 24 percent cell area gave values ranging from 3 hr 20 min to 3 hr 55 min, and a 10-in. unplastered wall of units having 37 percent cell area, gave a fire resistance of 4 hr 43 min.

A 10-in. cavity-type unplastered wall with a 2-in. air space between two 4-in. wythes built of units having 37 percent of cell area and made with cinder aggregate, had a fire endurance of 3 hr 45 min; a similar wall of units having 37 percent of cell area and made with expanded-slag I aggregate had a fire resistance of 4 hr 43 min. An 8-in. plastered wall faced with 4 in. of brick and backed with 4-in. slag-concrete units having 37 percent of cell area had a fire resistance of 7 hr 3 min.

The fire resistance of walls of the same type of units and kind of aggregates increases in proportion to the 1.7 power of the thickness of solid material through the wall.

The fire-resistance values of walls made of units with pumice aggregates were approximately the same as for similar walls made with expanded-slag or burned-shale aggregates, where the moisture content at the time of test was comparable. Walls of units with cinder aggregates, however, gave somewhat lower values than comparable walls of units of other aggregates, the differences being from ½ to 1 hr. Walls of units made with lightweight aggregates and tested after normal seasoning periods of 1 to 3 months gave fire-resistance values greater than those of comparable constructions of materials that do not retain moisture as tenaciously as the lightweight aggregates.

Plaster on one or both sides did not increase

Table 6. *Fire resistance of walls of lightweight-aggregate concrete masonry units*

Nominal thickness	Aggregate	Cell area	Restraint or load during fire test (on gross area)	Wall finish: On fire-exposed side	Wall finish: On unexposed side	Fire resistance of wall		Test wall No.
in.		*Percent*	*lb/in.²*			*hr*	*min*	
6	Cinders	50	Restrained	Plaster[1]	Plaster[1]	2	06	7A
6	do	39	do	None	None	1	[2]36	9A
6	do	39	do	do	do	1	[2]37	15A
6	do	39	do	Plaster[1]	do	2	12	8A
8	do	37	80	do	Brick, flat	6	26	13A
8½	do	39	80	None	Brick on edge	4	54	14A
10[3]	do	37	80	do	None	3	45	12A
4	Pumice	37	Restrained	None	None	1	54	5B
4	do	37	do	do	do	1	[2]16	6A
10	do	40	70	do	do	5	20	11A
10	do	40	Restrained	do	do	4	[2]33	16A
3	Expanded slag I	24	Restrained	Plaster[1]	Plaster[1]	2	08	2B
4	do	37	do	None	None	1	27	5A
4	do	37	do	do	do	1	[2]09	6B
6	do	50	do	Plaster[1]	do	2	28	7B
6	do	24	175	None	do	3	54	10A
6	do	24	Restrained	do	do	3	[2]20	9B
8	do	37	80	Plaster[1]	Brick, flat[1]	7	03	13B
10[3]	do	37	80	None	None	4	43	12B
3	Expanded slag II	24	Restrained	Plaster[1]	Plaster[1]	2	08	1B
4	do	24	do	do	None	2	24	3B
4	do	37	do	do	do	1	30	4A
6	do	39	do	do	do	2	54	8B
6	do	39	do	None	do	2	[2]25	15D
6	do	24	175	do	do	3	55	10B
6	do	24	Restrained	do	do	3	[2]29	15C
3	Expanded shale	24	do	Plaster[1]	Plaster[1]	2	02	1A
3	do	24	do	do	do	1	54	2A
4	do	24	do	do	None	2	42	3A
6	do	39	do	None	do	1	[2]54	15B
8½	do	39	80	do	Brick on edge	5	26	14B
10	do	40	70	do	None	4	42	11B
10	do	40	Restrained	do	do	4	[2]19	16B

[1] The plaster consisted of 1 part of fibered gypsum to 3 parts of sand by volume and was applied to a total thickness of ½ in.
[2] Tests were made after extended aging of units.
[3] These walls were of the cavity type and consisted of two 4-in. wythes spaced 2 in. apart.

the fire resistance of constructions in this series to the extent to be expected from the increase in over-all wall thickness. This was apparently due to the relatively high fire resistance of the concrete of which the units were made, a given thickness of solid wall material being more effective in increasing the fire resistance than an equal thickness of sanded gypsum plaster.

