NBSIR 73-135

Fire Endurance Tests of Steel Sandwich Panel Exterior Wall and Roof/Ceiling Constructions

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Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
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Final Report

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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by

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ABSTRACT

As part of the evaluation of a housing system proposed under Operation BREAKTHROUGH, fire endurance tests were performed at the National Bureau of Standards on an exterior wall assembly and a roof/ceiling assembly. Both constructions were assemblies of sandwich panels composed of paper honeycomb core with sheet steel facings.

The test method was in accordance with the requirements of ASTM E 119, Standard Methods of Fire Tests of Building Construction and Materials, for loadbearing structures. The applied live load was 237 pounds per linear foot (plf) for the wall assembly and 28.6 pounds per square foot (psf) on a 13 ft 5 in. span for the roof/ceiling assembly. The results of these tests are valid only for walls and roof/ceilings of such constructions described in this report and loaded at or below the stress levels developed by these loadings.

The fire endurance of the wall assembly was 7 minutes 50 seconds; and of the roof/ceiling, 9 minutes 09 seconds. In both cases, the failure was due to maximum temperature rise of 181°C (325°F) above the initial temperature on the unexposed surface.

Key Words: Exterior wall; fire endurance; fire test; housing systems; Operation BREAKTHROUGH; paper honeycomb; roof/ceiling assembly; structural sandwich panel

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1.0 INTRODUCTION

A loadbearing sandwich panel exterior wall assembly and a similarly constructed roof/ceiling assembly both designed for single family housing were submitted for fire endurance testing at the National Bureau of Standards. The work was sponsored by the Department of Housing and Urban Development under its Operation BREAKTHROUGH program. The test methods were generally in accordance with the requirements of the Standard Methods of Fire Tests of Building Construction Materials, ASTM E 119[1/].

The test structures consisted of steel-faced panels with paper honeycomb cores with wood tongue-and-groove edging. The constructions were innovative to the extent that the available results from existing fire tests could not be made applicable. Although the heat transmission characteristics of thin steel sheet has been long established, the performance of paper core sandwich panel, especially when partially filled with insulating material, required investigation.

2.0 DESCRIPTION OF TEST STRUCTURES

2.1 General

Both the exterior wall assembly and the roof/ceiling assembly were made of 4 ft wide panels consisting of a 3 in. thick paper honeycomb core partially filled with a solid polyurethane foam, and 26 gage (0.0179 in.) sheet steel facings.

[1/] Standard Methods of Fire Tests of Building Construction and Materials, American Society for Testing and Materials Designation E 119-71, available at 1916 Race St., Philadelphia, Pa. 19103

The paper honeycomb core weighing 99 lbs. per ream (3000 sq ft of sheet stock) had 3/4-in. hexagonal cells. The weight includes an impregnating phenolic resin representing 11 percent of the finished weight of the material. A rigid and friable sheet of polyurethane foam weighing 1.5 lb/ft^3 was pressed into the honeycomb core. An epoxy adhesive bonded the honeycomb core to the steel facing sheets. The steel sheets were galvanized, phosphatized and finished on exterior surfaces with a baked on silicon paint.

The long sides of each panel were closed with tongue-and-groove wood edge pieces and the short sides with nominal 2 x 4 in. wood edge pieces, which were attached to the steel sheets with 14 gage (0.08 in.) 5/8-in. leg staples at 12 in. centers for the wall assembly and at 15 in. centers for the roof/ceiling assembly. The wood members were hemlock-fir, No. 2 structural grade (West Coast Rules)[2/].

2.2 Wall Assembly

The 16 ft wide 8 ft high wall assembly consisted of four 4 ft wide by 8 ft high panels. The wall test specimen and construction details are illustrated in Figures 1-a and 1-b. The panel joints consisted of the tongue-and-groove wood edge pieces which were milled from nominal 2 by 4 in. stock. The solid polyurethane filling in the honeycomb core was 1-1/2 in. thick. Joint sealants were formed of butyl sealant 1/4 x 1/4 in. tape on the unexposed side, and vinyl 1/16 x 3/8 in. tape on the fire exposed surface (Figure 1-b).

