# Fire Resistance of Walls of Gravel-Aggregate Concrete Masonry Units

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report BMS120

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# Fire Resistance of Walls of Gravel-Aggregate Concrete Masonry Units

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

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## *Foreword*

This is the second report issued by the National Bureau of Standards dealing with the fire resistance of walls of concrete masonry units. The first report, Building Materials and Structures Report 117, dealt with walls built from units made with cinder, pumice, expanded slag, or expanded shale aggregates; this report deals with walls built of units made with calcareous or siliceous gravel aggregates.

The information given in this report should be helpful to those using locally produced gravel-aggregate concrete masonry units in residential and commercial buildings.

E. U. Condon, *Director.*

# Fire Resistance of Walls of Gravel-Aggregate Concrete Masonry Units

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

Fire-endurance test results for 12 walls of gravel-aggregate concrete masonry units are given and hose-stream test results for three of the walls. The concrete units used in five of the walls were made with calcareous aggregates representing the group of natural aggregates less susceptible to damage by fire. The units used in the other seven walls were made with siliceous aggregates representing the group more susceptible to fire damage. The constructions included 4-in. nonload-bearing partitions and 8- to 12-in. load-bearing walls. The fire resistance of the 4-in. unplastered partition of units made with calcareous aggregates and of the 4- and 8-in. walls of units made with siliceous aggregates were limited to 1 hr or less either by collapse or load failure. The values for the 4-in. plastered partition and the 8-in. load-bearing walls made with calcareous aggregates ranged from 1 hr 51 min for the partition to 3 hr 57 min for one of the 8-in. load-bearing walls, and were determined by the temperature rise on the unexposed surface. The values for the 12-in. single-unit plastered wall and the 12-in. two-unit wall of siliceous aggregates were 5 hr or more and were limited by the temperature rise on the unexposed surface.

The hose-stream tests conducted at the end of the fire-endurance tests indicated that masonry walls built of units made with calcareous aggregates would meet the requirements of that test. Walls of units made with siliceous aggregates that were 8 in. or less in thickness in most cases had fire-endurance values of less than 1 hr and did not require the hose-stream test. Walls of units thicker than 8 in. made with siliceous aggregates that withstood long fire exposures may be expected to meet the hose-stream test requirements.

## CONTENTS

# I. Introduction and Scope

The fire resistance of walls of concrete masonry units is governed to a large extent by the type of aggregate used in the units. This has been shown by the results of two series of fire tests of walls and partitions conducted at the National Bureau of Standards. One series of tests, the results of which are given in an earlier report,[1] included walls built of units made with lightweight aggregates. A second series, the results of which are given in this report, was conducted with walls built of units made with sand and pebble aggregates.

From the standpoint of fire resistance, natural aggregates for concrete may be divided into four general groups; namely, (1) calcareous, comprising chiefly limestone and dolomite; (2) trap rocks, consisting largely of basalt, diabase, and dolerite; (3) granitic rocks, comprised largely of feldspar and quartz, and rocks of cemented grains of quartz, such as sandstone and quartzite; and (4) siliceous, generally occurring as grains or pebbles of quartz, chert, or flint.[2] The aggregates used in the units for the walls of the present series were of the calcareous and siliceous groups.

The present series included ten 4-, 8-, 10-, and 12-in. walls built of units made with calcareous or siliceous aggregates. The results of this series of tests are supplemented by data from tests of two 8-in. load-bearing walls of units made with calcareous aggregates and tested at the Underwriters' Laboratories in Chicago.[3]

[1] Fire resistance of walls of lightweight-aggregate concrete masonry units, BMS117 (1949).

[2] Influence of mineral composition of aggregates on fire resistance of concrete, Proc. ASTM, **29**, pt. II, pp. 824–829 (1929).

[3] Report on 8-in. bearing walls, Underwriters' Laboratories reports, retardants 2619 and 2619–3.

# II. Materials

## 1. Concrete Masonry Units

The sizes and designs of the units are shown in figure 1. The sieve analyses of the aggregates are given in table 1. The physical properties of the units are given in table 2. The materials are identified in these tables with respect to the aggregates used in the manufacture of the units and the walls into which the units were built. The designation consists (1) of the letters C or S representing the type of aggregate, calcareous or siliceous; (2) H, P, V, E, or U representing the sources of the aggregates, the first three being from the Washington and the last two from the Chicago area; and (3) the numbers of the test walls 1 to 10 and U1 and U2. Thus the designation CE1 refers to units made of calcareous aggregates in the Chicago district and used in test wall 1.

### (a) Aggregates

The sand and gravel used in the units for walls U1 and U2 consisted of approximately 52 and 80 percent calcareous minerals, respectively, and can be classed as calcareous. The aggregates used for walls 1, 2, and 3 were obtained from the same district as those for walls U1 and U2 and are also

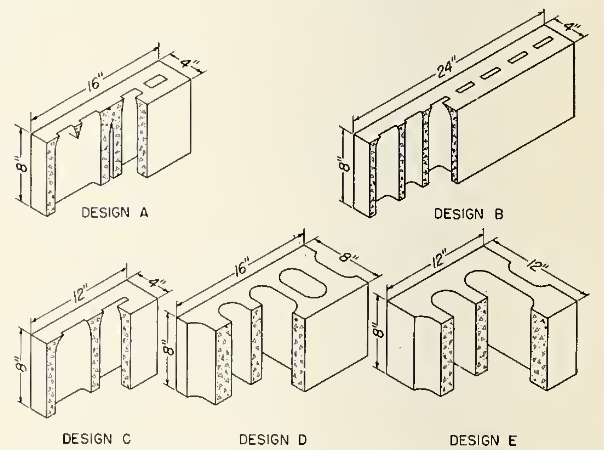


FIGURE 1. *Designs of concrete units used in fire-test walls.*

TABLE 1. *Sieve analysis of aggregates used in concrete units*

| Type of aggregate | Source | Grade | Aggregate retained on sieve | | | | | | | Fineness modulus [1] | Designation of units in which aggregates were used |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3/8 in. | No. 4 | No. 8 | No. 16 | No. 30 | No. 50 | No. 100 | | |
| | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | | |
| Siliceous | V | Sand | 1.6 | 8.1 | 21.9 | 34.8 | 64.1 | 92.7 | 98.6 | 3.21 | |
| Do | V | Gravel | | 43.7 | 85.9 | 94.0 | 96.4 | 97.9 | 99.1 | 5.17 | |
| Do | V | Combined | 1.1 | 20.0 | 43.2 | 54.5 | 74.9 | 94.4 | 98.8 | 3.87 | SV9 and SV10. |
| Do | P | do | | 3.0 | 16.0 | 28.0 | 45.0 | 76.0 | 94.0 | 2.62 | SP4, SP5, SP6, SP7, SP8, SP9, and SP10. |
| Do | H | do | | 4.0 | 17.0 | 28.0 | 47.0 | 76.0 | 98.0 | 2.70 | SH4, SH5, SH6, and SH8. |
| Calcareous | E | Sand | | 5.0 | 19.0 | 34.0 | 54.0 | 88.0 | 89.0 | 2.98 | |
| Do | E | Gravel | 1.0 | 90.0 | 96.0 | 97.0 | 98.0 | 99.0 | 100.0 | 5.81 | |
| Do | E | Combined | | 21.0 | 34.0 | 45.0 | 62.0 | 89.0 | 99.0 | 3.50 | CE1 and CE3. |
| Do.[2] | U | Sand | | 3.2 | 19.5 | 41.4 | 66.9 | 93.7 | 99.0 | 3.22 | |
| Do | U | Gravel | | 86.9 | 99.7 | 99.9 | 100.0 | 100.0 | 100.0 | 5.86 | |
| Do | U | Combined | | 24.2 | 38.6 | 56.0 | 74.5 | 95.4 | 99.0 | 3.87 | CU1 and CU2. |

[1] 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, Standard definitions of terms relating to concrete and concrete aggregates, ASTM Designation: C 125–39.

[2] The data on the aggregates from source U were from the Underwriters' Laboratories reports, retardants 2619 and 2619–3.

Table 2. *Some physical properties of the units used in test walls*

| Units | | | | | | | | | | Tests [2] | | | | Test walls in which units were used |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit designation | Type of aggregate used in units | Molding process | Average size | Shell thickness | Design [1] | Cell area | Weight | | | Moisture content [3] | Absorption | | Compressive strength based on gross area | |
| | | | | | | | As delivered | After drying | | | | | | |
| | | | *in.* | *in.* | | *Percent* | *lb/unit* | *lb/unit* | *lb/ft³* | *Percent* | *Percent* | *lb/ft³* | *lb/in.²* | |
| CE1 | Calcareous | Vibration | 4.02 by 15.78 by 7.68 | 1.00 | A | 37 | 24.8 | 24.6 | 124.6 | 10.6 | 8.7 | 10.8 | 500 | 1A and 2A. |
| CE3 | do | do | 4.02 by 23.78 by 7.98 | 0.64 | B | 37 | 34.0 | 33.4 | 130.0 | 30.0 | 6.5 | 8.4 | 860 | 3A. |
| CU1 | do | Dry tamp | 7.75 by 15.81 by 8.00 | 1.37 | D | 43 | | 43.3 | | | | | 1,760 | U1. |
| CU2 | do | do | 7.75 by 15.81 by 8.00 | 2.25 | D | 22 | | 61.4 | | | | | 2,975 | U2. |
| SH4 | Siliceous | Vibration | 3.80 by 11.82 by 7.71 | 1.26 | C | 26 | 17.1 | 16.8 | 113.7 | 17.2 | 10.5 | 11.8 | 810 | 4A. |
| SP4 | do | Dry tamp | 3.80 by 11.88 by 7.93 | 0.94 | C | 33 | 16.6 | 16.4 | 117.3 | 10.9 | 10.5 | 12.3 | 800 | 4B. |
| SH5 | do | Vibration | 3.75 by 11.78 by 7.65 | 1.24 | C | 26 | 16.6 | 16.4 | 112.6 | 12.1 | 13.5 | 15.2 | 1,250 | 5A. |
| SP5 | do | Dry tamp | 3.75 by 11.81 by 9.96 | 0.90 | C | 33 | 16.8 | 16.6 | 119.7 | 11.9 | 9.3 | 11.2 | 1,020 | 5B. |
| SH6 | do | Vibration | 7.80 by 15.8 by 7.74 | 1.40 | D | 45 | 33.8 | 33.3 | 108.7 | 10.1 | 14.8 | 16.0 | 540 | 6A. |
| SP6 | do | Dry tamp | 8.04 by 15.94 by 7.90 | 1.28 | D | 44 | 40.6 | 40.0 | 122.3 | 18.5 | 8.5 | 10.4 | 755 | 6B and 7B. |
| SH8 | do | Vibration | 7.76 by 15.8 by 7.70 | 1.35 | D | 45 | 33.8 | 33.6 | 114.7 | 4.5 | 13.3 | 15.2 | 605 | 8A. |
| SP8 | do | Dry tamp | 8.02 by 15.85 by 7.81 | 1.22 | D | 44 | 41.1 | 40.3 | 99.2 | 8.6 | 20.2 | 20.0 | 1,420 | 8B. |
| SP9-1 | do | do | 3.75 by 11.85 by 7.87 | 0.92 | C | 33 | 18.1 | 17.9 | 127.1 | 23.5 | 7.3 | 9.3 | 1,310 | 9B. |
| SP9-2 | do | do | 8.05 by 15.85 by 7.84 | 1.24 | D | 43 | 42.6 | 42.0 | 127.2 | 19.8 | 7.1 | 9.0 | 1,185 | 9B. |
| SV9 | do | do | 11.73 by 11.98 by 7.84 | 1.66 | E | 42 | 44.5 | 44.1 | 123.9 | 10.9 | 8.4 | 10.4 | 930 | 9A. |
| SP10-1 | do | do | 3.75 by 11.80 by 7.94 | 0.92 | C | 33 | 16.9 | 16.6 | 118.1 | 17.7 | 9.8 | 11.7 | 1,040 | 10B. |
| SP10-2 | do | do | 8.06 by 15.9 by 7.85 | 1.24 | D | 43 | 43.2 | 42.5 | 126.7 | 17.9 | 7.3 | 9.3 | 1,300 | 10A. |
| SV10 | do | do | 11.78 by 11.87 by 7.65 | 1.77 | E | 42 | 44.4 | 44.0 | 122.3 | 10.6 | 8.9 | 10.9 | 940 | 10B. |

