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FIRE TEST OF A "TRI-SEAL" FLOOR AND CEILING ASSEMBLY

BY

T. Z. HARMATHY

FIRE STUDY NO. 5

OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

JUNE 1961

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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 industrial company concerned upon payment of the regular test fee. The initial report was submitted privately to this company 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 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
June 1961

Robert F. Legget
Director

FIRE TEST OF A "TRI-SEAL" FLOOR AND CEILING ASSEMBLY

by

T. Z. Harmathy

This report describes a fire test conducted on a "Tri-Seal" floor and ceiling assembly of the Gypsum, Lime and Alabastine Limited, on November 11, 1959. The test was requested by the Toronto Office of the Gypsum, Lime and Alabastine Limited.

DESCRIPTION OF SPECIMEN

The main sizes and all construction details of the specimen are shown in Figs. 1 and 2. Specification of the parts and materials is given below. Note that the item numbers correspond to the part numbers in the figures.

1. Reinforced frame, made from refractory castable supplied by the Division of Building Research of the National Research Council.

2. Concrete slab 2 in. thick, made from ready-mixed concrete of 2500 lb/sq in. nominal compressive strength, supplied by a local firm. The actual strength of two specimens taken by N.R.C. personnel from two different batches during the placement of the concrete was found to be 3300 lb/sq in. and 2700 lb/sq in., respectively, at 28 days. (The tests were performed on cylinders made in conformance to ASTM C31-49 and loaded according to ASTM C39-49.) On the day before the test the relative humidity in the concrete (at a distance $1\frac{3}{4}$ in. from the surface) was found to be less than 40 per cent.

3. Clipped steel mat, fabricated in conformance to ASTM A184-37 from $\frac{1}{4}$-in. billet-steel bars (ASTM A15-54T) of structural grade, with 12- by 12-in. spacing.

4. Metal floor forms with inverted V-shaped corrugation along both edges, made by cold pressing from No. 28 gauge high strength low alloy cold-rolled steel sheet (ASTM A374-54T), cut to 10-ft by approximately 17-in. sizes.

5. "Macomber Allspan" steel floor joists of 12-ft clear span, conforming to size No. 210A of Macomber Design Manual MA-59.

6. $1\frac{1}{4}$-in. galvanized roofing nails with 3/8-in. diameter head.

7. Bridging angle of $1\frac{1}{2}$- by $1\frac{1}{2}$- by 3/16-in. sizes, conforming to AISI C1020.

8. $\frac{1}{2}$- by 2-in. hexagonal head bolts, with nuts.

9. "Tri-Seal Loop Channels", as shown in Fig. 3, made from No. 25 gauge galvanized cold-rolled carbon steel strips, conforming to temper No. 4 of ASTM A109-49T.

10. Galvanized double-strand tie wires of W and M gauge No. 18.

11. Pieces of perforated gypsum lath, with the fibre of paper coverings parallel to the short dimension (commonly known as "Perforated Tri-Seal Lath"), in 3/8- by 16- by 48-in. dimensions, conforming to ASTM C37-54.

12. Cold-drawn steel reinforcing wires of W and M gauge No. 12, conforming to ASTM A82-34.

13. Base coat, 9/16 in. thick, made from mill aggregated plaster of a composition of 100 lb neat gypsum plaster and 2.2 cu ft perlite aggregate.

14. 1/16 in. finish coat, made from standard lime putty-plaster of paris mixture.

15. Expanded metal lath in 12-in. wide strips, approximately 2.5 lb/sq yd.

16. Red clay bricks and mortar.

17. Asbestos wool.

As may be seen from Fig. 1, the edges of the specimen were simply supported. A clearance of 1 to $1\frac{1}{2}$ in. was left between the reinforced frame and the edges in order to eliminate any restraining forces resulting from horizontal thermal expansion of the specimen during the test. The gap around the edges was filled with loosely packed asbestos wool.

The plastered surface of the ceiling immediately before the test is shown in Fig. 10.

The floor and ceiling assembly was of ordinary good workmanship. During the conditioning period several cracks developed on the surface of the concrete slab; the largest continuous crack was approximately 30 in. in length and 1/16 in. in width.

The age of the specimen was approximately 120 days at the time of the test.

TESTING PROCEDURE

The test was carried out in accordance with ASTM Specification E119-58. Furnace temperature was measured by nine symmetrically disposed thermocouples enclosed in 13/16-in. O.D. Inconel tubes of 0.035-in. wall thickness, the tubes equipped with a carbon steel cap at the tip. The hot junction of the thermocouples was placed 12 in. away from the exposed face of the sample. 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 that the average temperature closely followed the prescribed temperature time correlation.

The unexposed surface temperature was measured by nine thermocouples (Nos. 1 to 9) covered with standard asbestos pads, 6 in. square and 0.4 in. thick, symmetrically disposed as shown in Fig. 4. In addition, four thermocouples were cemented to the unexposed surface in a way shown in Fig. 5. The location of these thermocouples (Nos. 11 to 14) is also shown in Fig. 4.

In order to study the flow of heat through the specimen, twelve additional thermocouples were installed within the structure. These thermocouples (Nos. 15 to 26) were also symmetrically disposed and are shown in the general thermocouple layout drawing (Fig. 4).

The surface of the specimen was subjected to a vertical load of 125 lb/sq ft, applied through a hydraulic loading device consisting of 30 jacks. The load was transferred to the specimen at ninety points (see Fig. 11) so that the condition of uniform load distribution was reasonably well approximated.

A mechanical device was used to measure the vertical deflection at the centre of the specimen.

A detailed description of the fire test facilities of the National Research Council is available (1).

RESULTS

Uniformity of the furnace temperature was very good throughout the test; maximum deviation from the average was always less than 100°F. A plot of the average temperature against time is shown in Fig. 7.