Acknowledgment is made to the National Concrete Masonry Association, represented by P. M. Woodworth, for manufacturing and supplying the lightweight-aggregate concrete units and for constructing most of the test walls.

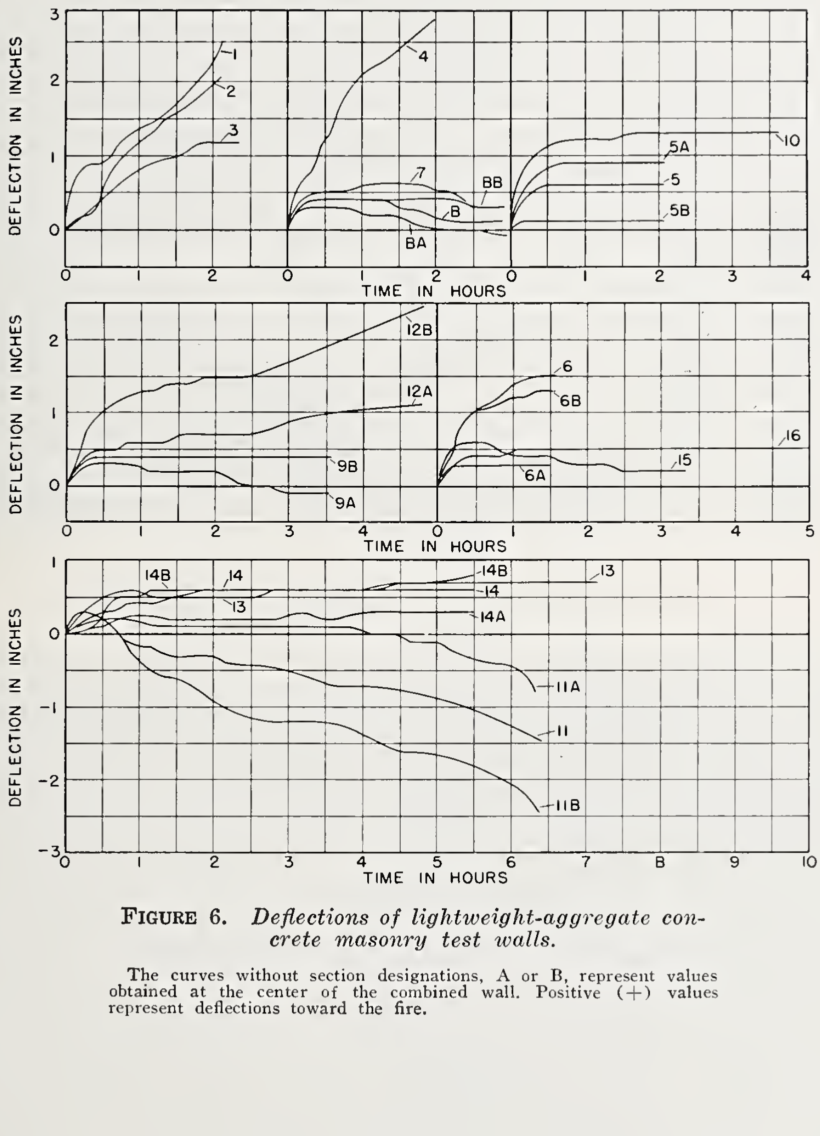

FIGURE 6. *Deflections of lightweight-aggregate concrete masonry test walls.*

The curves without section designations, A or B, represent values obtained at the center of the combined wall. Positive (+) values represent deflections toward the fire.