[1] The designs of the units, in cutaway sections, are indicated in figure 1, p. 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 are expressed as percentages of the total absorptions.

classed as calcareous. Those for walls 4 to 10, inclusive, consisted of 90 to 95 percent quartz, with small percentages of muscovite mica, feldspar, and clay, and are classed as siliceous.

### (b) Proportioning

The calcareous sand and gravel aggregates from sources E and U were graded and recombined to give fineness moduli of 3.50 and 3.87, respectively. The siliceous aggregates from source V were graded and recombined to give a fineness modulus of 3.87. The fineness moduli of the siliceous aggregates from the other two sources P and H were 2.62 and 2.70, respectively.

The cement-aggregate ratio for the 4-in. units designated CE1 was approximately 1:12 and for the 4-in. units designated CE3, 1:9. For the 8-in. units made with calcareous aggregates CU1 and CU2 the ratios were approximately 1:7 and 1:6, respectively. All of the units made with calcareous aggregates met the compressive strength requirement of the standard specifications.[4] The cement-aggregate ratio for units made with siliceous aggregates from source P was between 1:5 and 1:6 and for those from sources H and V, 1:7. All of the units, except the 8-in. units from source H, had the compressive strengths required by the standard specifications.

[4] Standard specifications for hollow load-bearing concrete masonry units, ASTM designation: C 90-44, and Standard specifications for hollow non-load-bearing concrete masonry units, ASTM designation: C 129-39.

### (c) Molding and Curing

The units were molded by the "dry tamp" or the "vibration" process as indicated in table 2. All of those made with calcareous aggregates and two lots of units made with siliceous aggregates, SV9 and SV10, were cured 12 to 14 hours in moist rooms or wet-steam tunnels and then stored in the open stockyard at the plant until shipped to the National Bureau of Standards for test.

## 2. Mortar and Plaster

The mortar for all of the walls except U1 and U2 consisted of one part of portland cement, one part of hydrated lime and six parts of sand, by volume. The mortar for walls U1 and U2 consisted of one part of portland cement, $^{15}/_{100}$ part of hydrated lime, and 3 parts of sand, by volume. Proper proportions were actually obtained by weight, assuming that portland cement weighs 94 lb/ft³, hydrated lime 40 lb/ft³, and loose, damp sand after drying weighs 80 lb/ft³. The portland cement and hydrated lime were of well-known brands obtained from local dealers. The sand for the walls tested at the National Bureau of Standards was Potomac River building sand, 95 percent of which was a mixture of siliceous minerals and the remaining 5 percent a mixture of 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

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 2.

The time of set, consistency, and tensile strength of the gypsum plasters were determined in accordance with Standard methods of testing gypsum and gypsum products, ASTM designation: C 26–33. The results are given in table 3.

Table 3 also gives the compressive strengths of the mortars and sanded plasters as determined with 2-in. cubes, which had been seasoned in locations adjacent to the walls for which they were used.

Table 3. *Results of tests of mortar and plaster*

| Test walls in which mortar and plaster were used | Mortar [1] | Plaster | | | | |
|---|---|---|---|---|---|---|
| | Compressive strength [2] | Consistency [3] | Time of set [3] | Tensile strength [3] (neat) | Mix, dry weight proportions | Compressive strength,[2] sanded |
| | *lb/in.²* | | *hr* | *lb/in.²* | | *lb/in.²* |
| 1A | 655 | | | | | |
| 2A | 691 | 49 | 8 | 275 | 1:3 | 558 |
| 3A | 351 | | | | | |
| 4A and 4B | 533 | | | | | |
| 5A and 5B | 574 | 48 | 13½ | 345 | 1:3 | 433 |
| 6A and 6B | 985 | | | | | |
| 8A and 8B | 499 | 48 | 13½ | 345 | 1:3 | 512 |
| 9A and 9B | 921 | | | | | |
| 10A and 10B | 657 | 50 | 15 | 230 | 1:3 | 434 |

[1] The mortar consisted of 1 part of portland cement to 1 part of hydrated lime to 6 parts of sand, by volume.
[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 they were cured 28 days in locations adjacent to the partitions.
[3] The times of set, consistencies, and tensile strengths of the plasters were determined in accordance with Standard methods of testing gypsum products, ASTM designation: C 26–33.

## III. Test Walls

### 1. Construction

The types of construction are indicated in figure 2. All of the 4- and 8-in. walls were built of 4- and 8-in. units laid with cells vertical in common bond. One section of each of the two 12-in. walls was built of units 12 in. thick laid in common bond

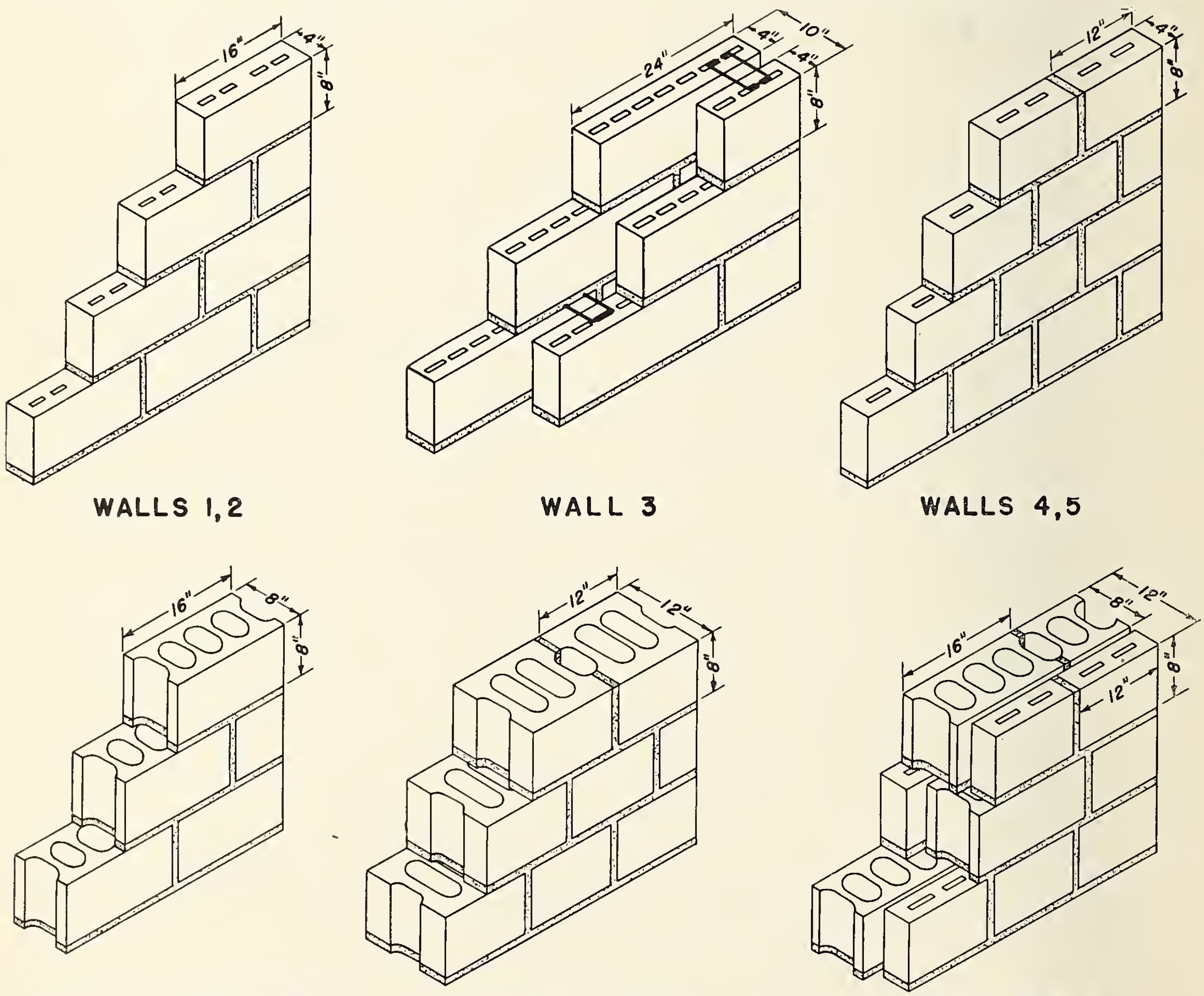


Figure 2. *Construction details of test walls.*

FIGURE 3. *Unexposed side of load-bearing wall, 10, after fire exposure of 3 hr 55 min on the opposite side.*

The test frame, the hydraulic jacks for loading the wall, and the asbestos pads over the thermocouples are shown.

and the other section of each wall of 4- and 8-in. units laid in combination, as indicated in figure 2. The 10-in. wall was the cavity type and consisted of two 4-in. walls spaced 2 in. apart, tied together at points 24 in. apart in alternate courses. The ties were of $\frac{3}{16}$-in. steel wire bent to a $3\frac{7}{8}$- by 6-in. rectangle with ends butted (not welded) at the center of one short side.