Variation of the unexposed surface temperature was roughly indicative of structural disintegration of the ceiling construction. Where the disintegration developed more rapidly, moderately higher temperatures were recorded on the unexposed surface. In Fig. 7 the variation of both the average and the maximum temperatures of the unexposed surface are shown. Thermocouples cemented to the surface recorded somewhat lower temperatures, the average of which is also plotted in the same figure.

Temperatures obtained from various points in the interior of the structure showed a very remarkable spread. This was obviously due to the irregular disintegration of the plaster layer and the gypsum lath. Generally speaking, the thermocouples placed nearer the centre or the exposed surface recorded higher temperatures than those farther from the centre or the exposed surface. Characteristic curves are shown in Fig. 7.

The variation of the central (maximum) deflection and the rate of deflection are plotted in Fig. 8. Deflection of 0.45 in. at zero time is due to the imposed 125 lb/sq ft load before the start of the test. After 2 hours of test the deflection at the centre became larger than the available stroke of the jacks, so that two jacks around the centre became ineffective. Thus the slope of the deflection curve shows a sudden decrease after 120 minutes testing.

The fire test was terminated at 2 hours and 7 minutes. According to ASTM E119-58 the test is regarded as successful for a 2-hour period.

COMMENT

The process of disintegration of the fire-exposed ceiling structure appears to have been as follows:

Within ½ minute of the start of the test the finish plaster began to peel from the ceiling in large patches. In other places moisture stains appeared on the surface. After 12 minutes the base plaster coat commenced to crack along the "Tri-Seal Loop Channels". Cracks gradually opened to a ¼-inch width as the pieces of gypsum lath and adhering base coat began to sag. After 25 minutes other cracks running at right angles to the previous ones, mostly at the joints of the pieces of gypsum lath, also appeared. Where the various pieces sagged differently, these latter cracks grew rapidly, and at 27 minutes the first gap on the ceiling, about 1 inch in width, became visible. In quick succession other gaps formed and at 35 minutes the first larger section of the gypsum lath, approximately 16 by 36 in. in size, fell off the ceiling together with the adhering base coat. The gap and hole formation on the ceiling marked the beginning of a rapid temperature rise inside the ceiling-floor assembly, as may be seen in Fig. 7, and resulted in an increased rate of deflection (Fig. 8).

From this point on the disintegration of the base coat and gypsum lath developed rapidly. Many new gaps formed perpendicular to the direction of the "Tri-Seal Loop Channels", but the tie wires prevented separate pieces from falling down. It was not until 55 minutes after the start of the test that a second, larger piece of ceiling gave way. At 1 hour and 18 minutes another large piece fell down and the steel joists became visible.

The disintegration process of the ceiling is illustrated in Fig. 9, where the total area of ceiling openings is plotted versus time. This curve is believed to be correct within ± 10 per cent.

Figure 6 shows the state of the ceiling after the test. The diagram was reconstructed from two photographs taken immediately after termination of the test; one of these is shown as Fig. 12. The area of complete disintegration is cross-hatched. Within this area several fragments of gypsum lath and plaster were still hanging on the tie wires, but these pieces no longer constituted significant shielding for the steel joists.

As may be seen from Fig. 12, the base coat adhered very well to the gypsum lath throughout the test. The two layers acted as a single unit, apparently because of the perforations of the lath. It may also be seen that the tie wires played an important part in the fire endurance of the structure. They held the pieces of plaster and gypsum lath in position even after most of their strength had been lost, and in this way, though indirectly, protected the load-bearing steel joists from the radiating heat.

As mentioned earlier, several cracks were observed on the surface of the concrete slab before the test. After 80 minutes a number of other cracks gradually developed, from some of which steam was issuing. At such places where the surface was below boiling point, the steam partly condensed in the cracks and slowly filled them up with moisture, as is shown in Fig. 11.

Robertson and Ryan (2) developed criteria for defining the load failure of fire test specimens in terms of deflection and rate of deflection. It has been proposed that the point at which both

$$D \geqslant \frac{L^2}{800d}$$

and

$$R \geqslant \frac{L^2}{150d}$$

can be regarded as an indication of load failure. In these correlations

D = maximum deflection, in.
R = rate of deflection, in./hr
L = span of the principal structural element, in.
d = distance between the upper and lower extreme fibres of the principal structural element, in.

In this case L = 144 in., d = 10.125 in., therefore the critical deflection is

$$D_{crit} = \frac{144^2}{800 \times 10.125} = 2.56 \text{ in.}$$

and the critical rate of deflection

$$R_{crit} = \frac{144^2}{150 \times 10.125} = 13.65 \text{ in./hr} = 0.228 \text{ in./min.}$$

These critical values are marked with arrows in Fig. 8. It may be seen that by the end of the test the maximum deflection exceeded the critical value by more than three times, although the rate of deflection remained below the above defined limit. According to the Robertson-Ryan criteria, therefore, the floor and ceiling assembly was not due to collapse at the time when the test was terminated.

REFERENCES

1. Shorter, G. W., and T. Z. Harmathy. Fire Endurance Test Facilities at the National Research Council. N.R.C., Division of Building Research, DBR Fire Study No. 1, Ottawa, July 1960. NRC 5732.

2. Robertson, A. F., and J. V. Ryan. Proposed Criteria for Defining Load Failure of Beams, Floors and Roof Constructions During Fire Test. J. Res. Natl. Bureau Stds., 63C, p.121-124 (1959).