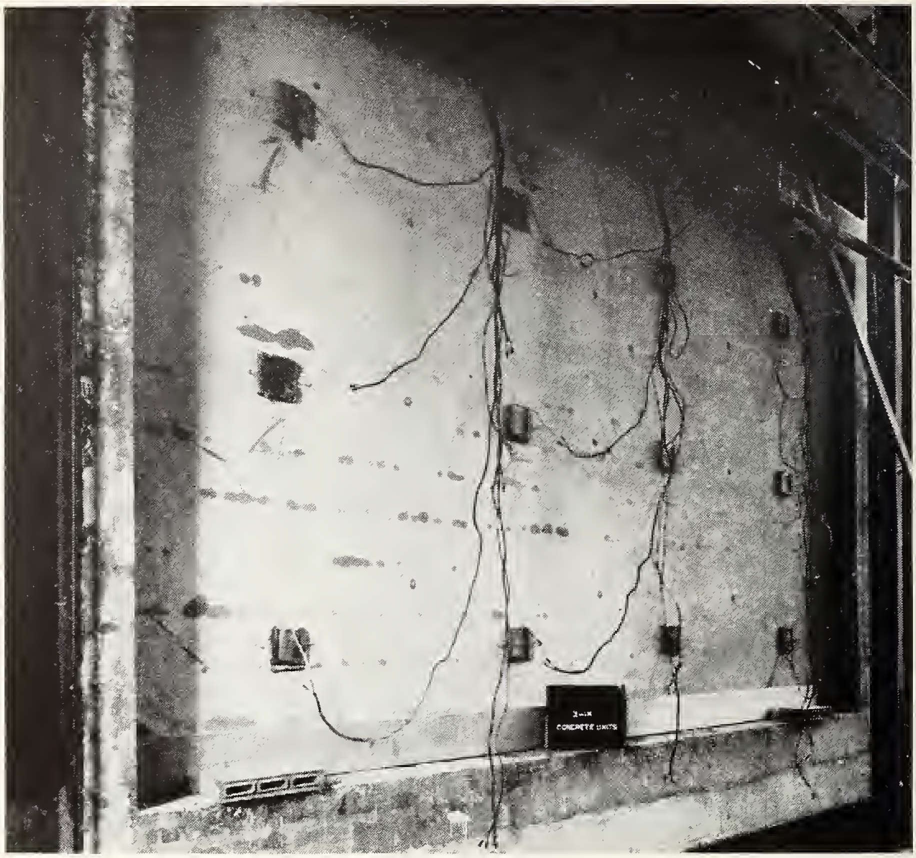

FIGURE 7. *Unexposed side of nonbearing partition, 1, after 1 hr 12 min of fire exposure on the opposite side.*

The dark spots were caused by condensation of steam in the plaster.

FIGURE 8. *Exposed side of 6-in. nonbearing partition, 8, after fire and hose-stream tests.*

Cinder aggregates were used in the dark-colored and expanded-slag II aggregates for the light-colored units.

FIGURE 9. *Exposed side of 8½-in. brick-faced wall, 14, after fire and hose-stream tests.*

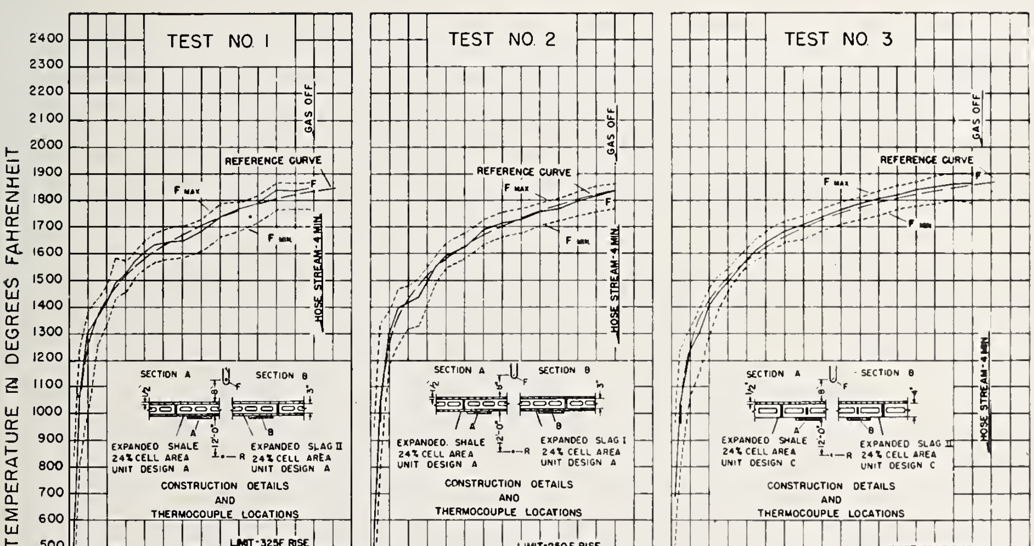

FIGURE 10. *Temperatures in fire-endurance tests of 3- and 4-in. nonbearing partitions, 1, 2, and 3.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketches.