## 2. Size

The walls tested at the National Bureau of Standards were built in fireproofed frames of 20-in. 140-lb steel-girder beams, bolted or riveted at the corners, with openings for test specimens 16 ft long and 8 to 11 ft high. The walls were built in two sections, each 8 ft long, bonded together along the vertical center line except when it was desired to load each section independently. The walls tested at the Underwriters' Laboratories were built as single units in similar frames having openings approximately 10 ft long and 11 ft high.

## 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, figures 3 and 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, and were bedded with mortar against the frames at the top. A clearance of approximately 1 in. was left at each end of the walls. Similar clearances were left between the two sections of the load-bearing walls. The spaces were filled with loosely packed mineral wool, and the two sections of wall 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 used for the 4-in. walls, including the 4-in. wythes of the cavity-type walls. Only the face shells of the units in the 8- and 12-in. walls were bedded. The vertical mortar joints were formed with mortar applied to the outside edges of the units before they were shoved into place. No attempt was made to point the joints in the walls which were to be plastered. However, the walls that were to be tested without plaster finish were carefully pointed.

## 5. Finish

Some of the walls were finished with 1:3 sanded gypsum plaster on one or both sides. Both the scratch and brown coats were applied the same day and given a float finish. The usual white-coat finish was omitted. The total thickness of the plaster was $\frac{1}{2}$ in. Wood baseboards, nailed to wood plugs set in the masonry, were applied on both sides of the plastered walls.

## 6. Storing and Aging

After the mortar or plaster had taken its initial set, the frames containing the walls were moved to storage tracks for seasoning for 1 month or more.

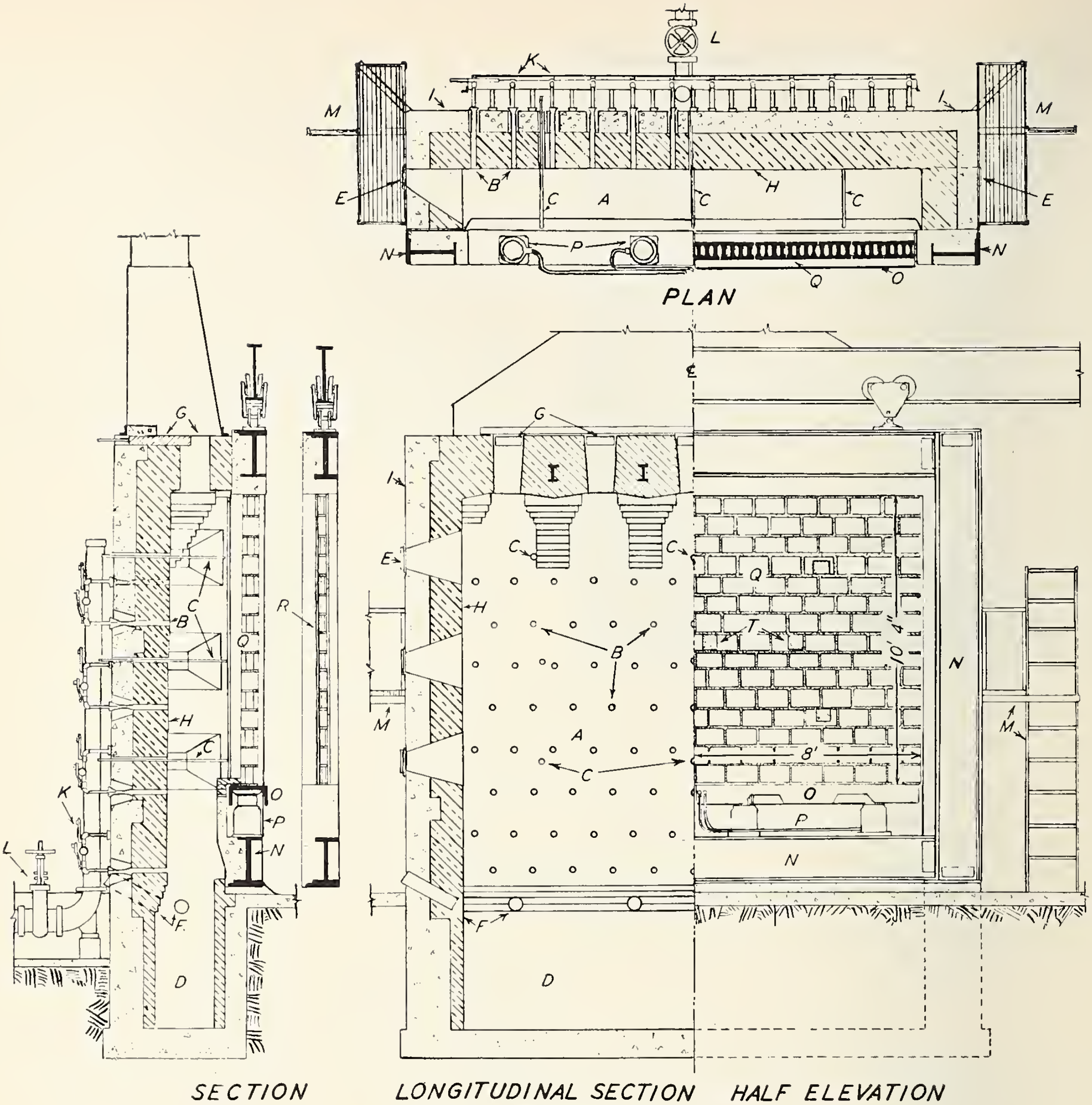


FIGURE 4. *Wall-testing furnace.*

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 fireproofed test frame; O, loading beams; P, hydraulic loading jacks; Q, load-bearing test wall; R, nonload-bearing test partition; T, asbestos pads covering thermocouples on unexposed surface of test wall.

## IV. Method of Testing and Equipment

The fire tests were conducted in accordance with the Standard methods of fire tests of building construction and materials of the American Standards Association, ASA No. A2–1934, (ASTM designation: C19–33), except that the 16-ft walls were built in two 8-ft sections.

### 1. Wall-Testing Furnace

The furnace used for the tests was built of reinforced concrete and lined with fire brick to form a combustion chamber 2½ ft deep and 16 ft long. The chamber extends 6 ft below the bottom of the wall so that debris from the test specimen does not obstruct the burners. The details of the construction of the furnace are shown in figure 4. The walls were exposed on one side to fires that were controlled to give average indicated furnace 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, and 2,300° F at 8 hr or over.

The test fire was produced by 92 gas burners (B, fig. 4) controlled with ¾-in. gas cocks, K, on each burner and also with one larger valve, L, on the main gas supply. The 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 on the unexposed side, (*b*) failure under the applied load, or (*c*) transmission of heat through the wall sufficient to raise the average temperature on its unexposed surface by 250 deg F or by 325 deg F at any thermocouple location.

### 2. Temperature Measurements

All of the temperatures were measured with chromel-alumel thermocouples at 5- to 10-min intervals. The temperatures in the furnace were measured with nine 18-gage thermocouples, C, figure 4. These thermocouples with their leads within porcelain insulators were protected by ¾-in. wrought-iron pipes, sealed at one end. The temperatures in the cells were measured with 18-gage thermocouples insulated with asbestos sleeving. The temperatures on the unexposed surface of the walls were measured with 22-gage thermocouples, the leads of which were insulated with asbestos sleeving except near the junctions. The leads 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 possible use over cracks or at 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 3 and 6.

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 potentiometers were subsequently converted to degrees F.

### 3. Deflection Measurements

The deflections were measured during the tests at nine locations on the unexposed surface of the walls. They were obtained by measuring the distance from the surface of the wall to three 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 was opposite the quarter points on each side of the center line.

### 4. Hose-Stream Test

Walls that withstand a fire-endurance test of 1 hr or more are required by standard test specifications to be subjected to a hose-stream test. This test is regularly made after subjecting a duplicate wall to a fire exposure of a duration equal to half of the desired fire-resistance rating but for not more than 1 hr. It is permissible, however, to apply the hose stream to a wall immediately after the fire-endurance test. This optional procedure was used for the three fire-endurance and hose-stream tests included in this series.

The water for the hose-stream test was delivered through a 2½-in. cotton, rubber-lined, fire hose and discharged through a National Standard playpipe equipped with a 1⅛-in. discharge tip. The tip of the playpipe was stationed 19 ft in front of the fire-exposed side, that is, 20 ft less 1 ft for the upward inclination of the hose stream. The water was discharged at pressures of 30 or 45 lb/in.$^2$ as required by the test methods. The pressures were measured by means of a gage connected to the base of the playpipe, and were regulated by a valve in the supply line.

## V. Results

The results of the fire-endurance and hose-stream tests are given in table 4 and in the logs of the individual tests.

### 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 5 showing the deflections, toward (+) and away (−) from the fire, at the center of the walls; to figures 6 to 8, showing the condition of some of the walls after test; and to figures 9 to 14, giving the temperatures of the furnace and the test walls.

**Test 1.**—Four-inch unplastered nonload-bearing partition; calcareous-aggregate concrete units, CE1, 37 percent of cell area, in section A. (The results of the test with section B are not included in this report.)

After 2 min of fire exposure, cracking sounds, which may have been caused by the cracking of the webs of the units, were heard. At 7 min, diagonal cracks across the bottom corners appeared. At 15½ min, similar cracks across the top corners appeared. At 19 min, the widening of the diagonal crack at the bottom of the partition indicated the approach of failure that occurred at 20¼ min. The failure consisted of the collapse of the lower portion of the partition.