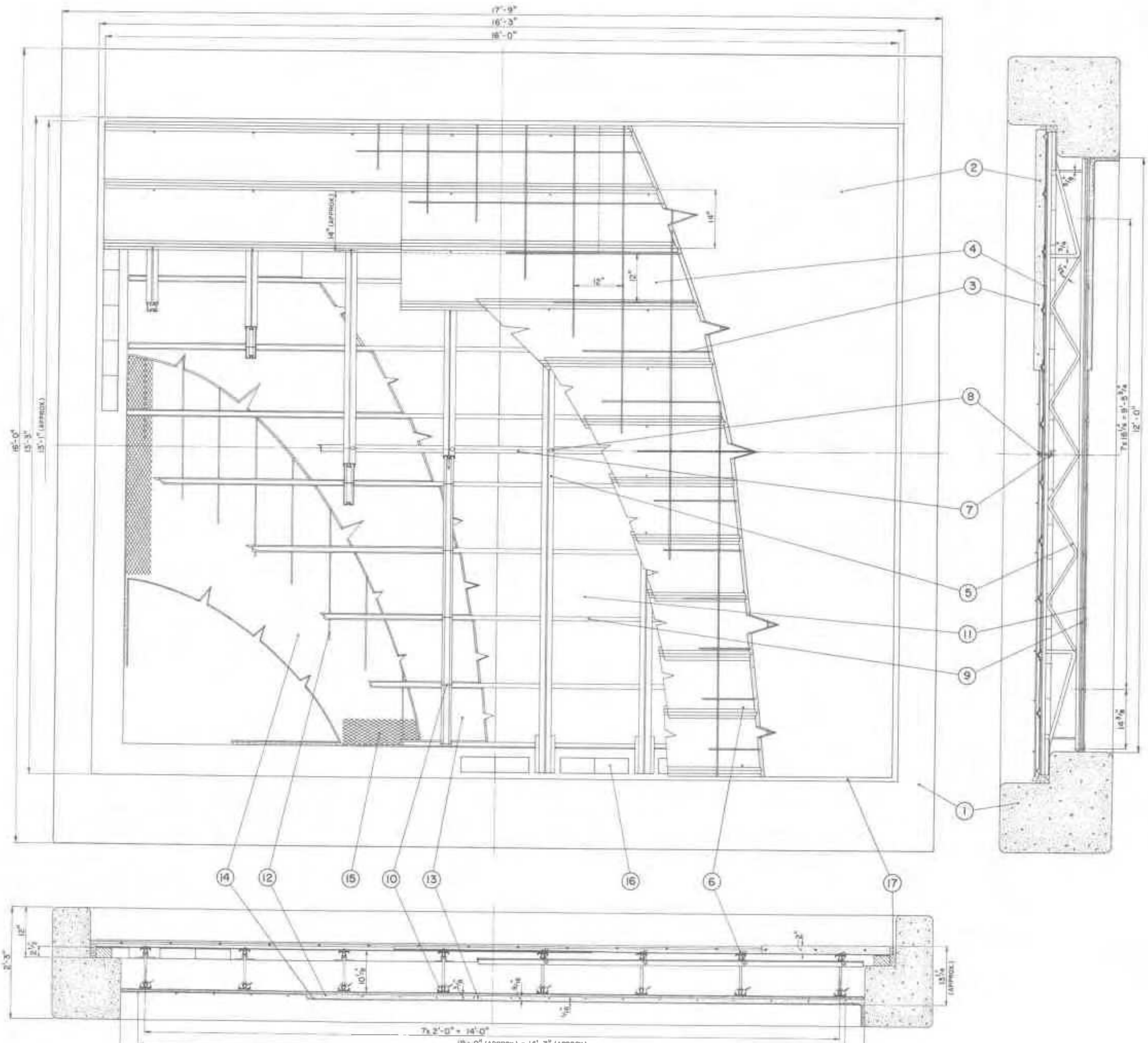


FIGURE 1 "TRI-SEAL" FLOOR & CEILING ASSEMBLY