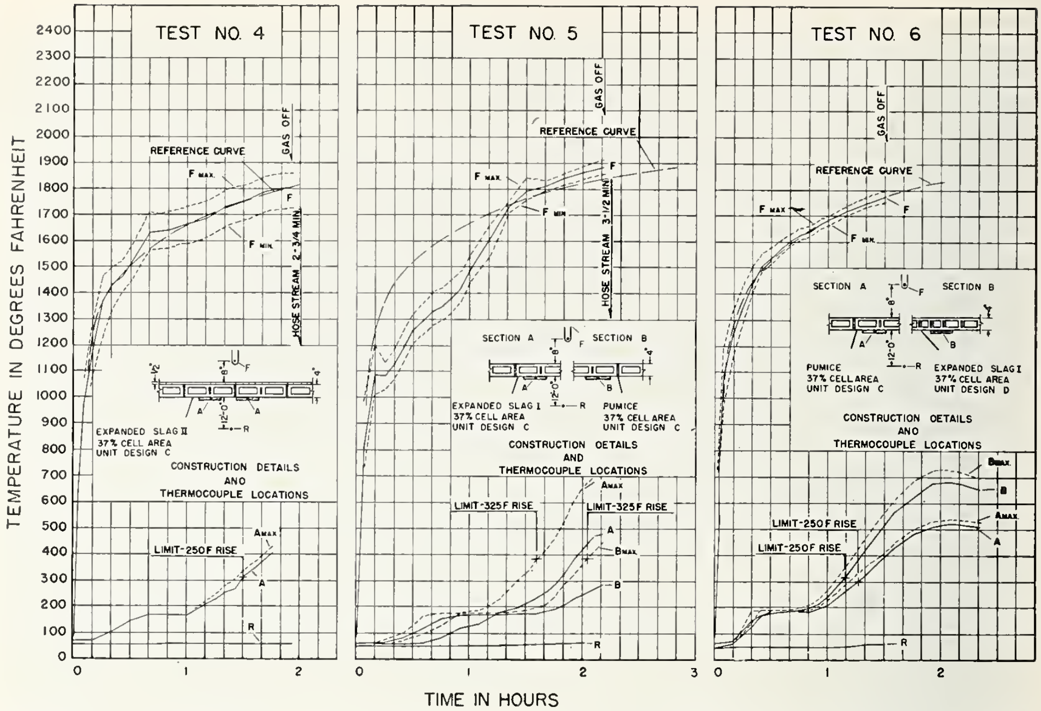

FIGURE 11. *Temperature in fire-endurance tests of 4-in. nonbearing partitions, 4, 5, and 6.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketches.

