Fire test of a load-bearing wall built from masonry units (89.1 per cent solid) of rotary kiln expanded shale aggregate

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FIRE TEST OF A LOAD-BEARING WALL BUILT FROM MASONRY UNITS (89.1 PER CENT SOLID) OF ROTARY KILN EXPANDED SHALE AGGREGATE

BY

J. A. C. BLANCHARD AND T. Z. HARMATHY

FIRE STUDY NO. 12

OF THE

DIVISION OF BUILDING RESEARCH

OTTAWA

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January 1964

PREFACE

This publication presents the results of a test carried out by the Division of Building Research of the National Research Council with the use of its fire research facilities. The test was carried out at the request of the agency concerned upon payment of the regular test fee. The initial report was submitted privately to this agency in accordance with regular DBR/NRC practice.

The test results obtained are now published in this form with the agreement of the sponsor of the test so that the information may be available for general use. This procedure is unlike that normally followed in the case of other tests carried out as required on proprietary products or constructions. It has been adopted in the case of fire resistance tests because of the considerable cost of each test which makes it desirable to eliminate, as far as possible, the necessity for repeating such tests on the same or similar constructions. Special care has been taken to describe all the pertinent features of the materials, the construction and the method of test, in order to make the results as useful as possible.

Ottawa,
January 1964

Robert F. Legget
Director

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J. A. C. Blanchard and T. Z. Harmathy

This report describes a fire test conducted on a bearing wall construction. The test was requested by the Expanded Shale Clay and Slate Institute, (1041 National Press Building, Washington 4, D. C.), and was carried out on November 1, 1962.

DESCRIPTION OF TEST SPECIMEN

The main sizes of the test specimen are shown in Figure 1. The specification of the materials is given below. The item numbers correspond to the part numbers in Figure 1. (Items Nos. 1, 2 and 3 were supplied by the Division of Building Research and did not constitute part of the specimen.)

1. Reinforced concrete beam (one) of 1 ft by 1 ft by 14 ft over-all dimensions; used for supporting the test specimen.

2. Welded steel box channel (one) of 8 in. by $2\frac{1}{2}$ in. by 13 ft 6 in. over-all sizes; used to improve the uniformity of the load on the top of the specimen.

3. Insulating strip (one) cut from 1/2 in. thick Fiberfrax blanket (1) to 8 in. by 14 ft sizes; used to close the cavity inside the specimen.

4. Concrete masonry units (89.1 per cent solid) of rotary kiln expanded shale aggregate, (209, 19 of which cut to approximately half length), manufactured by Henderson Concrete Products Limited, 1089 Nelson Street, Oshawa, Canada*.

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* This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in their report No. T62-6439, dated June 8, 1962, and signed by E. W. Fish.

(A) General information

(a) Dimensions

Nominal sizes: 6 in. by 8 in. by 16 in. (89.1 per cent solid).

Actual dimensions: see Figure 2.

(The dimensions shown in the figure are representative of measurements taken of several masonry units.)

Equivalent thickness (calculated on the basis of the "net area" as interpreted by ASTM C140-52): 4.71 in. *.

(b) Over-all composition** (see Note No. 1)

Material	as batched, lb/cu yd	based on dry aggregate, lb/cu yd
Portland cement	282	282
Rotary kiln expanded shale aggregate	1716	1607
Water	222	331
	2220	2220

(c) Manufacturing procedure***:

The blocks were manufactured at the plant of Henderson Concrete Products Limited, 1089 Nelson Street, Oshawa, Canada, on April 28, 1962, under the supervision of Donald Inspection Ltd., using the following equipment:

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* This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in a letter dated October 31, 1962, addressed to H. I. King of Domtar Construction Materials Limited, and signed by J. B. Kinnear.

** This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in a note "Additional Calculations Re Donald Inspection Limited, Report T62-6439", dated January 25, 1963.

*** This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in their report No. T62-6439, dated June 8, 1962, and signed by E. W. Fish.

Note No. 1 The mix proportion may also be stated as 1 part cement to 9 parts of aggregate on a dry, rodded basis.

Mixer: Go-corp
Block Making Machine: Go-corp
Moulds: Besser Manufacturing Co.

Immediately after manufacture the blocks were transported to the curing kiln where they were permitted to pre-set at atmospheric temperature for a period of 4 hr. At the end of the pre-set period steam was introduced and the temperature of the kiln raised to 180°F. The blocks were cured at this temperature for about 12 hr. The steam was then shut off, the kiln opened and the blocks permitted to cool for about 24 hr. After this period the blocks were removed from the kiln.

(B) Mechanical and physical properties

(a) Compressive strength (based on gross area)*:
1398 lb/sq in. (average at 9 days).
1536 lb/sq in. (average at 28 days).

(b) Water absorption (ASTM C140-52):
14.2 lb/cu ft (average)*.

(c) Water absorption (as interpreted by C20-46):
0.290 lb/lb.

(d) Bulk density (in oven-dry condition):
76.5 lb/cu ft (see Note No. 2)

(e) Apparent specific gravity (as interpreted by ASTM C20-46): 1.770.

(f) True specific gravity (as interpreted by ASTM C135-47): 2.563.

(g) Apparent porosity (as interpreted by ASTM C20-46):
0.305 cu ft/cu ft.

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* This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in their report No. T62-6439, dated June 8, 1962, and signed by E. W. Fish.

Note No. 2 In an attachment to Donald Inspection Ltd. Report No. T62-6439 dated June 8, 1962, the weight of concrete was reported as 78.2 lb/cu ft when determined in accordance with ASTM C-140.

(h) Thermal conductivity and specific heat (in oven-dry condition):

Temperature, °F heating cycle	Temperature, °F cooling cycle	Thermal conductivity, Btu/hr sq ft°F/in.	Specific heat, Btu/lb°F
88		2.90	0.199
289		3.05	0.230
599		3.25	0.261
	512	3.10	0.254
	385	2.85	0.245
	84	2.40	0.190

(i) Dilatometric analysis: see Figure 3.