TABLE 4. *Description of walls and results of fire-endurance and hose-stream tests*

| Wall | | Description of walls | | | | | | | | | Tests [4] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Section | Nominal thickness | Approximate size [1] | Kind of aggregates used in units | | Nominal dimensions of units | Cell area of units | Design of units [3] | Wall finish | | Age at time of fire-endurance test | | Load during fire test | Fire endurance | | | Results of hose stream with water on hot side of partition |
| | | | | Type | Source [2] | | | | On fire-exposed side | On unexposed side | Unit | Wall | | Severity of exposure | Time | Determining factor | |
| | | *in.* | *ft* | | | *in.* | *Percent* | | | | *Days* | *Days* | *lb/in.*[2] | *Percent* | *hr min* | | |
| 1 | A | 4 | 8 by 10 | Calcareous | E | 4 by 16 by 8 | 37 | A | None | None | 247 | 29 | Restrained | | 0 20 | Collapse | |
| 2 | A | 4 | 8 by 10 | do | E | 4 by 16 by 8 | 37 | A | Plaster [5] | Plaster [5] | 112 | 41 | do | 100.3 | 1 51 | Temp avg | Met requirements. |
| U1 [6] | | 8 | 10 by 11 | do | U | 8 by 16 by 8 | 43 | D | None | None | 60 | 30 | 80 | 99.7 | [10] 2 14 | do | Do. |
| U2 [6] | | 8 | 10 by 11 | do | U | 8 by 16 by 8 | 22 | D | do | do | 60 | 30 | 175 | 99.5 | 3 57 | do | Do. |
| 3 [7] | A | 10 | 8 by 10 | do | E | 4 by 24 by 8 | 37 | B | do | do | 233 | 32 | 80 | 101.2 | 1 16 | Failure under load | |
| 4 | A | 4 | 8 by 10 | Siliceous | H | 4 by 12 by 8 | 26 | C | do | do | 81 | 34 | Restrained | 99.1 | 17 | Collapse | |
| | B | 4 | 8 by 10 | do | P | 4 by 12 by 8 | 33 | C | do | do | 102 | 34 | do | 99.1 | 17 | do | |
| 5 | A | 4 | 8 by 10 | do | H | 4 by 12 by 8 | 26 | C | Plaster [5] | Plaster [5] | 209 | 55 | do | 102.4 | [8] 58½ | do | |
| | B | 4 | 8 by 10 | do | P | 4 by 12 by 8 | 33 | C | do | do | 105 | 55 | do | 102.4 | [8] 58½ | do | |
| 6 | A | 8 | 8 by 10 | do | H | 8 by 16 by 8 | 45 | D | None | None | 91 | 32 | 80 | 102.2 | 12 | Failure under load | |
| | B | 8 | 8 by 10 | do | P | 8 by 16 by 8 | 44 | D | do | do | 96 | 32 | 80 | 102.2 | 12+ | | |
| 7 | B [9] | 8 | 8 by 10 | do | P | 8 by 16 by 8 | 44 | D | do | do | | | 80 | 101.7 | 21 | Failure under load | |
| 8 | A | 8 | 8 by 10 | do | H | 8 by 16 by 8 | 45 | D | Plaster [5] | Plaster [5] | 219 | 55 | 80 | 102.8 | 32 | do | |
| | B | 8 | 8 by 10 | do | P | 8 by 16 by 8 | 44 | D | do | do | 193 | 55 | 80 | 102.8 | 40+ | | |
| 9 | A | 12 | 8 by 10 | do | V | 12 by 12 by 8 | 42 | D | None | None | 68 | 30 | 80 | 97.8 | 26 | Failure under load | |
| | B | 12 | 8 by 10 | do<br>do | P<br>P | 8 by 16 by 8<br>4 by 12 by 8 | 43<br>33 | D<br>C | do | do | 196 | 30 | 80 | 97.2 | 3 08+ | | |
| 10 | A | 12 | 8 by 10 | do<br>do | P<br>P | 8 by 16 by 8<br>4 by 12 by 8 | 43<br>33 | D<br>C | do | do | 83 | 35 | 80 | 101.7 | [10] 5 33 | Temp max | |
| | B | 12 | 8 by 10 | do | V | 12 by 12 by 8 | 42 | E | Plaster [5] | Plaster [5] | 104 | 35 | 80 | 101.7 | [10] 6 05 | do | |

[1] All walls except U1 and U2 were 16 ft long and approximately 10 ft high and consisted of two 8-ft sections A and B of the same or similar design. In those cases where data are given for only one section of the test wall, the other section was constructed of a different type of material and test results are not included in this report.

[2] The aggregates from sources E and U were from the vicinity of Chicago and those from sources H, P, and V from the Washington, D. C., area.

[3] The designs of the units are indicated in fig. 1, p. 2.

[4] All fire-endurance and hose-stream tests were made in accordance with Standard specifications for fire tests of building construction and materials, ASTM designation: C19-33 (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 thickness of ½ in.

[6] The data from these walls are from Underwriters' Laboratories reports, retardants 2619 and 2619-3.

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

[8] The fire-endurance time may be increased by 1 min if advantage is taken of a subsequent change in the fire-test specification, per sec. 5 (b) of ASTM Standard E 119-47.

[9] This was a retest of wall 6B.

[10] The determining factor for the fire endurance of walls with combustible framed-in members is temperature rise within the wall as per sec. 24 (b) of ASTM Standard E 119-41. The limiting temperature rise was reached at 56 min for wall U1 (see fig. 10) at 2 hr 28 min or 3 hr 54 min for wall 10A and at 2 hr 31 min for wall 10B (see fig. 14, p. 17).

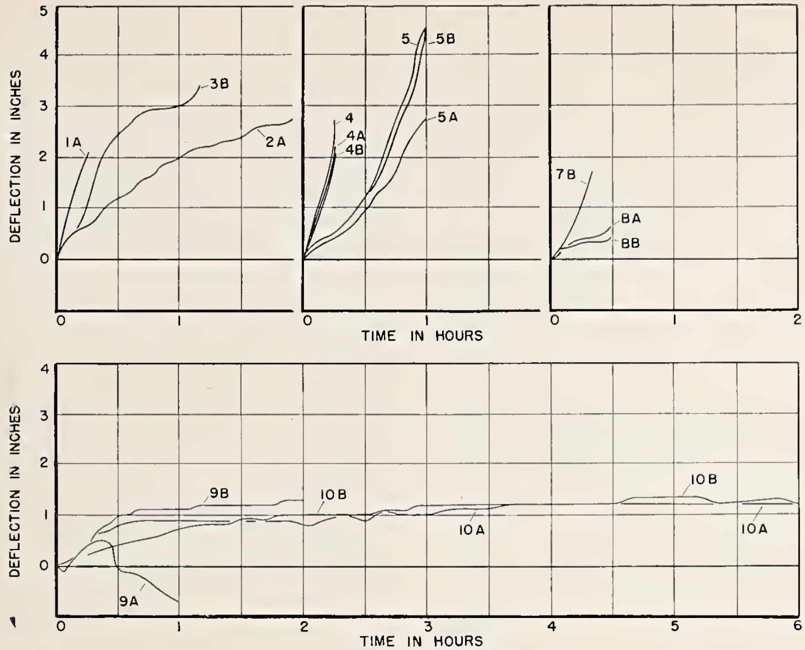


FIGURE 5. *Lateral deflections at centers of gravel-aggregate concrete masonry test walls.*

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

The fire endurance was limited to 20 min by the collapse of the partition. The deflection and temperature curves are given in figures 5 and 9.

**Test 2.**—Four-inch nonload-bearing plastered partition; calcareous-aggregate concrete units, CE2, 37 percent of cell area, in section A. (The results of the test with section B are not included in this report.)

At 25 min, fine diagonal cracks extending across the corners of the unexposed side appeared. At 30 min, steam began to issue at the borders of the wall and wet spots soon appeared on the unexposed surface, diminishing in size at 1 hr 5 min. At approximately 1 hr 25 min, horizontal cracks appeared in the unexposed side plaster near the top and bottom of the partition. The gas was turned off at 1 hr 55 min.

The fire endurance of the partition was limited by an average temperature rise of 250 deg F on the unexposed surface at 1 hr 51 min. The deflection and temperature curves are given in figures 5 and 9.

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. The hose stream washed off most of the plaster and slightly pitted the surface of some of the units. As no water passed through the wall, it met the requirements of the hose-stream test.

**Test U1.**—Eight-inch unplastered load-bearing wall; 80-lb/in.$^2$ load; calcareous-aggregate concrete units, CU1 43 percent of cell area. (This was one of the walls tested at Chicago by the Underwriters' Laboratories.)

Cracking sounds, accompanied by the formation of vertical cracks extending from the top to the bottom of the unexposed side of the wall, were heard intermittently during the first 40 min. The four most prominent cracks appeared at 1, 2, 13, and 60 min near the midlength of the wall. Other cracks near the ends of the wall followed the vertical and horizontal mortar joints. The most prominent of the vertical cracks had opened to a maximum of approximately $\frac{3}{32}$ in. at 1 hr 10 min. At 21 min, the mortar in one of the exposed joints near the top of the wall spalled. Steam issued from the cracks after 20 min and during the remainder of the first hour of the test. Some

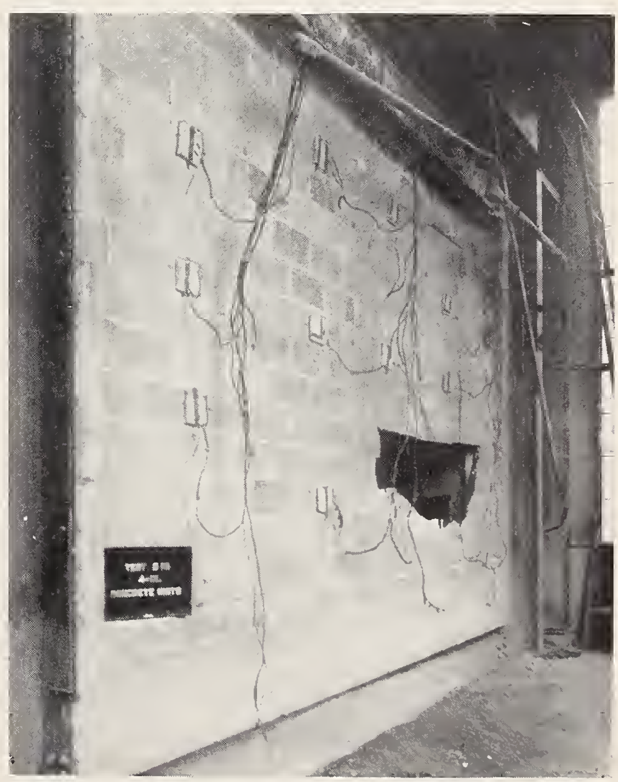

FIGURE 6. *Unexposed side of 4-in. unplastered nonload-bearing wall 1 after fire-endurance test.*

of the steam condensed at the surface of the wall to form wet spots that disappeared at 1 hr 45 min. The gas was turned off at 2 hr 16 min.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F at 2 hr 14 min. The deflection and temperature curves are given in figures 5 and 10.