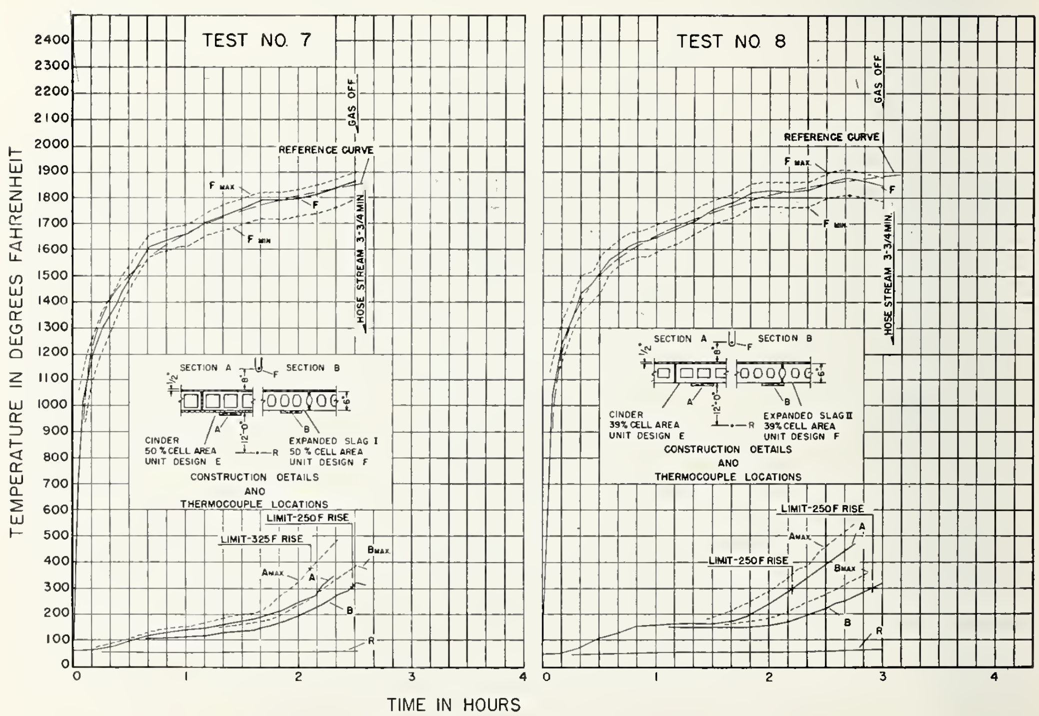

FIGURE 12. *Temperatures in fire-endurance tests of 6-in. nonbearing partitions, 7 and 8.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketches.

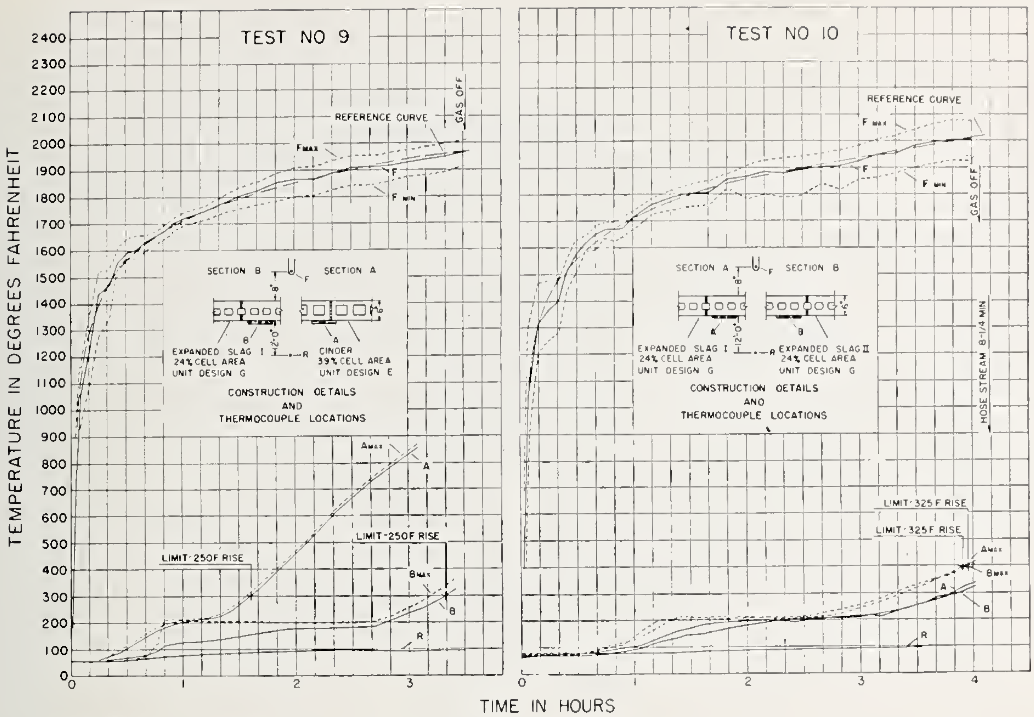

Figure 13. *Temperature in fire-endurance tests of 6-in. nonload-bearing partition, 9, and 6-in. load-bearing wall 10.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketches.