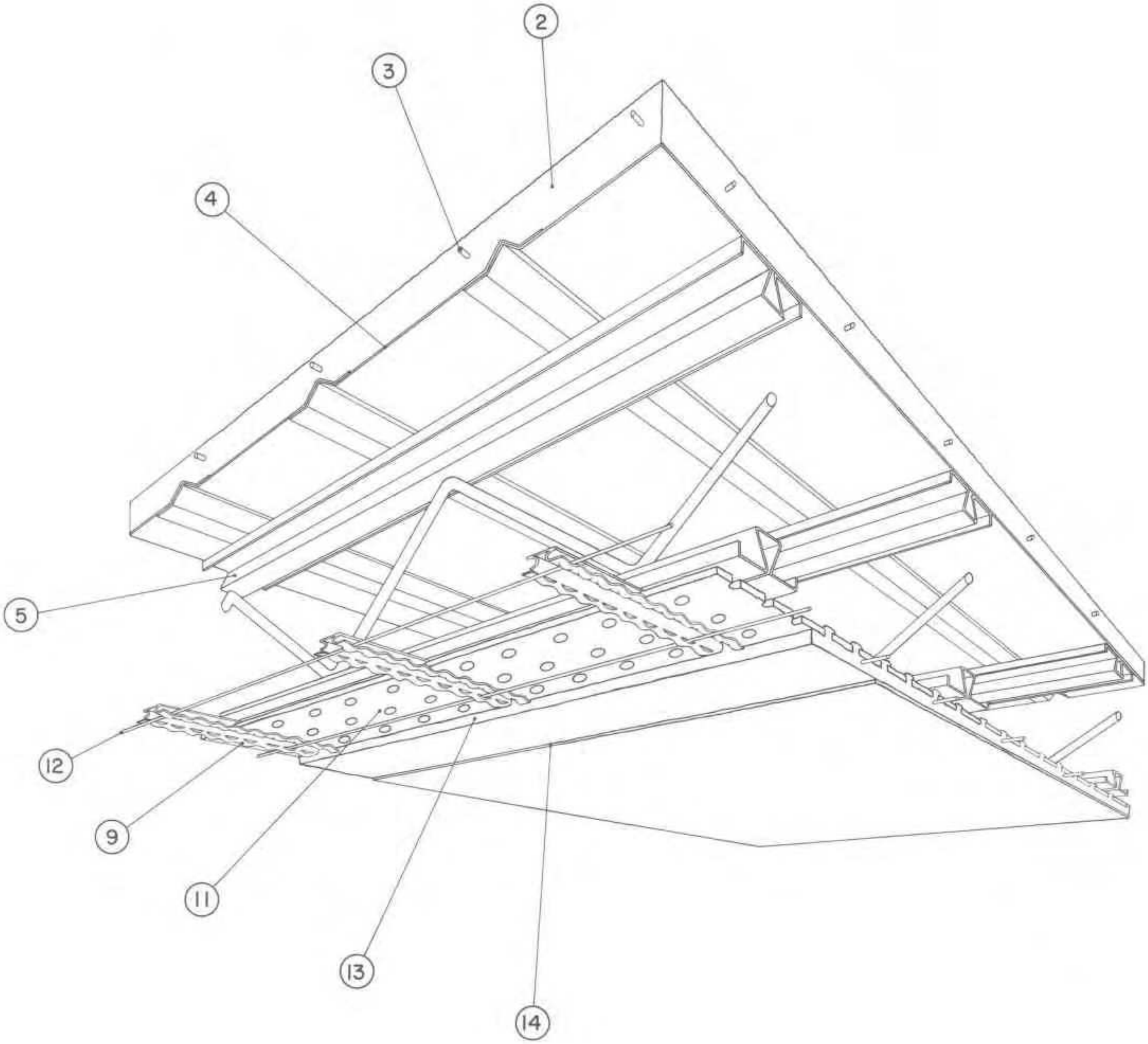
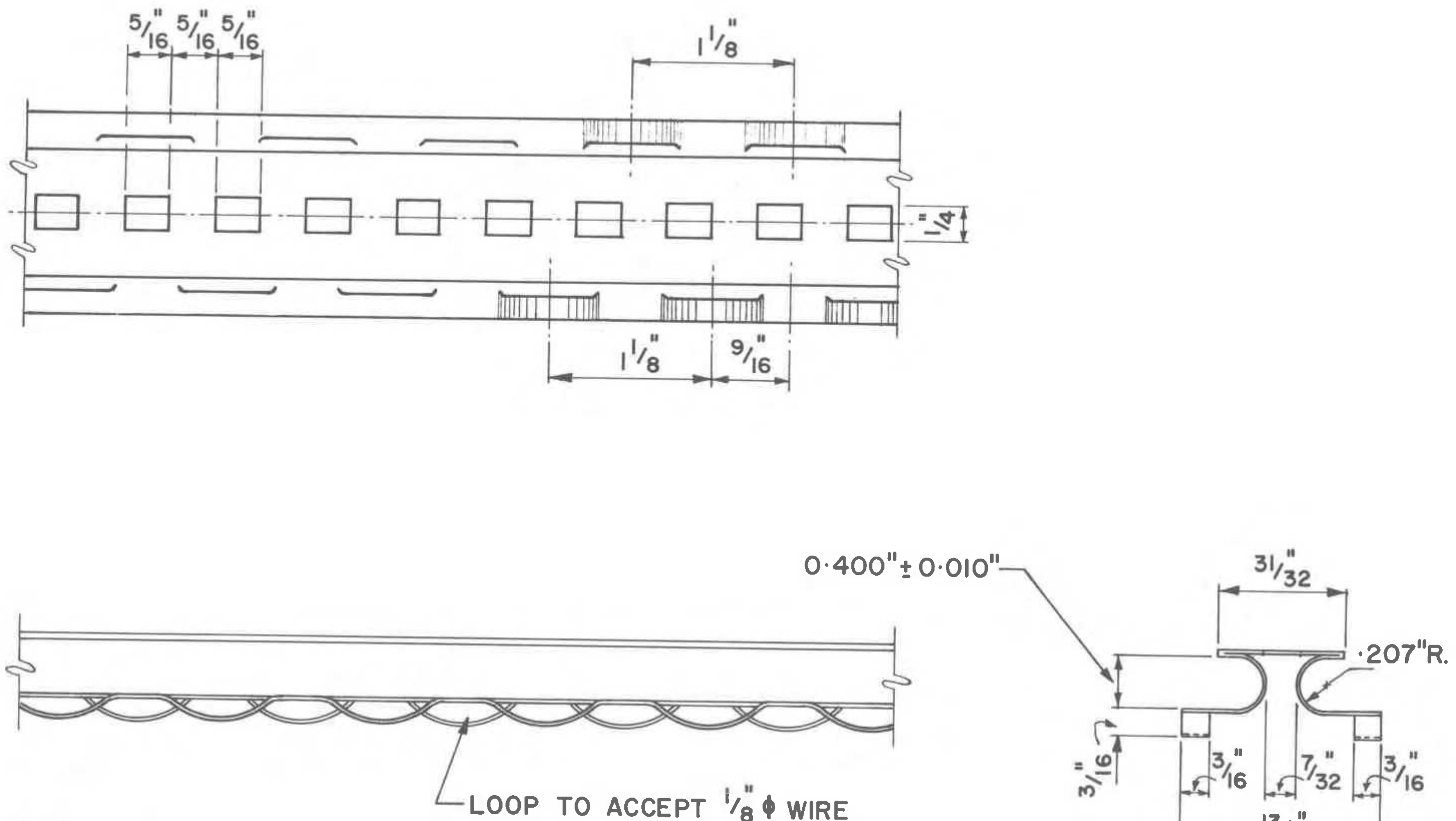