2/ West Coast Rules, available from Western Wood Products Association, 1500 Yeon Building, Portland, Oregon 97204

Galvanized steel angles, 2-1/2 in. by 2-1/2 in., 11 gage (0.1196 in.) were attached to the panels at the bottom of the exposed side and the top of the unexposed side with 1/4 by 2-1/2 in. lag screws. The top edge of the exposed side was trimmed with galvanized sheet metal angles, 1-1/8 by 1-3/8 in., 26 gage (0.0179 in.), attached with No. 6 sheet metal screws on 24 in. centers. Grooves in the wood top and bottom edges of the unexposed side were filled with 1/4 in. butyl sealant tape (Figure 1-a).

2.3 Roof/Ceiling Assembly

The 17 ft wide 13 ft 5 in. long roof/ceiling assembly consisted of four 4 ft wide 13 ft 5 in. long panels and one 1 ft 10 in. wide 13 ft 5 in. long panel. Although similar in construction, the roof/ceiling assembly differed from that of the wall principally in the size of the wood edge closures, the thickness of the polyurethane foam, and the closing of the joints between panels. The floor/ceiling specimen and construction details are shown in Figures 2-a and 2-b.

As can be seen in the illustrations, the vertical long edge closures were 5-1/4 in. overall height, forming a double tongue-and-groove joint. The design calls for the exterior steel facing sheet to be bent up at the wood blocks. A sheet metal cap over the joint and overlapping the vertically up turned edges of the steel sheet formed a weather seal, which was augmented with butyl and vinyl tapes. In this assembly, the polyurethane foam in the honeycomb core was 2-1/4 in. thick.

The photograph in Figure 3 show a typical joint on the underside (fire exposed side) of the completed floor/ceiling test specimen.

3.0 TEST METHOD AND EQUIPMENT

The tests of both the wall and the roof/ceiling assemblies were made generally in accordance with the requirements of ASTM E 119, which provides that one side of a wall or the underside of a roof structure be exposed to a fire controlled to conform as closely as possible to a time-temperature curve specified in ASTM E 119.

The specimens were installed in furnaces suitable for testing each type of assembly. Temperatures in both the wall testing and roof testing furnaces were determined from the readings of 12 thermocouples in each, mounted in iron pipes and symmetrically distributed in the furnace chamber.

A total of 12 thermocouples was applied to the unexposed surface of the wall, four on joints and eight at locations away from the joints between the panels, at the center of the core and under each of the two facing sheets (disposition indicated in Figure 1-a).

For the roof/ceiling assembly, 18 thermocouples were used, two on joints and 10 away from the joints on the unexposed surface. and six within two of the panels at three different levels. (See Figure 2-a.)

All thermocouples on the unexposed surface of the test specimens were covered with 5 in. by 6 in. by 0.4 in. thick felted asbestos pads. Temperature readings indicated by thermocouples in the furnace, on the unexposed surface, and inside the panels were recorded at one minute intervals by a data logger and were later processed and plotted by computer.

A lateral deflection reference wire was stretched horizontally 4 1/4 in. from the unexposed surface of the wall at the specimen center

height. The distance from the wire to the unexposed surface of the specimen was measured at the mid-point of each of the four panels periodically during the test with a ruled gage.

Deflections of the roof/ceiling assembly were measured at four points along the longitudinal center line: at the center, both quarter points, and at the joint nearest the center. Wires with measuring riders fixed to pass before a vertical scale were attached at the reference points and also passed over pulleys connected to linear deflection potentiometers.

A calculated load of 237 plf was applied to the wall specimen through four hydraulic jacks 5 min. before the test started. The loading represented the weight of the roof (30 plf) and the roof live load (207 plf) Figure 4 shows the unexposed surface of the wall, the thermocouple connections and the loading equipment with the test frame in place as a wall of the panel testing furnace.

Seven minutes prior to the test a load of 31.6 psf (28.6 psf live load + 3 psf dead load) was applied approximately uniformly through 36 channels (2 ft x 5 in. x 1/4 in. thick) of the loading rig on the roof/ceiling assembly. The unexposed surface of the roof/ceiling assembly with the loading rig in place may be seen in Figure 5. The 28.6 psf load produces the same bending moment over a 13 ft 5 in. span as a 40 psf load over a 12 ft span. The loading rig, which supplied 15 psf of the required load, was placed on the specimen a day prior to the test.

4.0 TEST EVALUATION

The fire endurance according to ASTM E 119 of an assembly of either type is determined by the time required to reach the first occurrence of the following failure criteria:

1. Inability to sustain the applied load.
2. Passage of flame or gas through the structure to the unexposed surface hot enough to ignite cotton waste applied at the point of passage.
3. A temperature rise of 139°C (250°F) average, or 181°C (325°F) at one point, above the initial temperature on the unexposed surface.