(C) Information concerning the components

(I) Portland cement
Air-entraining portland cement (supplied by St. Mary's Cement Co. Ltd., 2221 Yonge St., Toronto) of specific surface 4000 sq cm/g, as measured with Blaine meter*.

(II) Rotary kiln expanded shale aggregate

(a) Origin:
Shale deposit**.

(b) Description:
Colour: 98 per cent grey, the remainder from buff to red**.

(c) Conformance to some specification:
The material conforms to ASTM C331-53T (drying shrinkage test was not performed)**.

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* This information has been supplied by H. I. King of Domtar Construction Materials Ltd., in a letter dated February 11, 1963, and addressed to T. Z. Harmathy of Division of Building Research, National Research Council.

** This information has been supplied by the Warnock Hersey Company Ltd., 250 Madison Ave., Toronto 7, Ont., in a letter of June 6, 1961, signed by N.P. Henley, M.Ch.E., and confirmed by H. I. King of Domtar Construction Materials Ltd. in a letter of February 11, 1963, addressed to T. Z. Harmathy of Division of Building Research, National Research Council.

(d) Chemical analysis*:

Compound	Per Cent by Wt
SiO_2	58.40
Fe_2O_3	8.00
Al_2O_3	18.20
CaO	4.98
MgO	5.07
Alkali oxides	3.78
SO_3	0.38
Water soluble matter	0.30
Loss on ignition	0.89
	100.00

(e) Sieve analysis**:

Sieve	Percentage Passing (average)
3/8 in.	100
No. 4	95.9
No. 8	71.7
No. 16	44.7
No. 30	28.6
No. 50	18.3
No. 100	12.2
No. 200	8.5

(f) Unit weight**:

Damp loose:	46.9 lb/cu ft (average)
Damp rodded:	56.6 lb/cu ft (average)
Dry loose:	52.4 lb/cu ft (average)
Dry rodded:	59.5 lb/cu ft (average)

(g) Organic impurities (ASTM C40-56T): Nil*.

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* This information has been supplied by The Warnock Hersey Company Ltd., 250 Madison Ave., Toronto 7, Ont., in a letter of June 6, 1961, signed by N.P. Henley, M.Ch. E., and confirmed by H.I. King of Domtar Construction Materials Ltd. in a letter of February 11, 1963, addressed to T.Z. Harmathy of Division of Building Research, National Research Council.

** This information has been supplied by Donald Inspection Limited, 340 Richmond St. W., Toronto, Ont., in their report No. T62-6439, dated June 8, 1962, and signed by E.W. Fish.

(h) Unburned and underburned lumps (ASTM C142-55T): Nil*.

5. Mortar

Thickness of mortar layer: approximately 3/8 in.

(A) General information

(a) Composition of mix:

Material	Per Cent by Weight (average)	Per Cent by volume
Cement	19.1	25.0
Sand	68.5	75.0
Water	12.4	
	100.0	100.0

(B) Mechanical and physical properties

(a) Density (in oven-dry condition): 106.2 lb/cu ft.

(b) Compressive strength: 786 lb/sq in. (average).

(c) Thermal conductivity (in oven-dry condition): 4.79 Btu/hr sq ft°F/in. at 88°F.

(d) Specific heat (in oven-dry condition): 0.200 Btu/lb°F at 88°F.

(C) Information concerning the components

(I) Cement:
Masonry cement, CSA A8, type H, manufactured by St. Lawrence Cement Co.

(II) Sand:
No information available.

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* This information has been supplied by The Warnock Hersey Company Ltd., 250 Madison Ave., Toronto 7, Ont., in a letter of June 6, 1961, signed by N.P. Henley, M.Ch.E., and confirmed by H.I. King of Domtar Construction Materials Ltd. in a letter of February 11, 1963, addressed to T.Z. Harmathy of Division of Building Research, National Research Council.

Figures 4 and 5 show the reverse and obverse sides of the specimen respectively prior to the fire test.

The specimen was of ordinary good workmanship. It had aged 128 days at the time of the test.

CONDITIONING OF TEST SPECIMEN

Since the moisture content of the masonry units was too low during the construction, the test specimen was moved into a conditioning chamber where the temperature was maintained between 80 and 90°F, and the relative humidity between 90 and 100 per cent.

During the conditioning period the moisture content and relative humidity (in the pores) of the masonry units were measured at more or less regular intervals, in order to obtain information on the progress of moisture adsorption. By means of a laboratory core drill, cylindrical samples of about 7/8 in. diameter and 2.82 in. length were taken from the wall through the web of some masonry units. Each sample was divided into three smaller cylinders of about 0.94 in. length, which were subsequently crushed into pieces not larger than 1/4 in. and analysed separately for relative humidity and moisture content. The relative humidity was measured by means of an "El-Tronics" portable hygrometer (2).

The results of final humidity and moisture analyses which were carried out the day before the fire test, are shown in Table I.

TABLE I

MOISTURE CONTENT AND HUMIDITY OF MASONRY UNITS BEFORE THE FIRE TEST

Location	Moisture content Referred to Oven-Dry Weight, per cent	Relative Humidity in the pores, per cent
Near outside surface	2.8	51.5
At approximately 1.4 in. from outside surface	5.2	68.5
At centre of web	5.5	72.5

The holes left in the masonry work after the removal of the cylindrical samples were filled with fast setting high-temperature mortar.

TESTING PROCEDURE

The fire endurance test was carried out in accordance with ASTM E119-61. The furnace temperature was measured by nine symmetrically distributed thermocouples enclosed in 13/16 in. O.D. Inconel tubes of 0.035 in. wall thickness, the tubes equipped with carbon steel cap at the tip. The hot junction of the thermocouples was placed 6 in. away from the exposed surface of the specimen. Both the individual temperatures at nine points of the furnace and the average of the nine temperatures were recorded. The fuel input into the furnace was controlled in such a way to make the average temperature follow the prescribed temperature versus time curve.

The temperature of the unexposed surface of the specimen was measured by nine thermocouples covered with standard asbestos pads, 6 in. square and 0.4 in. in thickness symmetrically distributed as shown in Figure 6.