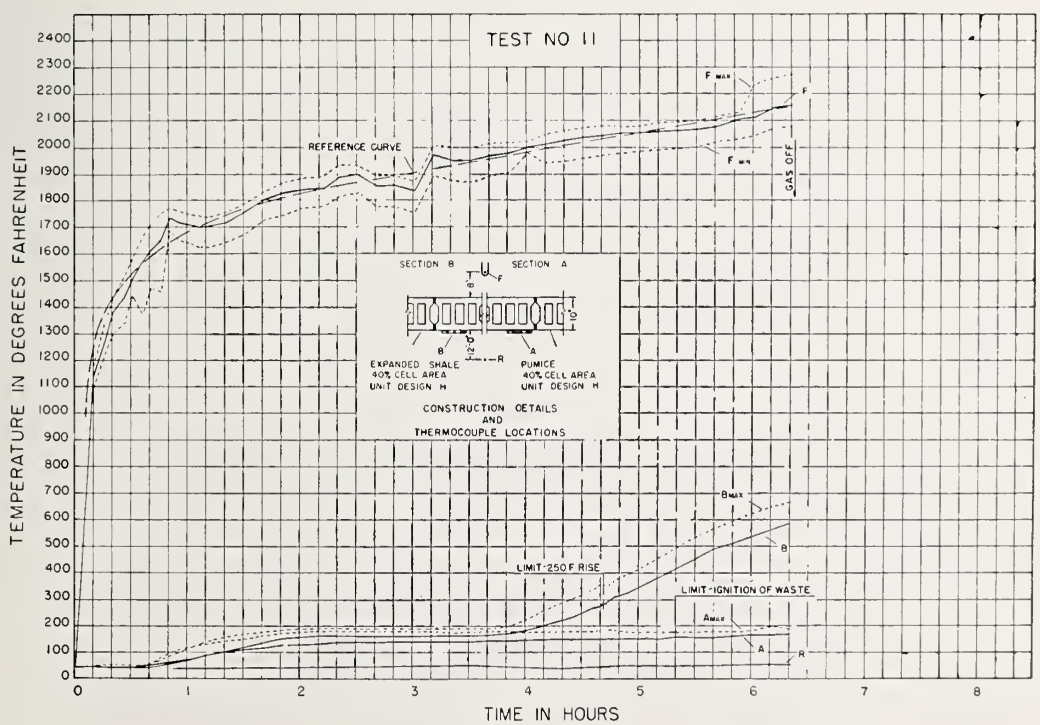

Figure 14. *Temperatures in fire-endurance test of 10-in. load-bearing wall, 11.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketch.

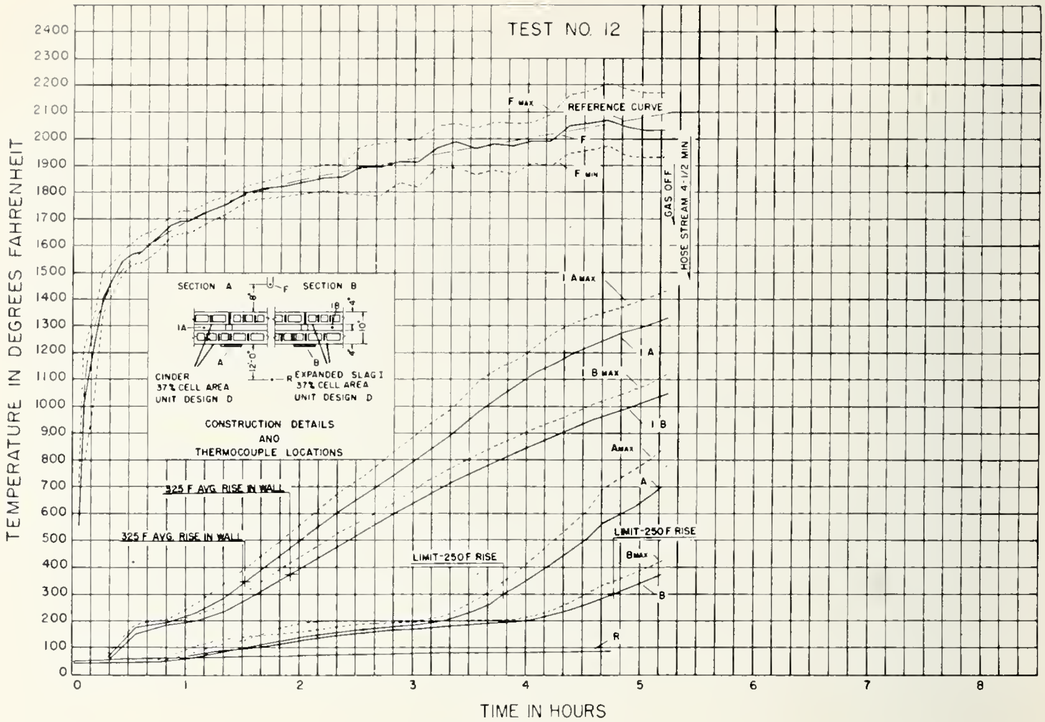

FIGURE 15. *Temperatures in fire-endurance test of 10-in. cavity-type load-bearing wall, 12.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketch.