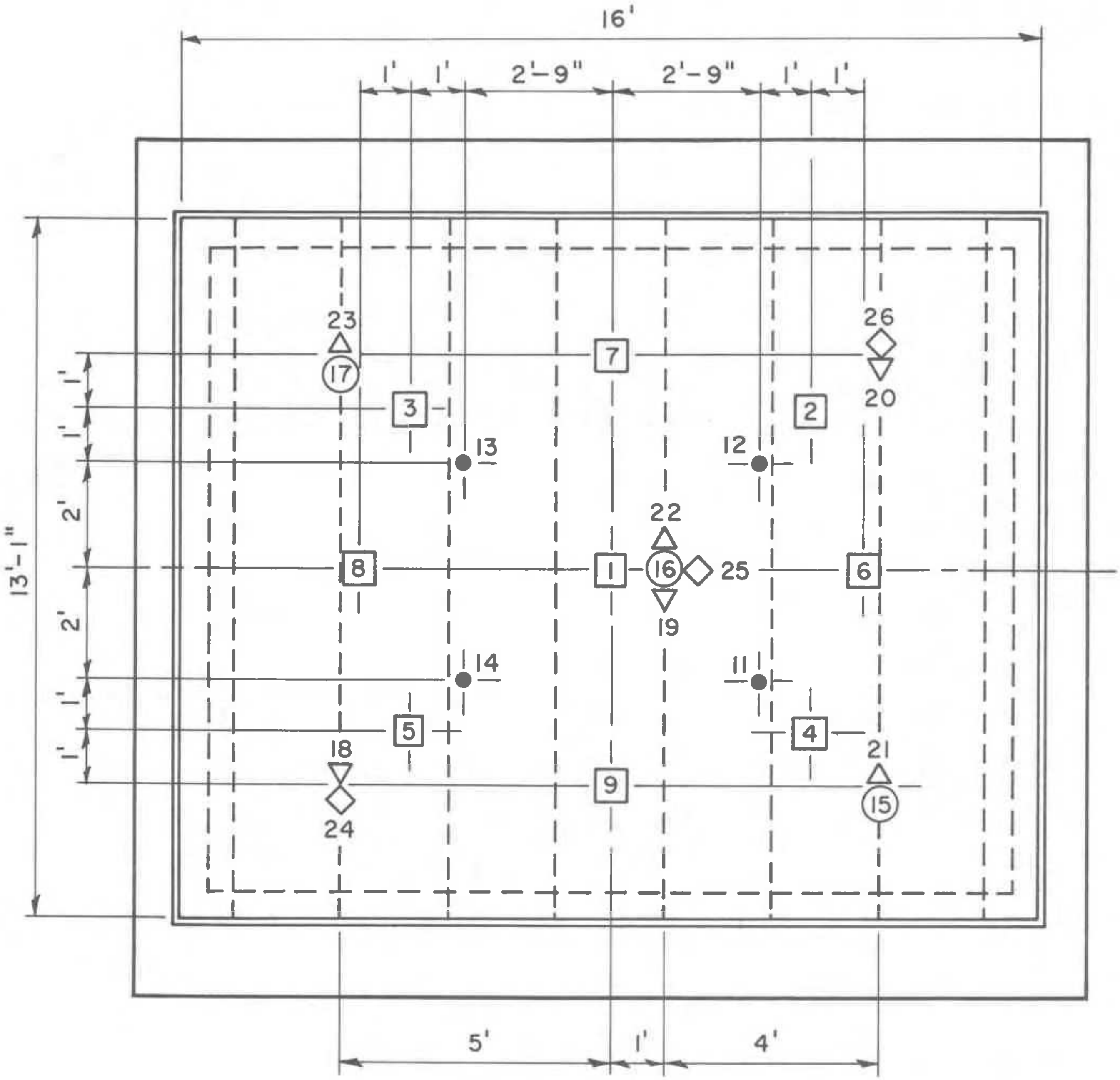
FIGURE 2 PERSPECTIVE OF "TRI-SEAL" FLOOR & CEILING ASSEMBLY



MATERIAL:

25 GA. GALV. STEEL

FIGURE 3 TRI-SEAL LOOP CHANNEL



THERMOCOUPLES ON THE UNEXPOSED SURFACE

2 UNDER STANDARD ASBESTOS PADS

● CEMENTED TO THE SURFACE

THERMOCOUPLES WITHIN THE STRUCTURE

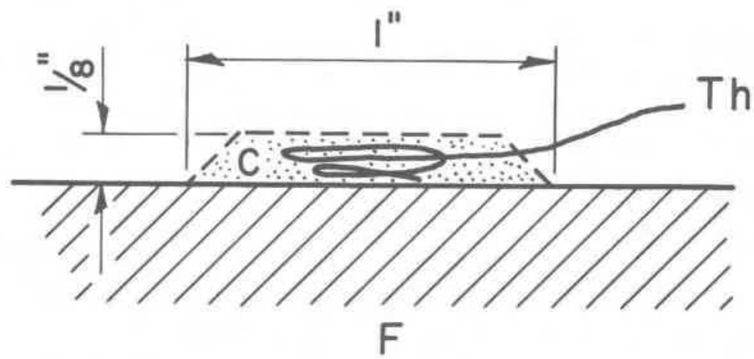
17 ON TOP OF GYPSUM LATH

▽ ON THE BOTTOM CHORD OF STEEL JOISTS

△ ON THE TOP CHORD OF STEEL JOISTS

◇ ON TOP OF METAL FLOOR FORMS

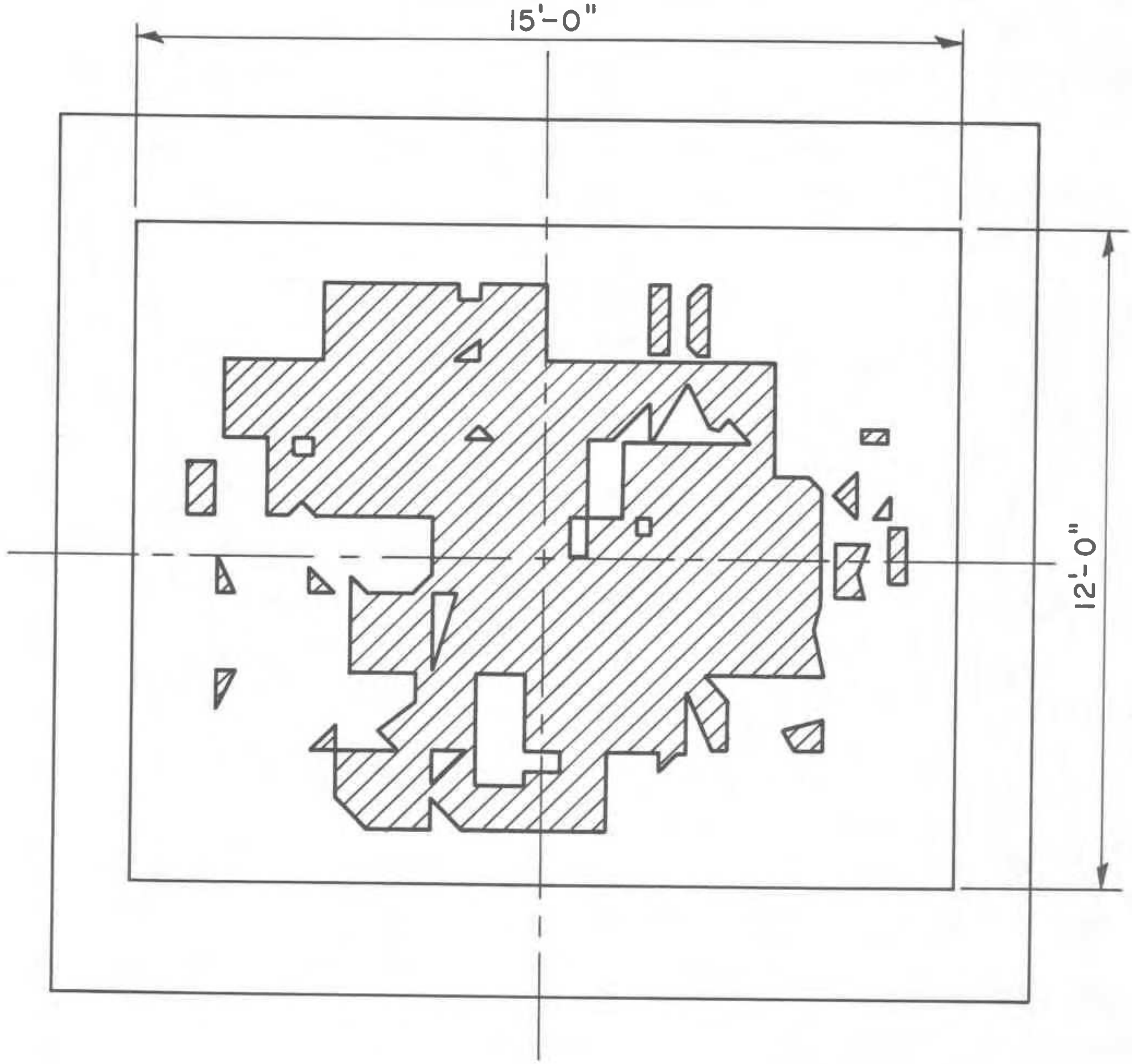
FIGURE 4 - LAYOUT OF THERMOCOUPLES



LEGEND

Th THERMOCOUPLE WIRES
F FLOOR
C CEMENT

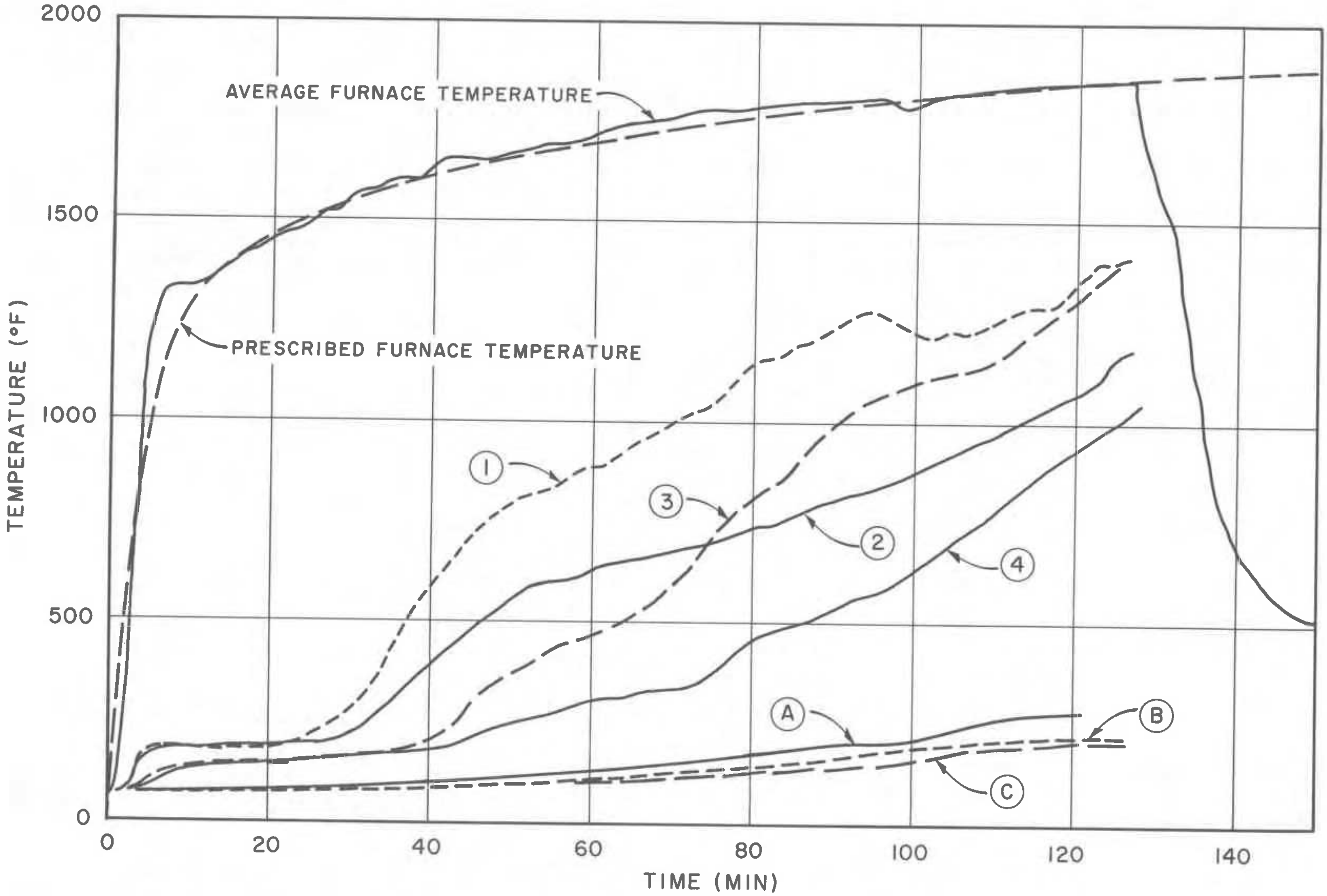
FIGURE 5
NON-STANDARD UNEXPOSED SURFACE THERMOCOUPLES



BOTTOM VIEW

FIGURE 6

THE STATE OF THE CEILING AFTER FIRE TEST
(DISINTEGRATED PORTIONS CROSS HATCHED)



TEMPERATURES WITHIN THE STRUCTURE

1 AVERAGE NEAR THE GYPSUM LATH, NEAR THE CENTRE
2 AVERAGE NEAR THE GYPSUM LATH, FAR FROM THE CENTRE
3 AVERAGE NEAR THE CONCRETE SLAB, NEAR THE CENTRE
4 AVERAGE NEAR THE CONCRETE SLAB, FAR FROM CENTRE

TEMPERATURES ON THE UNEXPOSED SURFACE

A MAXIMUM OBTAINED BY STANDARD METHOD
B AVERAGE OBTAINED BY STANDARD METHOD
C AVERAGE OBTAINED BY METHOD SHOWN IN FIGURE 5