During the test the specimen carried a vertical load of 80 lb/sq in. (referred to gross sectional area) applied by 8 hydraulic jacks. The specimen was not restrained along the vertical edges.

The lateral deflection at three points of the specimen was observed and recorded. The sketch in Figure 8 shows how the various deflection measurements should be interpreted.

A detailed description of the fire test facilities of the National Research Council is available (3).

RESULTS

The variation of the average temperature of the furnace is shown in Figure 7. The uniformity of the furnace temperature was very good. After 10-min run the maximum local deviation from the average temperature was always less than 115°F.

The average and the maximum unexposed surface temperatures are also plotted in Figure 7. The point of failure is indicated by an arrow. The failure was due to the average temperature of the unexposed surface exceeding the allowable limit (in this case 50 + 250 = 300°F) and occurred at 4 hr 3 min.

The deflection measurements are plotted in Figure 8.

Cracking of the specimen started at a fairly early stage. The first crack on the unexposed surface developed from top to bottom after 8-min run. Within an hour two other similar cracks had developed. At 3 hr 5 min, the glow of furnace could be seen through one of the cracks. The temperature was checked over and in the vicinity of this crack by means of a roving thermocouple was found to be lower than the allowable limit (50 + 325 = 375°F).

Immediately after reaching the point of failure the furnace was opened and the specimen subjected to a $7\frac{1}{2}$ min hose stream test. The water pressure at the base of the nozzle was 45 lb/sq in. gauge, as specified by ASTM E119-61. Figure 9 shows the exposed surface of the specimen immediately before and Figure 10 a few minutes after the application of the stream. It is seen that a layer of roughly 5/8 in. thickness was washed off from the surface.

Twenty-four hours after the completion of the tests the specimen was reloaded. The load was gradually increased. The specimen collapsed at 158 lb/sq in. superimposed load (referred to gross sectional area) which is slightly lower than that specified by ASTM E119-61 (twice the load exerted during the fire test = 160 lb/sq in.). Figure 11 shows the collapsing specimen.

CONCLUSION

A test specimen of a load-bearing wall built from masonry units (89.1 per cent solid) of rotary kiln expanded shale aggregate and of 6 in. by 8 in. by 16 in. nominal sizes, was subjected to standard fire endurance, hose stream and reload tests, specified by ASTM E119-61, on 1 November, 1962. The specimen yielded a fire endurance of 4 hr 3 min. The failure was due to the average temperature of the unexposed surface exceeding the allowable limit, 300°F in this case. The specimen collapsed during the reload test.

According to ASTM E119-61 the fire test can be regarded as successful for a period of 4 hr 3 min, if the specimen is subjected to a superimposed load not higher than 79 lb/sq in. (referred to gross sectional area).

REFERENCES

1. "Fiberfrax Ceramic Fiber". Pamphlet issued by The Carborundum Company, Research and Development Division, Niagara Falls, N. Y.

2. "El-Tronics Portable Hygrometer, Operating and Maintenance Manual, Model 103". Pamphlet issued by El-Tronics Inc., Philadelphia, Pa.

3. G. W. Shorter and T. Z. Harmathy. Fire Research Furnaces at the National Research Council, National Research Council, Division of Building Research, Fire Study No. 1, Ottawa, July 1960 (NRC 5732).