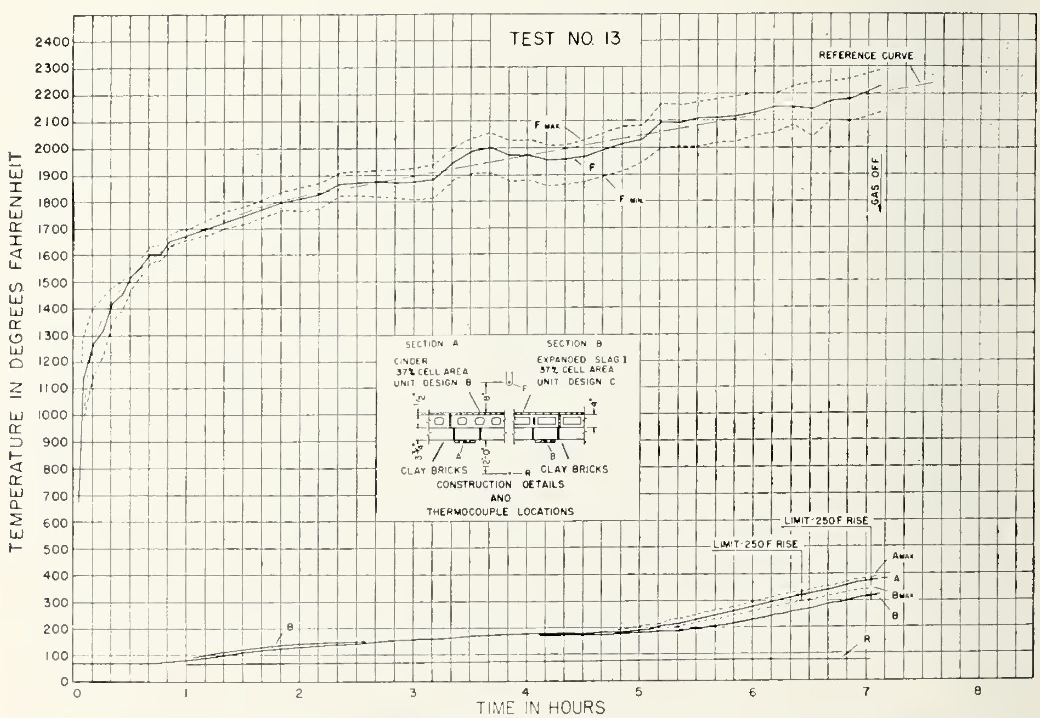

FIGURE 16. *Temperatures in fire-endurance test of 8-in. load-bearing brick-faced wall, 13.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketch.