The wall was subjected to the hose stream at a nozzle pressure of 30 lb/in.$^2$ for 2½ min for each 100 ft$^2$ of exposed area. The surface of the exposed shells became eroded to a depth of ¼ to ⅜ in. The hose stream washed out some of the mortar from the joints but did not pass through the wall. The applied load, 80 lb/in.$^2$, was carried throughout the tests and doubled after the wall had cooled, without indications of distress. The load was subsequently increased until failure occurred at approximately 297 lb/in.$^2$ The wall met the requirements of the hose-stream test.

**Test U2.**—Eight-inch unplastered load-bearing wall; 175-lb/in.$^2$ load; calcareous-aggregate concrete units, CU2, 22 percent of cell area. (This was one of the walls tested at Chicago by the Underwriters' Laboratories.)

Cracking sounds were heard during the first 5 to 11 min of the test. Vertical cracks, generally extending along the vertical mortar joints and across the intervening units, appeared in the unexposed side during this time. Some of the cracks opened to a maximum of 3/32 in. during the early part of the test and closed somewhat after 40 min. Steam issuing at the cracks condensed on the wall surface to form wet spots. These spots were first noted at 25 min. They increased in number and size during the first hour of the test and then gradually disappeared. The gas was turned off at 4 hr.

The fire endurance of the wall was limited by an average temperature rise of 250 deg F on the unexposed surface at 3 hr 57½ min. The deflection and temperature curves are given in figures 5 and 10.

The wall 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. The exposed shells were eroded to a depth of ½ to 11/16 in. by the hose stream, which washed out some of the mortar from the joints but did not pass through the wall. The applied load, 175 lb/in.$^2$, was carried throughout the tests. After the test wall had cooled for approximately 20 hr, the amount of the load was gradually increased. When a load of 327 lb/in.$^2$ was reached, some of the mortar in the joints in the upper part of the wall appeared to be crushing. When it reached 343 lb/in.$^2$, or 7 lb less than twice the load applied during the tests, the wall failed. Considering that the hose-stream test was made on the wall after the fire-endurance test rather than on a duplicate specimen after a fire exposure of 1 hr, the results indicate that the construction would have met the hose-stream test requirements had a duplicate specimen been tested.

**Test 3.**—Ten-inch unplastered cavity-type wall of two 4-in. wythes spaced 2 in. apart and tied together with metal ties 24 in. apart in alternate horizontal joints; 80-lb/in.$^2$ load; calcareous-aggregate concrete units, CE3, 37 percent of cell area, in section A. (The test results for section B are not included in this report.)

At 5 min, cracking sounds were heard. At 15 min, a slight amount of spalling from the top portion of the exposed surface was noted. At 28 min, a fine vertical crack, starting near the middle and extending almost to the top of the unexposed side of the wall, appeared. This crack became pronounced during the next 10 minutes. Wet spots appeared on the upper part of the unexposed surface after approximately 45 min. At 1 hr 16 min, the wall failed under the applied load and fell toward the fire.

The fire endurance of the wall was limited by its failure under load at 1 hr 16 min. The deflection and temperature curves are given in figures 5 and 9.

**Test 4.**—Four-inch unplastered nonload-bearing partition; siliceous-aggregate concrete units, SH4, 26 percent of cell area, in section A; siliceous-aggregate concrete units, SP4, 33 percent of cell area, in section B.

At 5 min, a fine diagonal crack appeared across the lower corner of the unexposed surface of the partition. A similar crack across the other lower corner appeared 2 min later. At 10 min, the deflection toward the fire was pronounced. At 12 min, the diagonal cracks at the lower corners had opened. At 17 min, the partition collapsed, falling toward the fire.

The fire endurance of the partition was limited by its collapse at 17 min. The deflection and temperature curves are given in figures 5 and 11.

**Test 5.**—Four-inch plastered nonload-bearing partition; siliceous-aggregate concrete units, SH5, 26 percent of cell area, in section A; siliceous-aggregate concrete units, SP5, 33 percent of cell area, in section B.

Horizontal cracks extending the length of the test partition, 3½, 5½, and 9½ ft from the lower edge of the unexposed side plaster, appeared at 5, 10, and 19 min, respectively. At 16 min, wet spots outlining the mortar joints, began to show in the unexposed plaster. At 25 min, steam was issuing at cracks. At 35 min, some of the plaster near the middle of the unexposed side loosened but did not fall. At 58½ min, due to the restraint, some of the units at midheight and near one end of the partition failed by crushing. This condition is shown in figures 7 and 8.

The fire endurance of the partition was limited by its structural failure at 58½ min. The deflection and temperature curves are given in figures 5 and 11.

**Test 6.**—Eight-inch unplastered load-bearing wall; 80-lb/in.$^2$ load; siliceous-aggregate concrete units, SH6, 45 percent of cell area, in section A; siliceous-aggregate concrete units, SP6, 44 percent of cell area, in section B.

During the period from 6 to 10 min after the start of the test vertical cracks formed, first near the middle of each of the two sections and then near the ends. These cracks extended both upward and downward from midheight to near the top and bottom of the wall. At 12 min, section A collapsed without warning. The webs of the units had broken allowing the exposed portion of the wall to fall toward the fire and the unexposed portion to fall outward. The fire exposure on section B could not be continued.

The fire endurance of section A of the wall was limited to 12 min by its failure under load; that of section B was not determined. The deflection and temperature curves are given in figures 5 and 12.

**Test 7.**—Eight-inch unplastered load-bearing wall; 80-lb/in.$^2$ load; siliceous-aggregate concrete units, SP6, having 44 percent of cell area, in section B. This was a retest of section B remaining from test 6.

At 8 min, the cracks formed during test 6 began to reappear. At 18 min, one of the exposed shells spalled and fell. At 21 min, the wall collapsed in the same manner as section A of the previous test.

The fire endurance of this wall was limited in its retest to 21 min by its failure under load. This result may not be fully representative, considering the previous exposure in test 6. The deflection and temperature curve are given in figures 5 and 12.

**Test 8.**—Eight-inch plastered load-bearing wall; 80-lb/in.$^2$ load; siliceous-aggregate concrete units, SH8, 45 percent of cell area, in section A; siliceous-aggregate concrete units, SP8, 44 percent of cell area, in section B.

Vertical cracks extending the full height of the wall appeared in the unexposed side of section A during the period from 2½ to 16 min after the start of the fire exposure. At 20 min, steam began to issue from the cracks and wet spots showed over the mortar joints in the unexposed plaster. At 32 min, section A of the wall failed under load, and some of the plaster and shells fell from its unexposed side. At 40½ min, the remaining portion of section A collapsed, making it impossible to continue the test of section B.

The fire endurance of section A of the wall was limited to 32 min by its failure under load.

Section B of the wall was not subjected to a retest. It was dismantled and inspected for damage to the individual units. They appeared to be relatively free from fire damage, showing that the plaster had protected them during the fire exposure. The deflection and temperature curves are given in figures 5 and 12.

**Test 9.**—Twelve-inch unplastered load-bearing wall; 80-lb/in.$^2$ load; 12-in. siliceous-aggregate concrete units, SV9, 42 percent of cell area, in section A; 8-in. units, SP9–2, having 43 percent of cell area with 4-in. units, SP9–1, having 33 percent of cell area (laid as shown in fig. 2) and made with siliceous-aggregates, in section B.

After approximately 45 min of fire exposure, a vertical crack extending the full height of the wall appeared near the middle of the unexposed sides of each section. At 26 min, section A failed under the applied load but did not fall from the frame. As the partially crushed masonry of section A remained in place, it was possible to continue the test of section B. At 56 min, steam was issuing from the wall and wet spots were forming in the unexposed plaster of section B. At 3 hr 8 min, section A collapsed, so that the test on section B had to be discontinued.

The fire endurance of section A of the 12-in. units was limited to 26 min by its failure under load. The fire endurance of section B of 8- and 4-in. units was not reached, but it can be taken as exceeding 3 hr and 8 min. The deflection and temperature curves are given in figures 5 and 13.

**Test 10.**—Twelve-inch unplastered load-bearing wall; 80-lb/in.$^2$ load; 8-in. units, SP10–2, having 43 percent of cell area, with 4-in. units, SP10–1, having 33 percent of cell area (laid as shown in fig. 2) and made with siliceous-aggregates, in section A; 12-in. siliceous-aggregate concrete units, SV10, 42 percent of cell area and plastered on both sides, in section B.

At 15 min, a vertical crack extending from the bottom to the midheight of the wall appeared in the middle of the unexposed side of section A. During the period from 22 to 44 min, vertical cracks appeared in the plaster on the unexposed side of section B. At 44 min, wet spots began to appear in the plaster of section B, and at 1 hr 3 min, horizontal cracks were observed. The cracks gradually widened as the test progressed, one of those in the plaster opening to a width of approximately $\frac{3}{16}$ in. At 1 hr 43 min, the cracks in the unplastered section A were wider than those of the plastered section B. Additional fire effects observed during the remainder of the test were the growth and widening of the cracks. The gas was turned off at 6 hr 16 min.

The fire endurance of the unplastered section A, with a thickness of two units, was limited to 5 hr 33 min by a temperature rise of 325 deg F at one place on the unexposed surface. The fire resistance of the plastered section B, with a thickness of one unit, was limited to 6 hr 5 min by a temperature rise of 325 deg F at one place on the unexposed surface. The condition of the unexposed side of the wall, after a fire exposure of 3 hr 35 min on the opposite side, is shown in figure 3. Deflection and temperature curves are given in figures 5 and 14.

## VI. Discussion of Results

The limit of the fire endurance of walls and partitions may be determined (*a*) by structural damage sufficient to allow the passage of flames or gases hot enough to ignite cotton waste, (*b*) by an average temperature rise on the unexposed surface of 250 deg F or a rise of 325 deg F above the initial temperature at any point, or (*c*) in the case of a load-bearing wall, by failure under load.