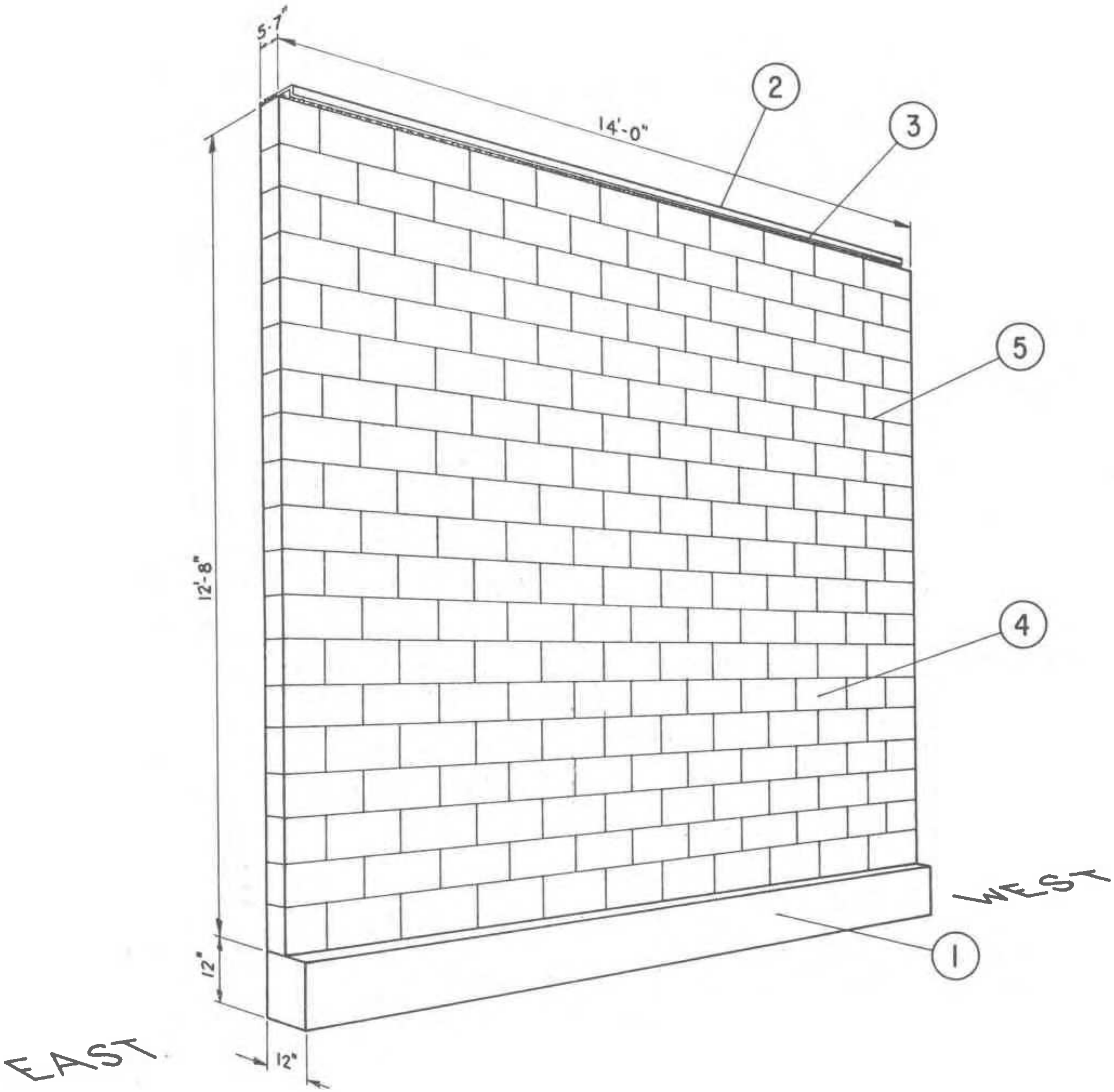

FIGURE I FIRE TEST SPECIMEN

BR. 2869-1

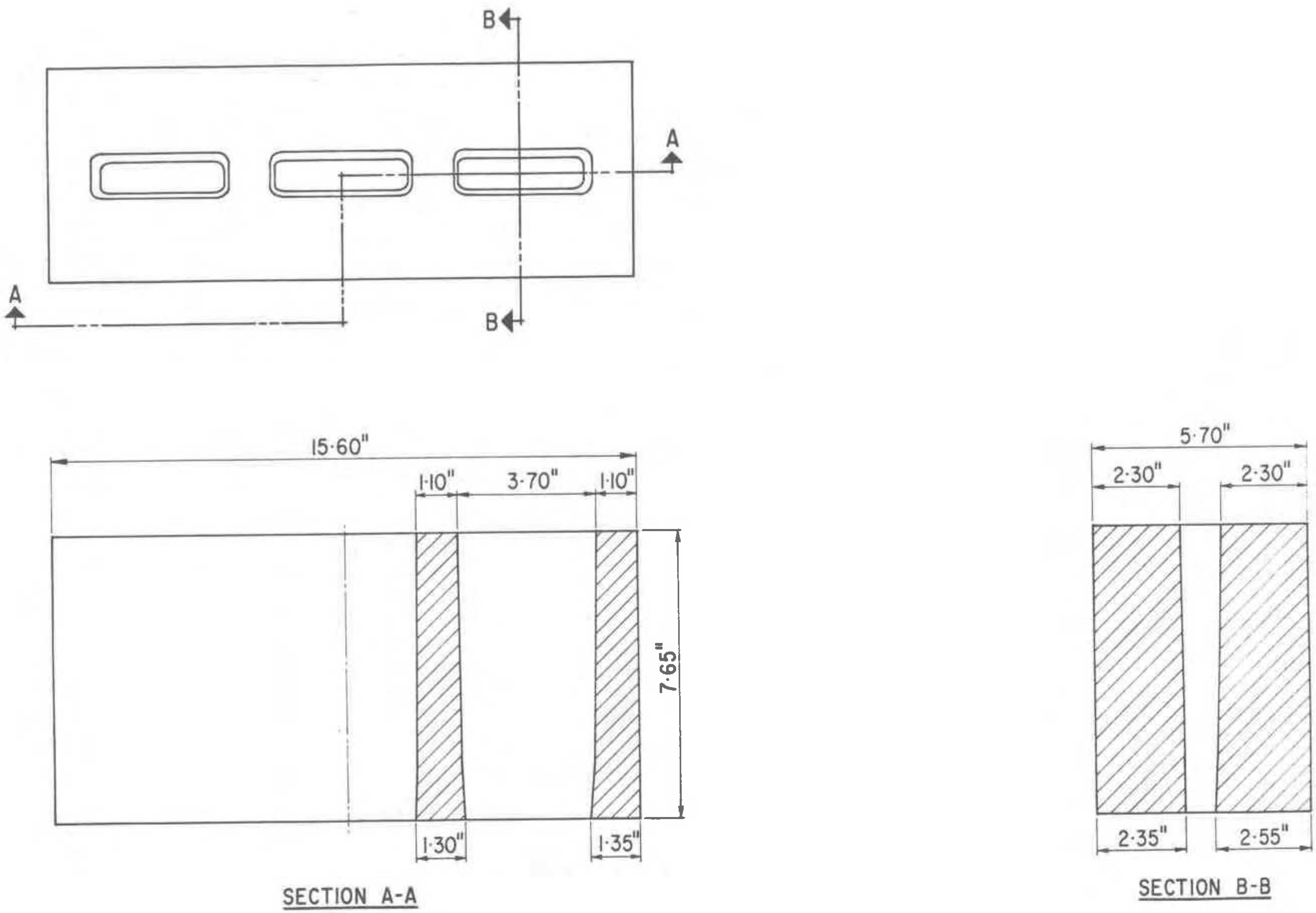

FIGURE 2 SIZES OF MASONRY UNITS

BR 2849-2

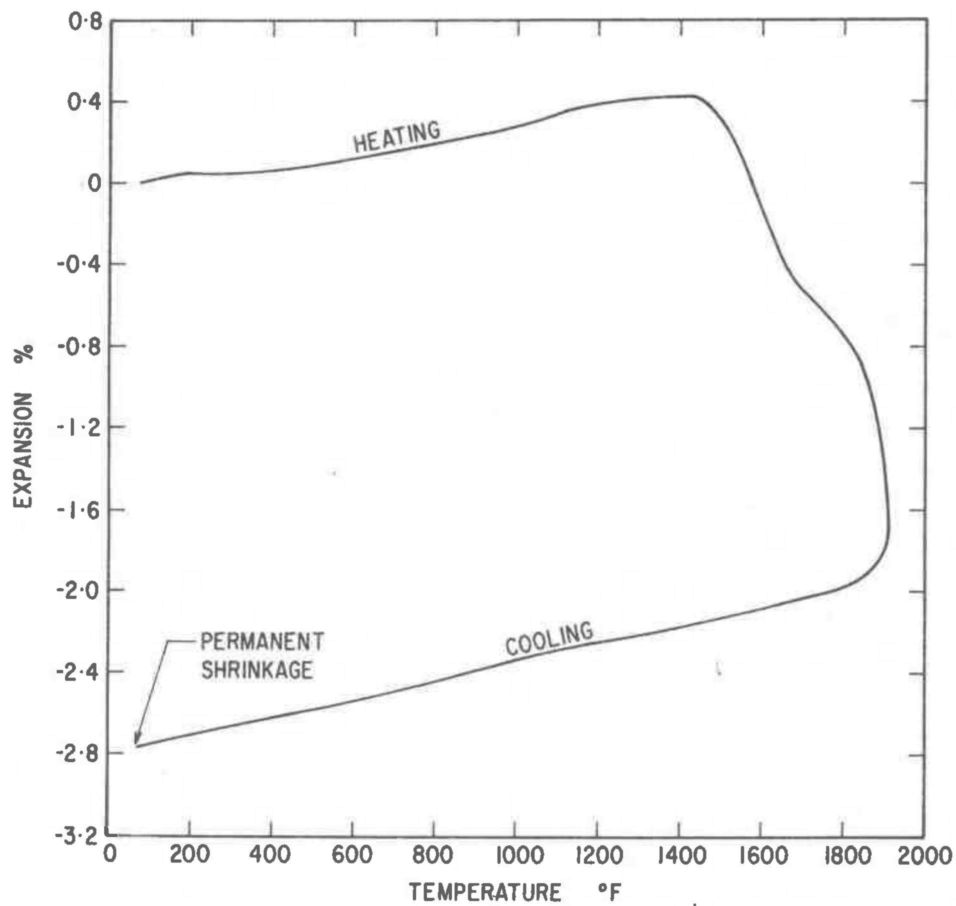