FIGURE 7 – TEMPERATURE MEASUREMENTS DURING FIRE TEST

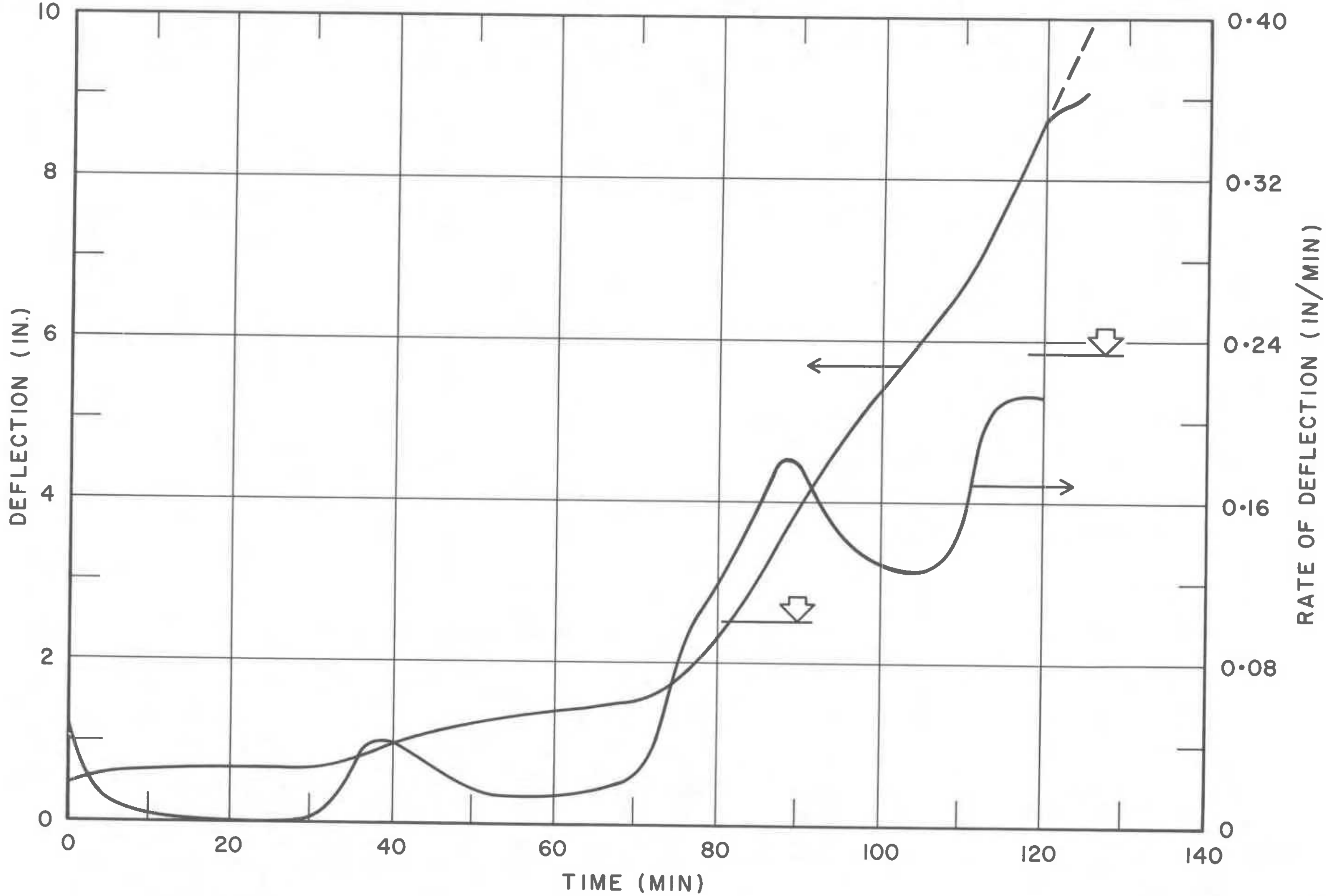


FIGURE 8
CENTRAL DEFLECTION AND RATE OF DEFLECTION DURING FIRE TEST

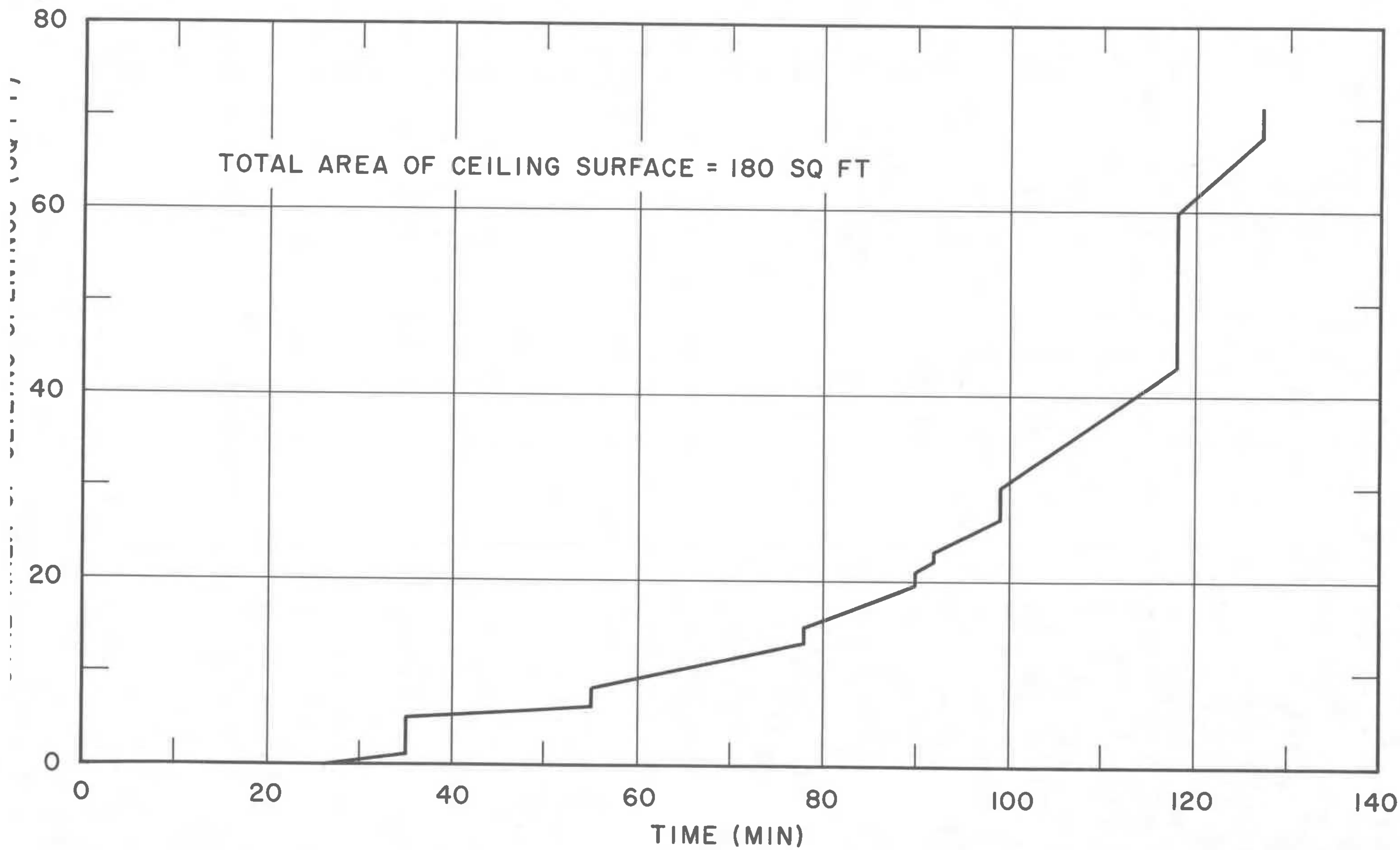


FIGURE 9
DISINTEGRATION OF THE CEILING DURING THE FIRE TEST

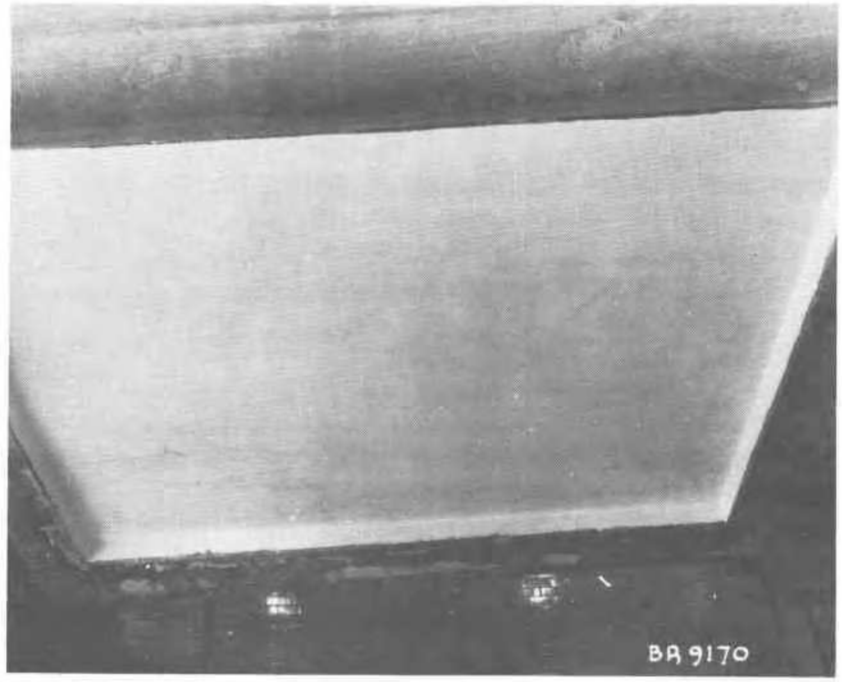


Figure 10 Plastered surface of the ceiling before the fire test

Figure 11 Development of cracks on the unexposed surface

Figure 12 The specimen after the fire test