### 1. Effect of Type of Aggregate

As indicated in these and previous tests reported in BMS117 (see footnotes 1 and 2), susceptibility of individual concrete units to spalling or cracking on fire exposure is dependent mainly upon the type of aggregate with which the unit is made. Those made with siliceous aggregates consisting largely of siliceous minerals, such as quartz and chert, are subject to decided damage. Siliceous minerals also undergo abrupt volume changes at temperatures as low as 410° F (210° C) for chert and at about 1,063° F (573° C) for quartz, the inversion point from the alpha to the beta form. The high stresses resulting from unequal expansion in the different parts of the units made with siliceous aggregates generally result in the rupture of the webs rather than the spalling or flaking of the shells.

The webs of units made with calcareous aggregates are less likely to crack than those made with siliceous aggregates due to the lower expansion of the concrete. Under fire exposure, calcareous aggregates undergo calcination, a process that requires heat and produces a material that is a relatively good insulator. This retards heat transfer and consequently delays the occurrence of high temperatures on the unexposed side of the wall.

The effect of type of aggregate on fire endurance may be demonstrated with the results obtained from walls 5 and 2. Wall 5, a plastered non-load-bearing partition of units made with siliceous aggregates, collapsed after 58½ min of fire exposure. Wall 2, similar in construction to wall 5 except that the units were made with calcareous aggregates, withstood the test for 1 hr 51 min, at which time an average temperature rise of 250 deg F on the unexposed surface was reached.

### 2. Effect of Loading and Restraint on Type of Failure

Location of cracks and type of failure are influenced by the restraint and the loading of the walls. Loaded walls that are not fixed at the vertical edges take on a more or less continuous curvature

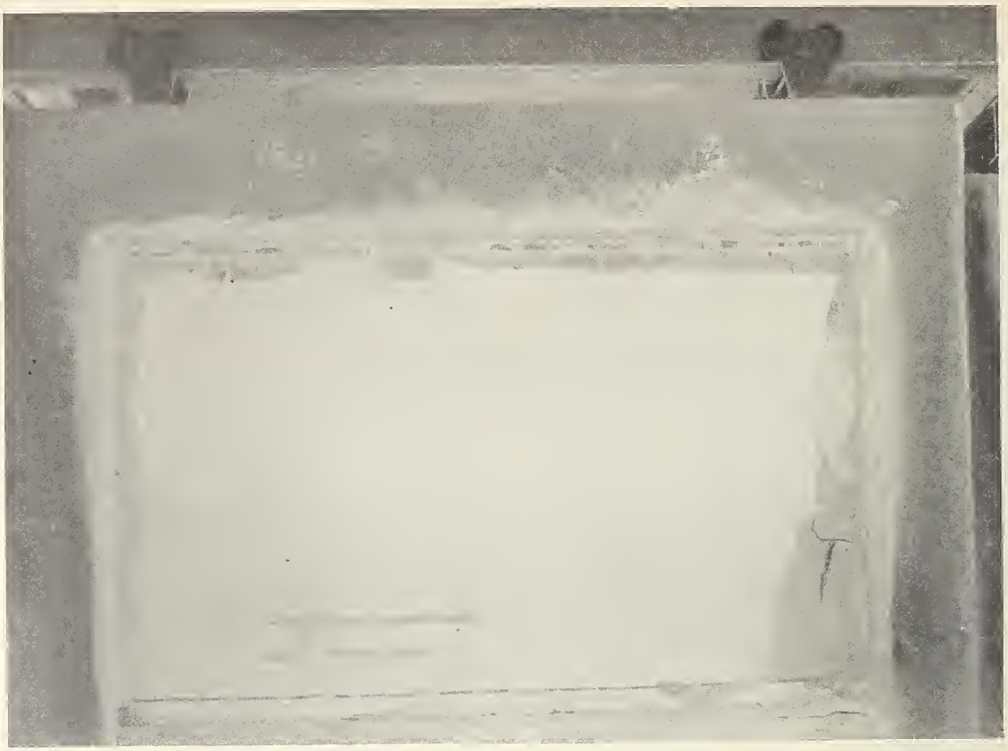

FIGURE 7. *Exposed side of 4-in. plastered nonload-bearing wall 5 after fire-endurance test.*

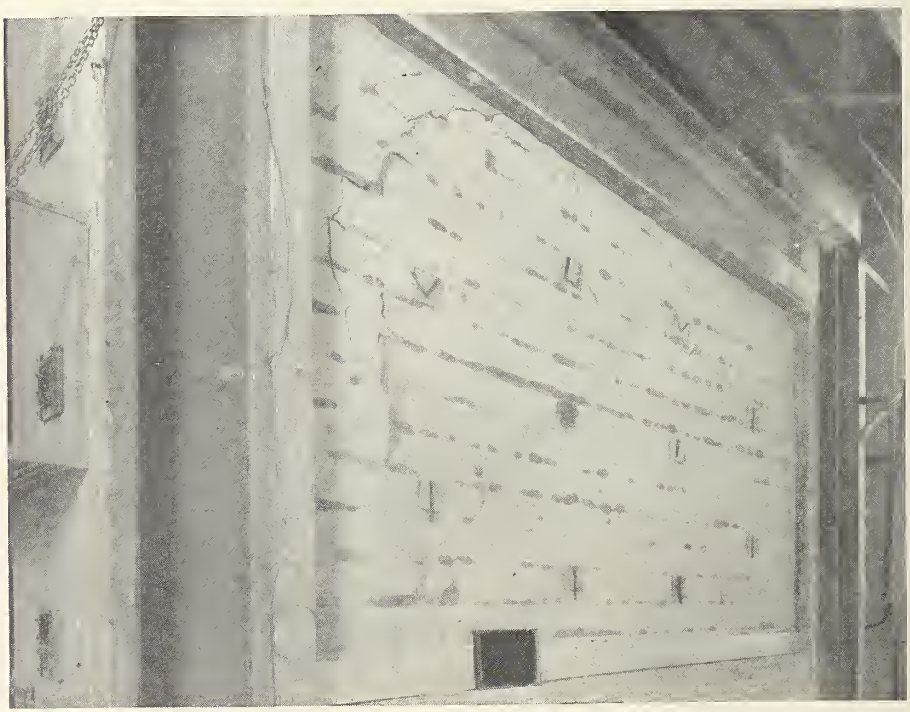

FIGURE 8. *Unexposed side of 4-in. plastered nonload-bearing wall 5 after fire-endurance test.*

from near the top to near the bottom edge. Since the units of the restrained wall are bedded against the restraining frame, the curvature of the deflected wall does not extend over the whole area but is confined more nearly to an ellipse having axes somewhat less than the dimensions of the wall. The deflection of the units adjacent to this elliptical area is restrained by contact with the frame and, consequently, the units bounding the ellipse are, in many cases, crushed or the shells on the exposed side are loosened. This is illustrated by the test of wall 5, a 4-in. plastered partition of units made with siliceous aggregate. (See figs. 7 and 8.)

Vertical cracks that were more or less continuous on the central part of the unexposed side of the loaded walls, but which did not show on the exposed side, indicated vertical restraint and freedom for lateral expansion in the central portion of the walls.

### 3. Effect of Strength of Unit

Indications are that the time to failure in the fire test is affected by the strength of the units. In the test of the 8-in. unplastered load-bearing wall 6, section A, which was built of units from source H having a compressive strength of 540 lb/in.$^2$, failed at 12 min; section B, which was built of units from source P having a compressive strength of 755 lb/in.$^2$, was allowed to cool and was subjected to a retest for 21 min before failure took place. In a similar 8-in. plastered load-bearing wall 8, section A, which was built of units from source H having a compressive strength of 605 lb/in.$^2$, failed at 32 min; section B, which was built of units from source P having a compressive strength of 1,420 lb/in.$^2$, continued to carry the load after failure of section A, and the individual units were found to be relatively free from damage.

### 4. Effect of Plaster

The importance of plaster in increasing fire endurance as established by temperature rise on the unexposed surface was not determined in these tests. Only the unplastered 8-in. load-bearing walls of units made with calcareous aggregates and the two-unit 12-in. unplastered wall of units with siliceous aggregate were able to withstand the fire exposure until the limiting temperature rise on the unexposed surface was reached. All of the other unplastered walls in this series failed under load or collapsed early during the fire exposure. The plastered walls withstood longer fire exposures than the similar unplastered walls before failure under load or collapse took place or before the limiting temperature rise on the unexposed surfaces was reached.

The effectiveness of plaster in increasing the stability of walls under fire exposure is shown by the test results from the 4-in. unplastered nonload-bearing wall 1, and the 4-in. plastered nonload-bearing wall 2, which were built of units made with calcareous aggregate and which gave fire-endurance values of 20 min and 1 hr 51 min, respectively. This is also shown by the test results from the 4-in. unplastered nonload-bearing wall 4, and the 4-in. plastered nonload-bearing wall 5, which were built of units made with siliceous aggregate, and which gave fire-endurance values of 17 min and 58½ min, respectively. Similar comparisons may be made from the results with the 8-in. unplastered load-bearing wall 6A and the 8-in. plastered load-bearing wall 8A, which were built of units made with siliceous aggregates and which gave fire-endurance values of 12 min and 32 min, respectively. The 12-in. unplastered load-bearing wall 9A and the 12-in. plastered load-bearing wall 10B, which were built of units made with siliceous aggregate and which gave fire-endurance values of 26 min and 6 hr 5 min, respectively, also show this comparison.

### 5. Performance of Cavity-Type Construction

The unplastered cavity-type or double wall 3B built of two wythes of 4-in. units made with calcareous aggregates failed under load at 1 hr 16 min. The single 4-in. restrained wall 1 of similar units failed at 20 min. Failure of the exposed 4-in. wythe of the cavity-type wall was delayed because its deflection was restrained by the ties into the unexposed part. Also, as this wall was loaded and free at the vertical edges, it may not have been subjected to as high stresses as probably were imposed on the restrained wall 1A.

### 6. Effect of Combustible Framed-In Members

The time at which a limiting temperature rise of 325 deg F as an average or of 422 deg F at any single location is reached at points approximately 4 in. from the unexposed surface or in the cell next to the unexposed side will determine the fire-resistance values of walls with joists or other combustible members framed into the wall, unless an earlier failure from some other cause takes place.[5] The fire-resistance values for walls with combustible framed-in members are given in table 4. These values are based on the assumption that the ends of the joists in the walls are bedded in masonry on the sides as well as on the bottom.