FIGURE 3 DILATOMETRIC CURVE
HEATING RATE: 9 °F/MIN

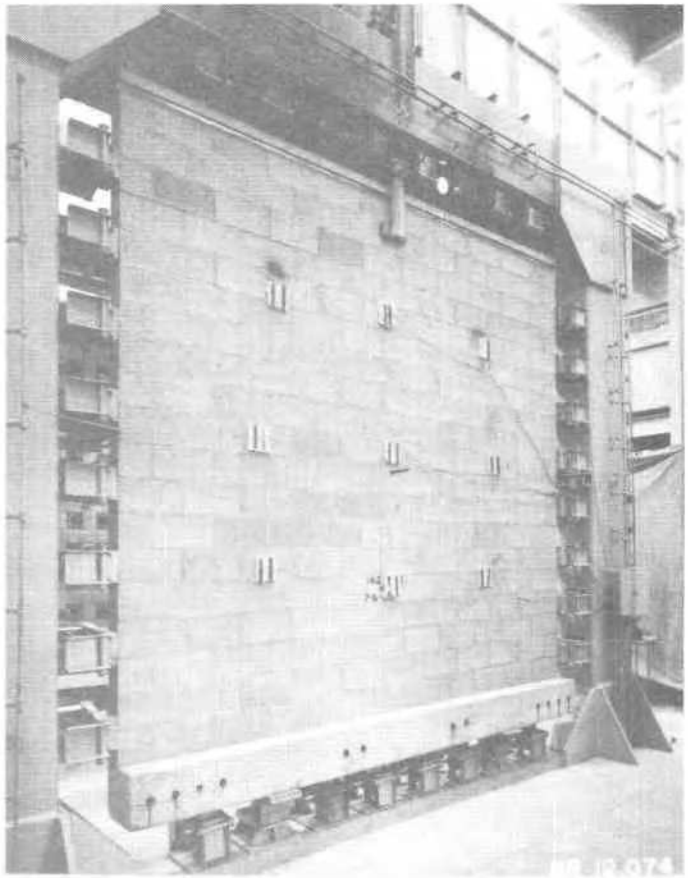

Figure 4
Reverse side of the specimen prior to fire test

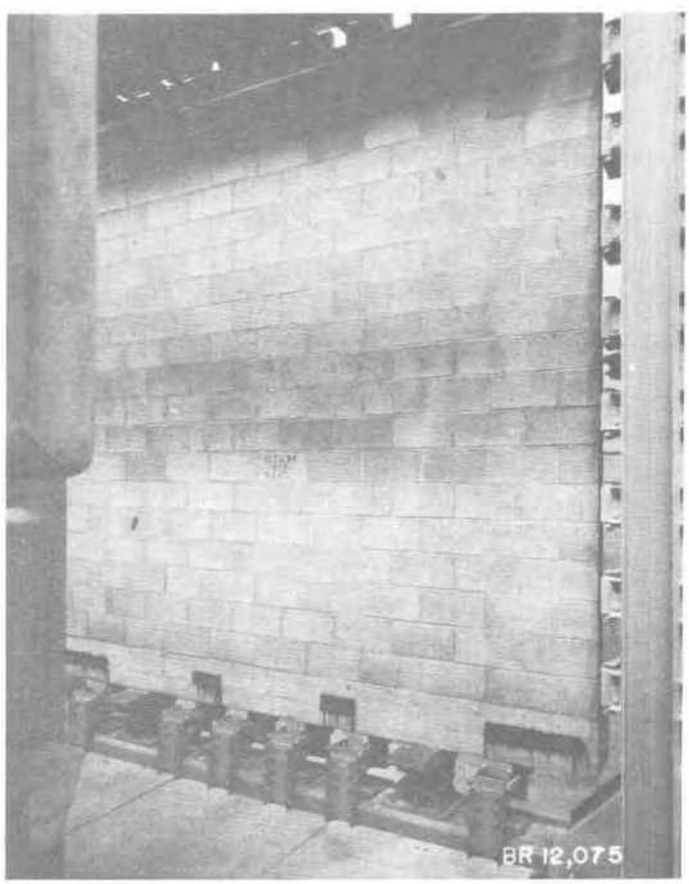

Figure 5
Obverse side of the specimen prior to fire test