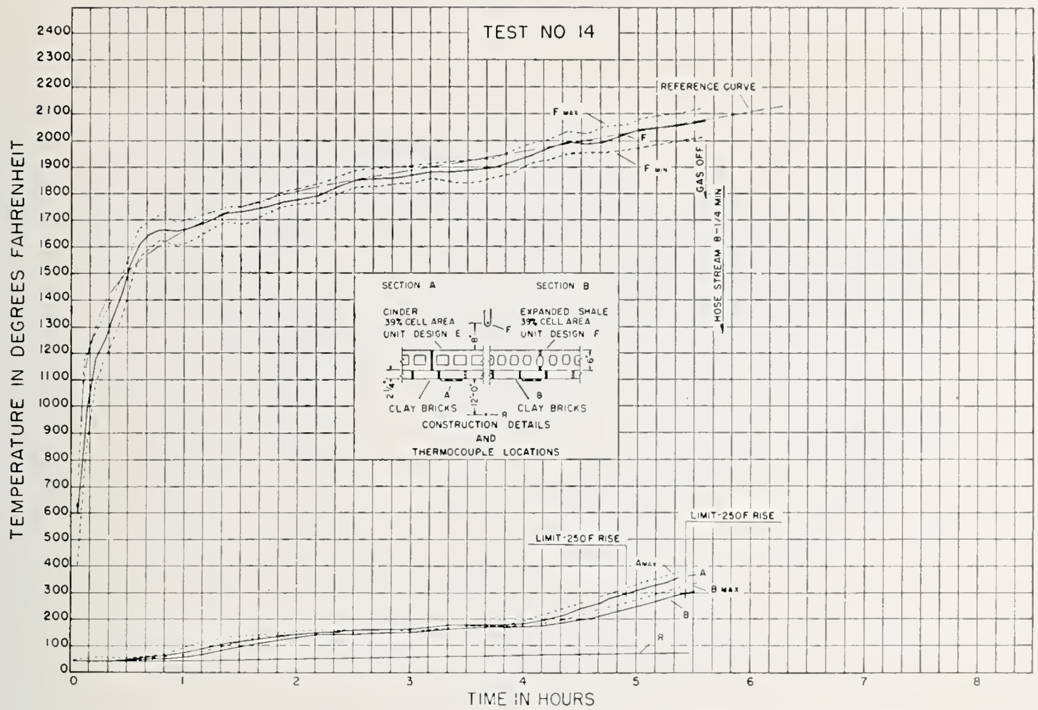

Figure 17. *Temperatures in fire-endurance test of 8½-in. load-bearing brick-faced wall, 14.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketch.

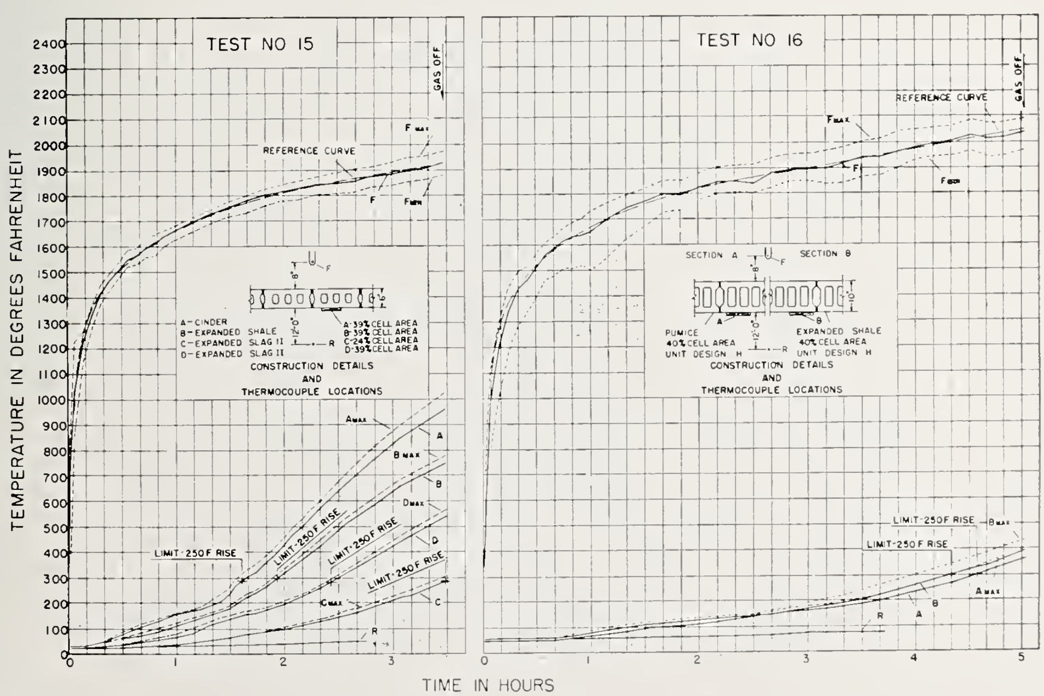

Figure 18. *Temperatures in fire-endurance tests of 6- and 10-in. nonbearing walls, 15 and 16.*

The solid curves show the average temperatures, and the broken-line curves show the maximum and minimum temperatures at the locations indicated in the construction sketches.

Washington, June 2, 1949.

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