The 8-in. unplastered wall U1, of units made of calcareous aggregates, would have a fire resistance of 56 min for the condition that would exist with wood joists projecting 4 in. into the wall as compared with 2 hr 14 min with incombustible or no bearing members framed in the wall. The single-unit 12-in. plastered bearing wall, section B of wall 10, would have a fire resistance of 2 hr 31 min with combustible framed-in members as compared with 6 hr 5 min with incombustible or no framed-in members.

For the two-unit unplastered bearing wall, section A of wall 10, with combustible members framed into the 8-in.-thick units on the unexposed side, the fire resistance would be 2 hr 28 min. It would be 3 hr 54 min with the combustible mem-

[5] Standard methods of fire tests of building construction and materials, ASA No. A2.1-1942 (ASTM C 19-41), sec. 24b.

bers placed with ends between the 4-in.-thick units on the unexposed side, leaving a full thickness of an 8-in. unit between the end of the framed-in member and the fire-exposed side. The fire resistance of walls with combustible members framed into hollow units can be increased by filling the units between, above, and below these combustible members with masonry materials.[6]

### 7. Resistance to Hose-Stream Test

Only the walls of units made with calcareous aggregates were subjected to the hose-stream test. The three walls to which the test was applied showed good performance even though they were subjected to a long fire exposure before the hose stream was applied. All of the walls of units made with siliceous aggregates failed in the fire-endurance tests after short fire exposures or were damaged so that a subsequent hose-stream test would have been misleading unless duplicate test specimens were used. However, it seemed fairly assured that the two-unit 12-in. unplastered walls, section B of wall 9 and section A of wall 10, and the single-unit plastered 12-in. wall, section B of wall 10, would have passed the hose-stream test after 1 hr of fire exposure, which is the maximum required by the standard fire-test specifications before the hose stream is applied.

The 10-in. cavity-type wall 3B, which had a fire endurance of 1 hr 16 min established by load failure, apparently would have met the hose-stream test requirements had a duplicate wall been used and subjected to a fire exposure of half of the duration of the fire-endurance test. At that time, the deflection of the wall was 2½ in. and all units in the fire-exposed wythe, and their shells, were in place.

The 4-in. plastered nonload-bearing wall 5, built of units made with siliceous aggregates, failed near one end at 58½ min by the crushing of individual units. This fire endurance can be increased from 58½ min to 59½ min by correcting for the high severity of the fire exposure.[7] With this correction and the usual tolerance allowance, this wall would be considered as having a fire endurance of 1 hr and be required to meet the hose-stream test requirements. Although the deflection at the center of the wall was approximately 5 in. just before failure occurred, it was only 1.2 in. at 30 min, which is the fire exposure required when a duplicate specimen is used for the hose-stream test. The margin of stability thereby shown, taken together with the general experience with hose-stream tests applied to masonry partitions, indicates that the hose-stream requirements probably would have been met after a 30-min fire exposure, although in the absence of a test this cannot be assured.

[6] National Bureau of Standards BMS92, Fire resistance classifications of building constructions, p. 27.

[7] ASTM Standard, E 119-47, sec. 5 (b).

## VII. Summary

The fire-resistance values of the walls of gravel-aggregate concrete masonry units determined in the present series of tests are given in table 4. The table includes data from which the fire-resistance values for walls with combustible framed-in members can be obtained.

The mineral composition of the aggregates in the concrete units had a decided effect upon the fire resistance of the walls. The walls of this series apparently included the upper and lower range of performance attributable to the usual types of natural aggregates. The pebble gravels of the calcareous aggregates had approximately 80 percent of calcareous minerals, and the sand had approximately 50 percent. The siliceous aggregates consisted of 90 to 95 percent of quartz, with small amounts of feldspar, mica, and clay.

The fire resistance of the 4-in. unplastered wall of units made of calcareous aggregates was limited by collapse of the wall at 20 min. A plastered wall of the same size and type of units had a fire resistance of 1 hr 51 min, as determined by the temperature rise on the unexposed surface. The 8-in. unplastered walls of units made with calcareous aggregates, which had 43 and 22 percent of cell area, developed fire-resistance values of 2 hr 14 min and 3 hr 57 min, respectively, as determined by an average temperature rise of 250 deg F on their unexposed surfaces. The fire resistance of the 10-in. cavity-type wall of two wythes of 4-in. walls of units made with calcareous aggregates was limited to 1 hr 16 min by high deflection and consequent failure under load.

The fire-resistance values of the 4- and 8-in. unplastered or plastered walls and the 12-in. single-unit unplastered walls of units made with siliceous aggregates were limited by collapse of the test specimen after excessive deflections or by failure under load. The 12-in. plastered single-unit walls and the 12-in. unplastered two-unit (4-in. and 8-in.) walls successfully carried the applied load for extended fire exposures until specified limiting temperatures were reached on the unexposed surfaces.

The fire-resistance values limited by temperature rise on the unexposed surface of walls with incombustible or no framed-in members are two to three times those of walls with combustible framed-in members, for which the values are determined by temperature rise within the wall adjacent to or at the end of the combustible member.

Acknowledgment is made to the National Concrete Masonry Association for manufacturing and supplying the 4-in.-thick concrete masonry units made with calcareous aggregates, and to the Underwriters' Laboratories for the use of data from their tests of two 8-in. walls of units made with calcareous aggregates.

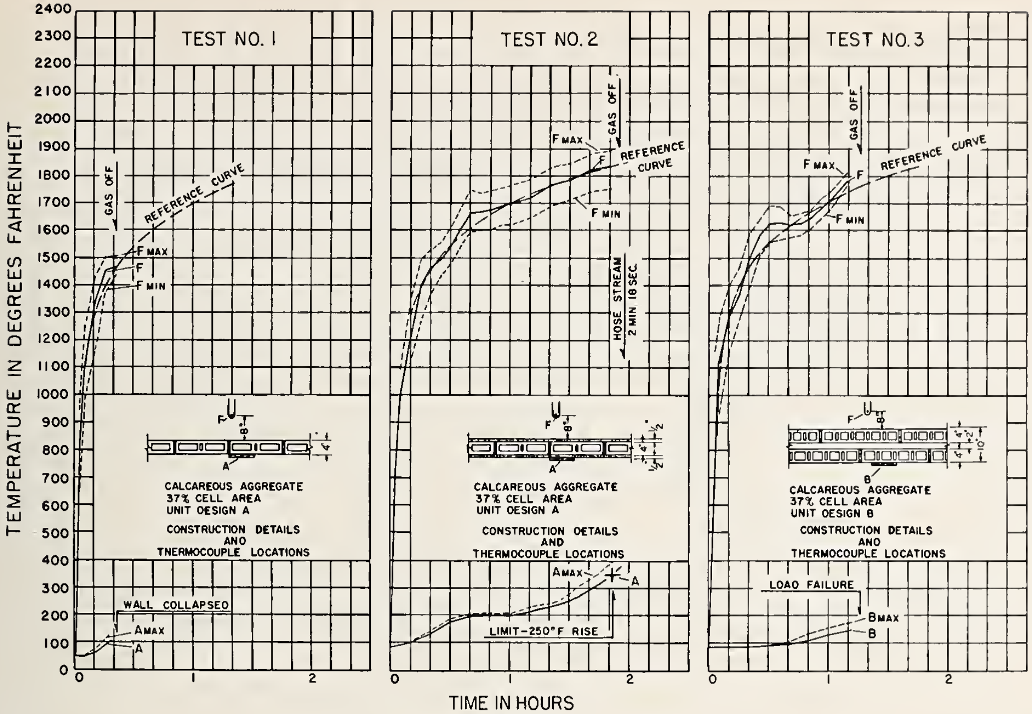


Figure 9. *Temperatures in fire-endurance tests of 4-in. nonload-bearing walls 1 and 2 and 10-in. cavity-type load-bearing wall 3 built of units made with calcareous aggregates.*

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

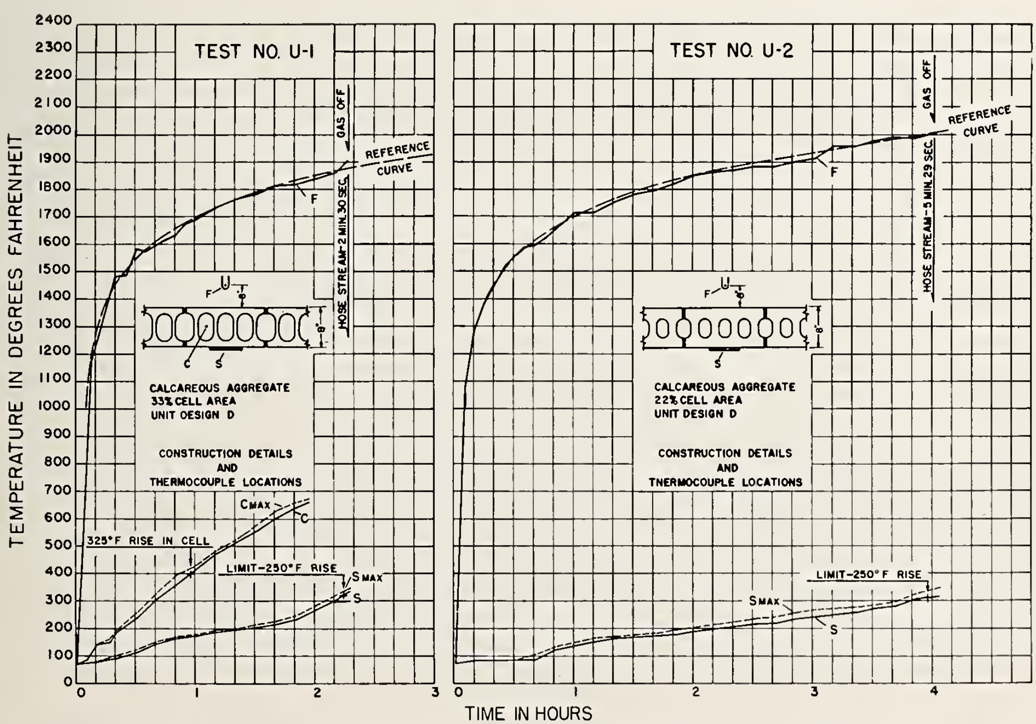


Figure 10. *Temperatures in fire-endurance tests of 8-in. load-bearing walls U1 and U2 built of units made with calcareous aggregates.*