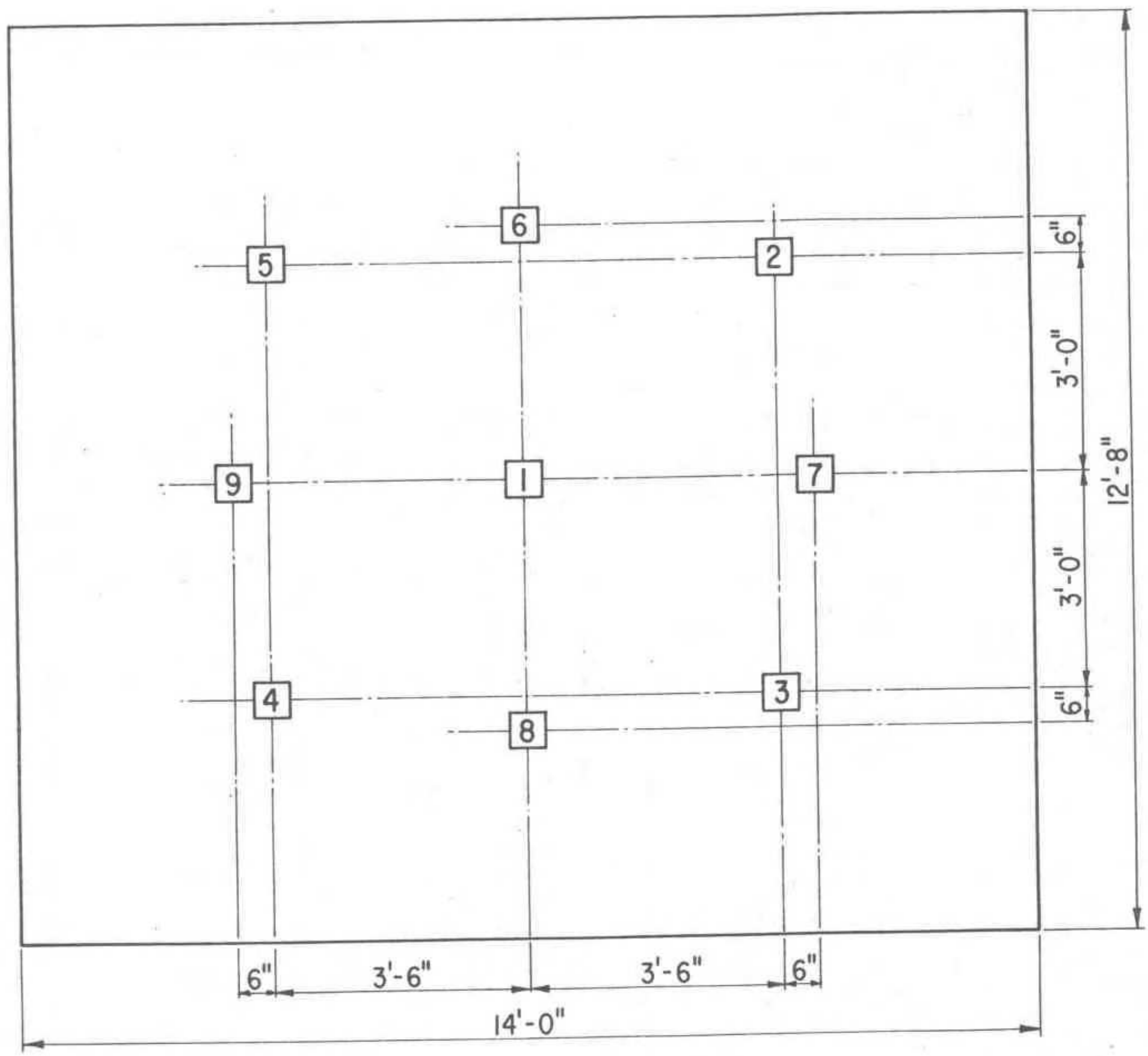

FIGURE 6 LOCATION OF THERMOCOUPLES ON THE UNEXPOSED SURFACE

BR. 2869-3

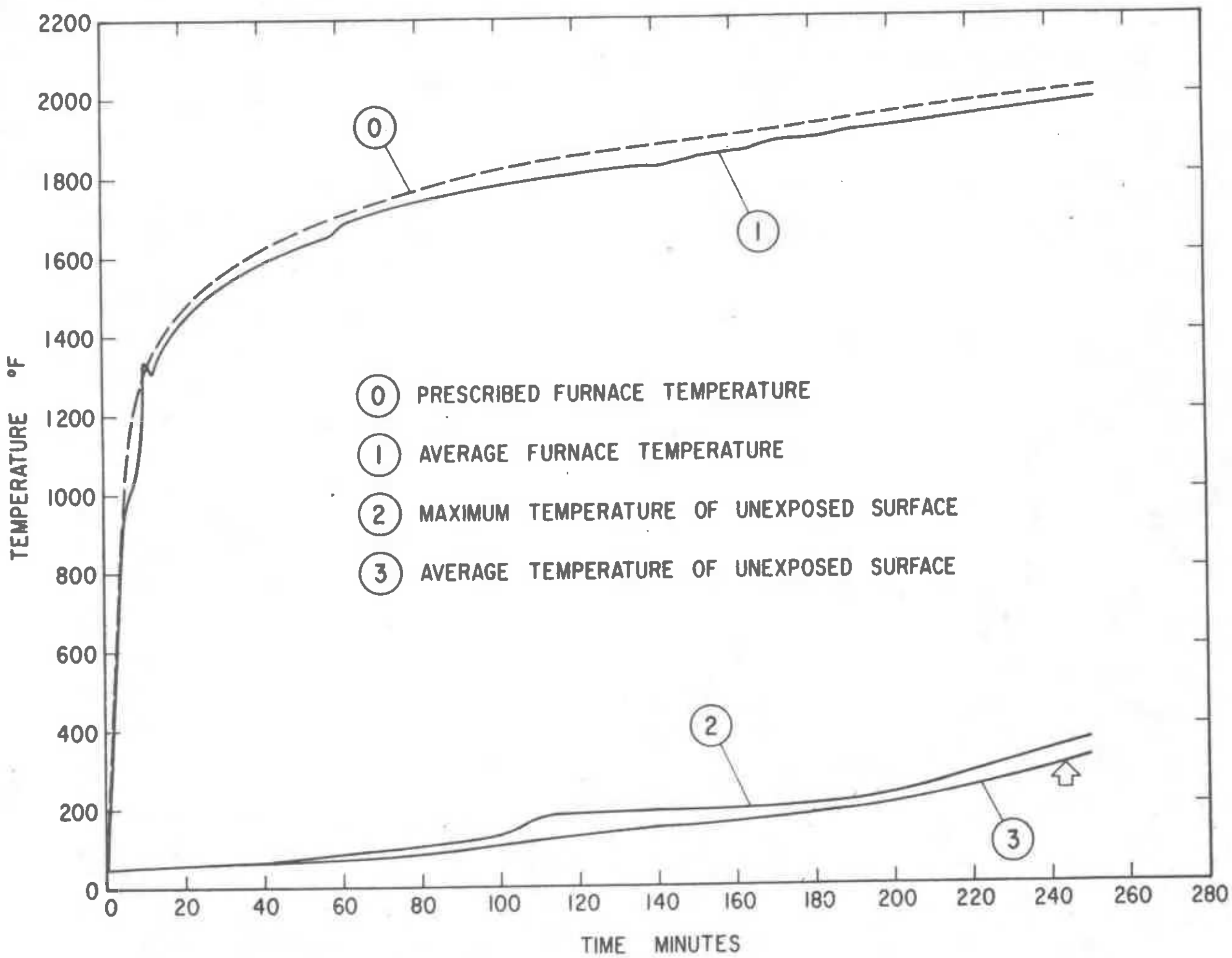

FIGURE 7 GENERAL TEMPERATURE VS TIME PLOT

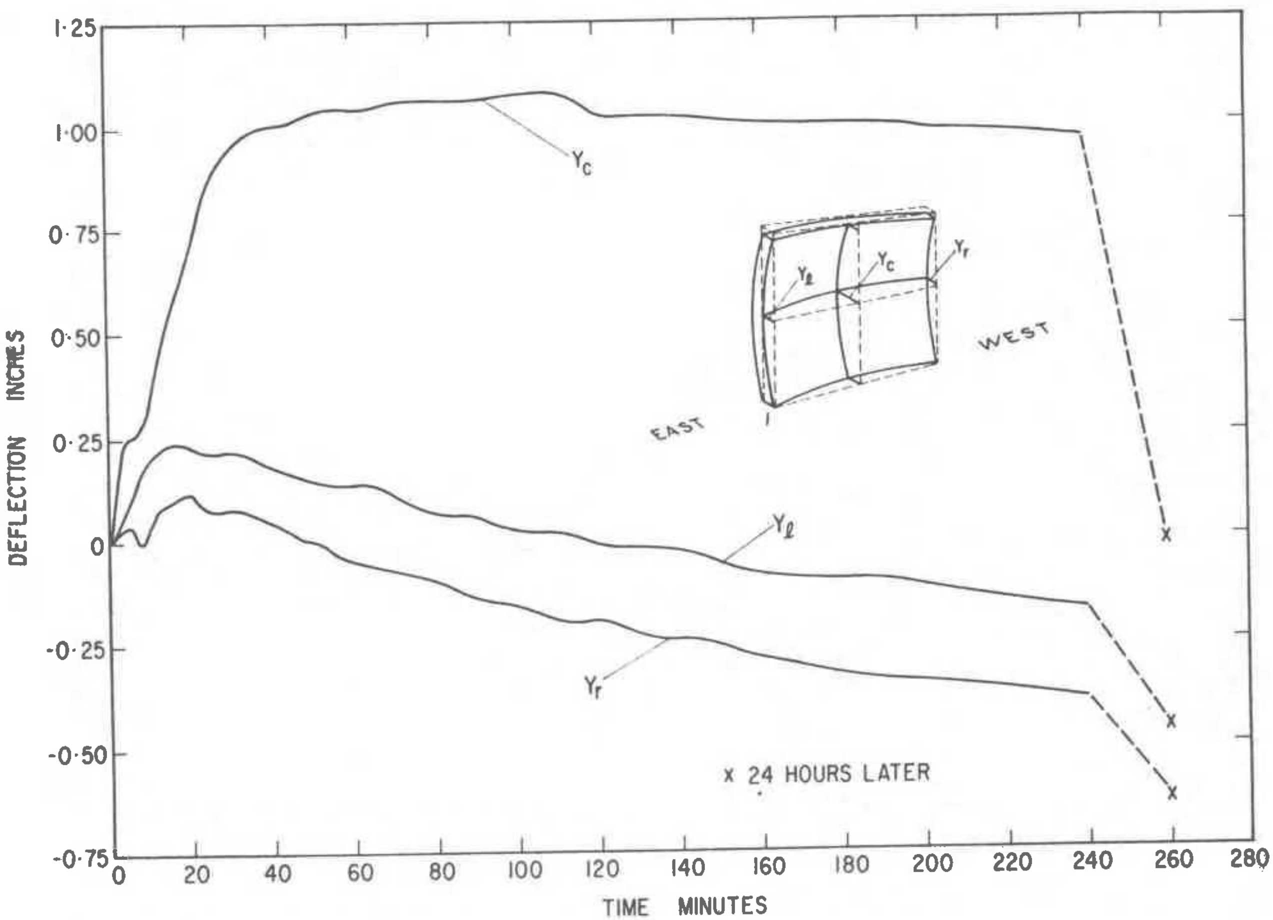

FIGURE 8 LATERAL DEFLECTION DURING FIRE TEST

BR 2069 5

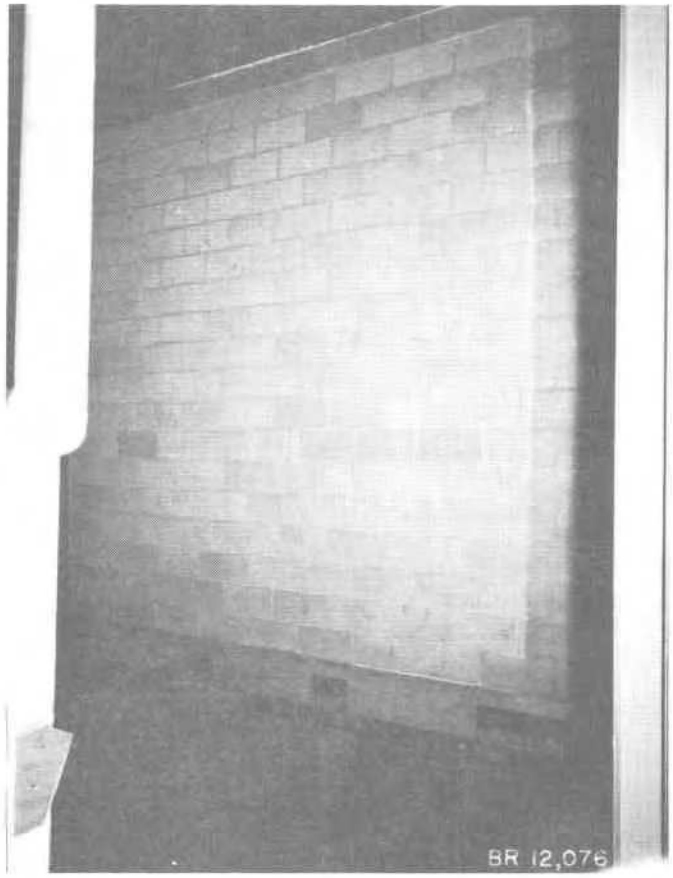

Figure 9
Exposed surface of the specimen after the fire test, prior to hose stream test