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

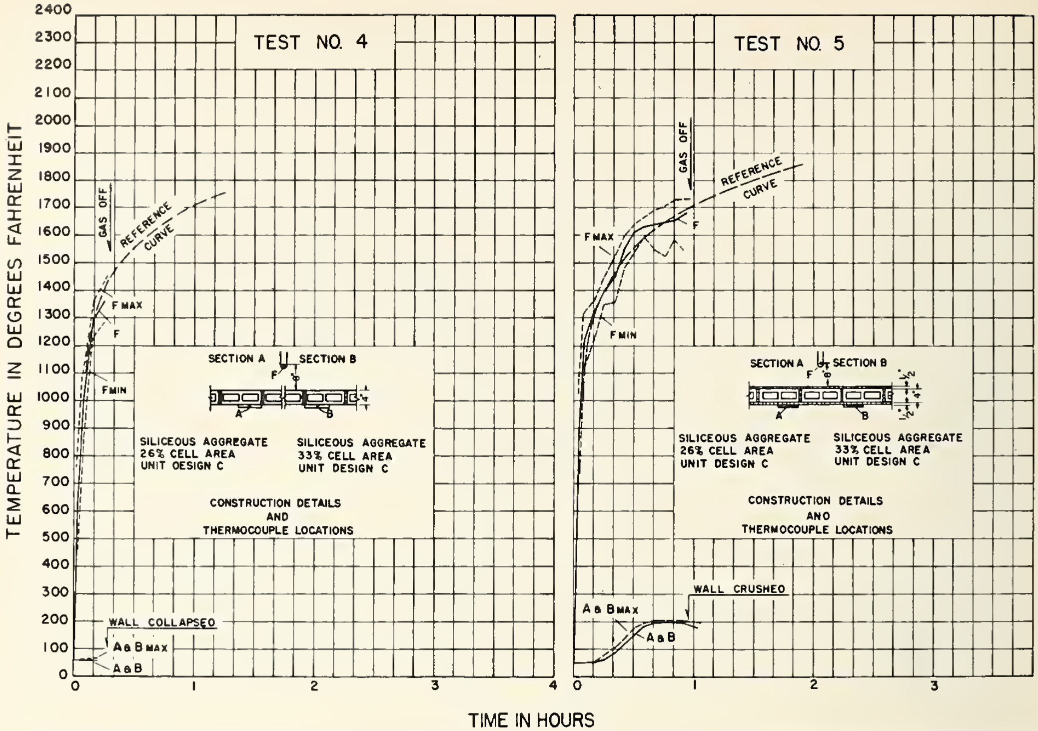


FIGURE 11. *Temperatures in fire-endurance tests of 4-in. nonload-bearing walls 4 and 5 built of units made with siliceous aggregates.*

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

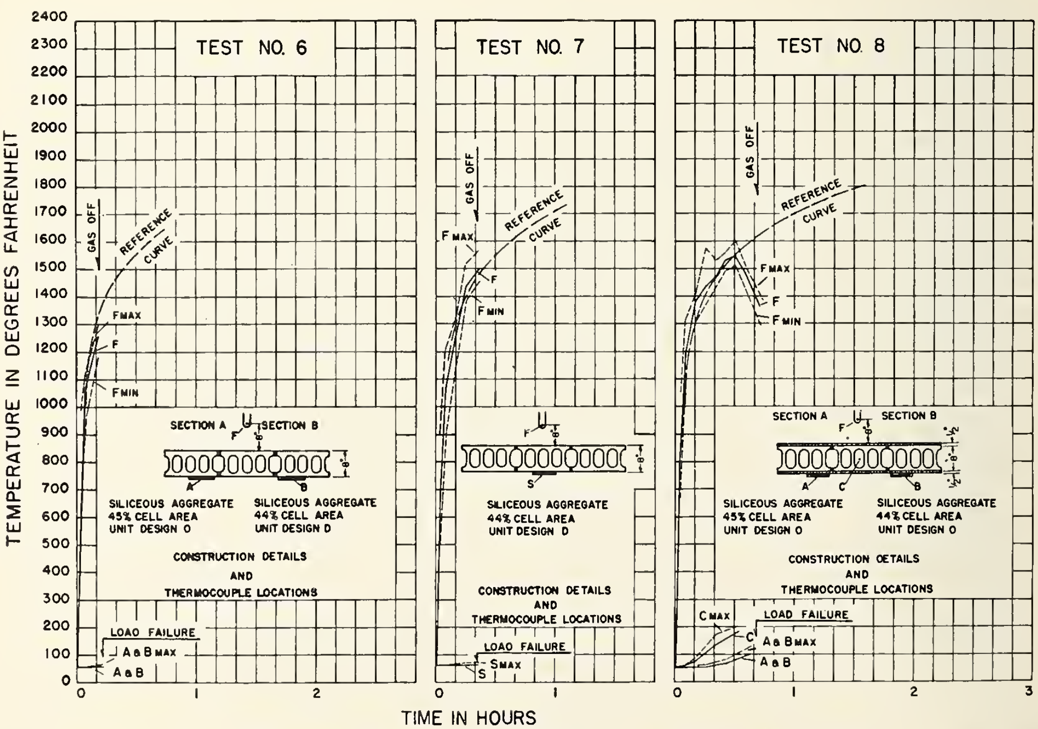


FIGURE 12. *Temperatures in fire-endurance tests of 8-in. load-bearing walls 6, 7, and 8 built of units made with siliceous aggregates.*

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

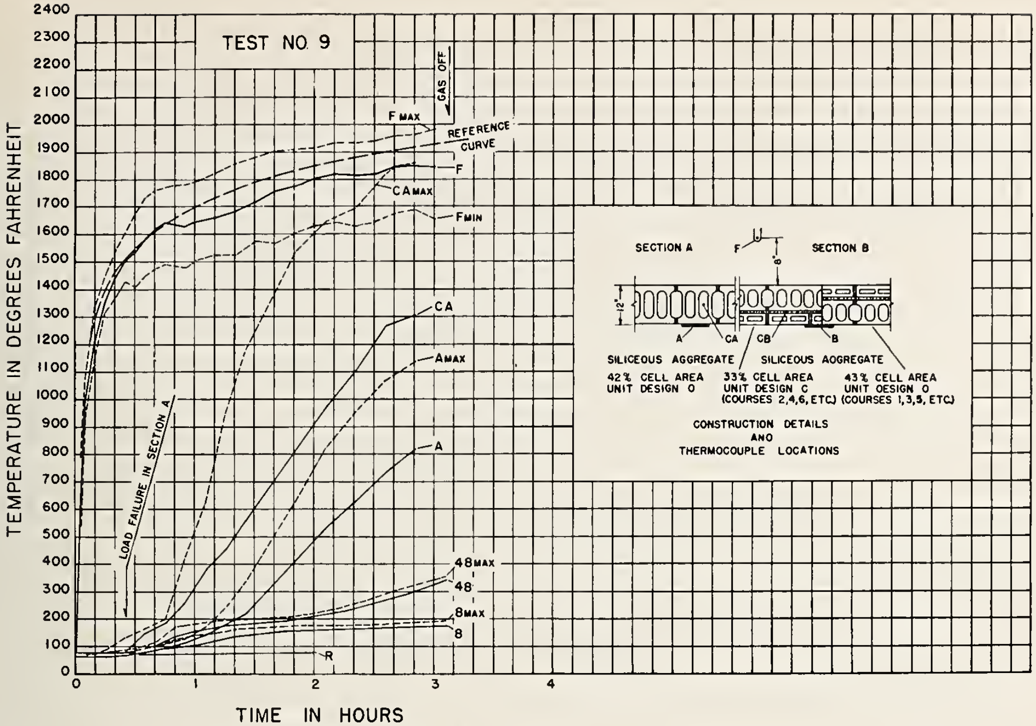


Figure 13. *Temperatures in fire-endurance tests of 12-in. load-bearing wall 9 built of units made with siliceous aggregates.*

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

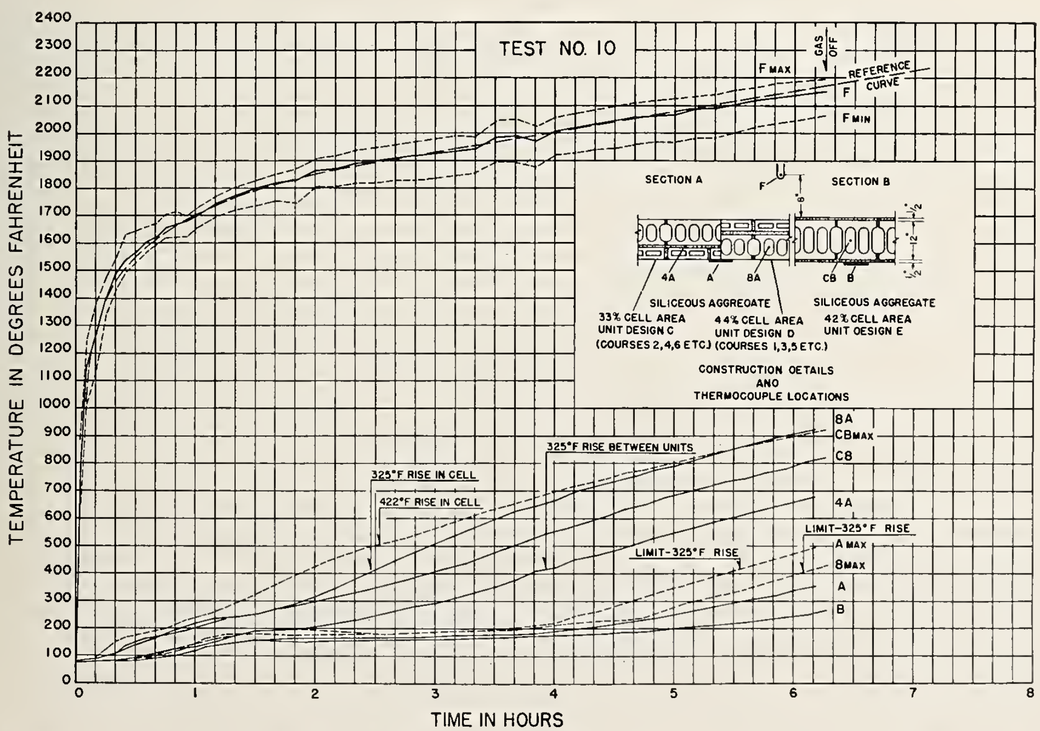


Figure 14. *Temperatures in fire-endurance tests of 12-in. load-bearing wall 10 built of units made with siliceous aggregates.*

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

Washington, April 24, 1950.



U. S. GOVERNMENT PRINTING OFFICE: 1951

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