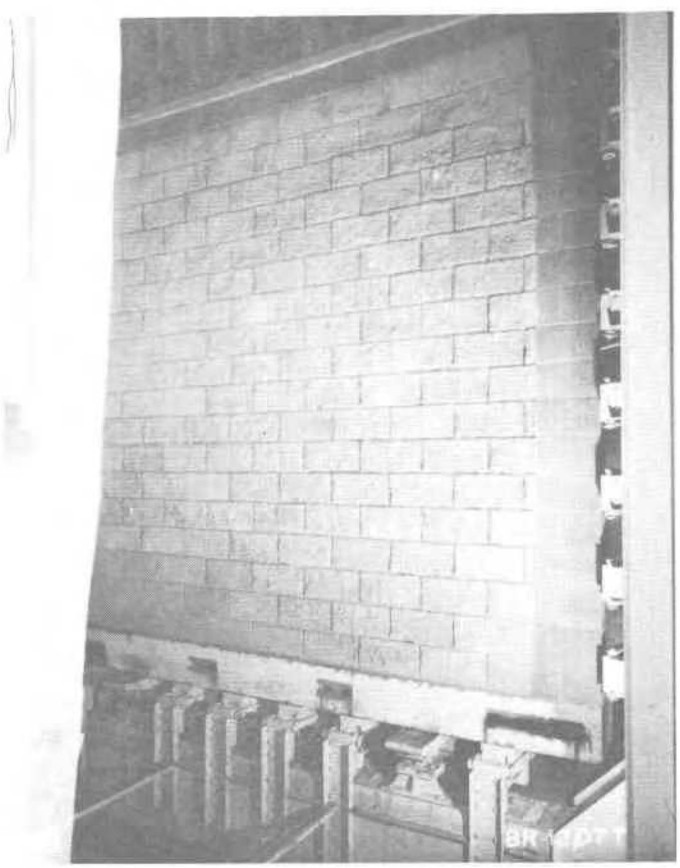

Figure 10
Exposed surface of the specimen a few minutes after hose stream test

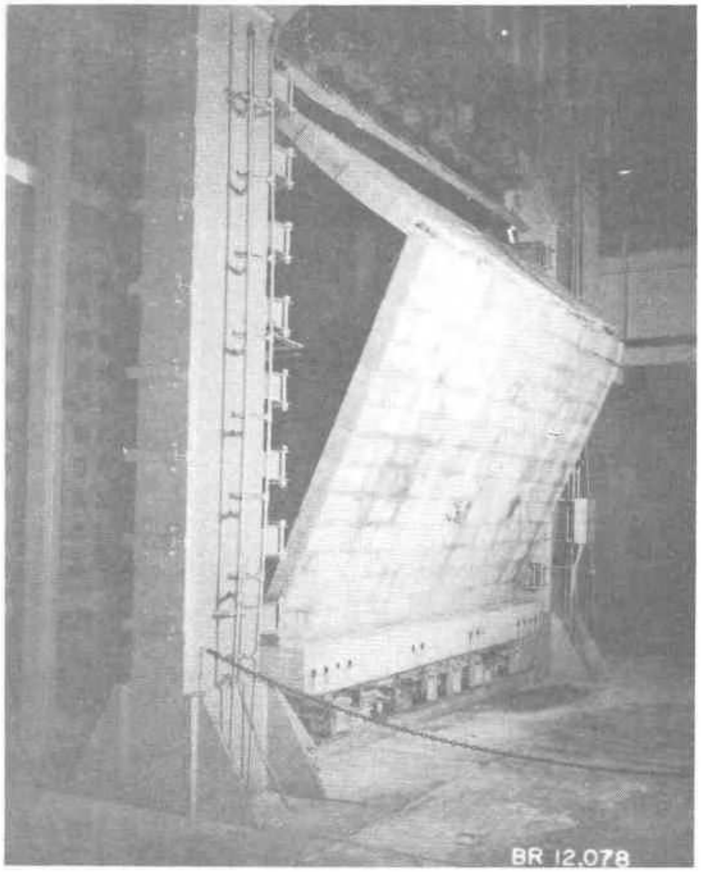

Figure 11
Collapse of the
specimen during
reload test