5.0 RESULTS OF TESTS

A log of test observations is given in Table 1 for the wall test and Table 2 for the roof/ceiling test.

The plotted results of the tests indicated as the average and one-point maximum temperature rises of all the thermocouples on the unexposed surfaces of the assemblies are shown in Figure 6 for the wall assembly and in Figure 7 for the roof/ceiling assembly. The average temperature profile across the wall and roof/ceiling assemblies are shown in Figures 8 and 9, respectively. Movement of the four panel wall assembly from the vertical plane is indicated in Figure 10. Figure 11 shows the deflections of the four measured points on the roof/ceiling.

The severity of the fire exposure in the wall assembly test was slightly below that prescribed by the standard time-temperature curve (Figure 12). According to the standard correction formula in ASTM E 119, based on the comparison of the areas under the actual time-temperature

curve and the standard curve, the fire endurance time was corrected. Similarly, a correction was made in the time to failure observed in the roof/ceiling test to compensate for the somewhat higher than standard furnace severity that occurred in that test (Figure 13).

5.1 Wall Assembly Results

The fire endurance time for the wall was 8 min:25 sec observed, corrected to 7 min:50 sec, with failure by maximum temperature rise of 181°C (325°F) on the unexposed surface. Initial inability to sustain load was observed at 23 min. Flame through occurred at 26 min on a joint between an end panel of the wall and the adjacent panel.

Deflection of the unexposed surface of the wall from its initial vertical plane varied from 1 1/4 in. toward the furnace to 2 1/2 in. away from the furnace chamber.

During the test, smoke appeared in the furnace almost at the beginning of the test, and by 2 min. it was seeping through to the unexposed side of the wall (Figure 14). Buckling of the exposed wall surface was observed at 2 1/2 min. At 5 min the smoke was of sufficient volume and density to largely obscure the surface (Figure 15). Flaming occurred on the exposed joints at 3 1/2 min, with extensive flaming by 8 min (Figure 16).

Figure 17 is a photograph showing the fire side of the panel after it was removed from the furnace just before extinguishment of the fire. Surfaces were buckled and most of the wood members, paper honeycomb, and polyurethane foam were consumed.

5.2 Roof/Ceiling Assembly Results

For the roof/ceiling assembly, the fire endurance time was 9 min:09 sec with failure by maximum temperature rise on the unexposed surface (rise of 325°F or 181°C). This was corrected from 8 min:30 sec observed because of excessive furnace temperatures. Deflections showed a steady increase until the occurrence of a sudden failure to withstand the applied load at 17 min at the joint nearest the center of the specimen (Figures 18 and 19).

Light flaming was observed on the exposed roof/ceiling surface as early as 1 min. after the start of the test. The exposed sheet steel facings began buckling soon thereafter, and by 2 min. there was considerable generation of smoke.

The photographs in Figures 18 and 19 show the unexposed surface of the assembly after the loading rig was removed and the exposed surface at the failed joint, respectively, at the end of the test.

Although most of the wood members and polyurethane foam was consumed during the test and the paper honeycomb was charred and delaminated from the bottom facing, it was not necessary to apply any extinguishment agent after the test. All of the exposed joints had opened up and the failed joint showed the maximum opening of 4-1/4 inch (figure 19) compared with 11/16 inch (Figure 13) before the test.

When the specimen was being demantled 15 hours after the end of the test, some flaming occurred at the east end of the second joint from the north end to a height of several feet (Figure 20).

6.0 DISCUSSION OF RESULTS

Although the wall assembly and the roof/ceiling structure carried their expected service loads, failure in both cases occurred by the attainment of the limiting average temperature rise on the unexposed surface.

The load applied to the wall was 237 plf and the results of this test are applicable to such a structure loaded to develop a stress in the structural members not exceeding that developed in the structure tested. Similarly, the results of the roof/ceiling assembly are applicable to such a structure loaded to develop a bending moment in the structural members not exceeding the equivalent of 40 psf over a 12 ft span.

Table I - Log of Wall Test Observations

Time Min:Sec	Observations
0:00	Start of test.
2:00	Smoke appearing on top of the unexposed side of the panel. (Figure 14.) Cracking sound from back of the specimen.
2:30	Exposed surface buckling.
3:30	Flames observed on the joints of the exposed surface.
4:00	Much black smoke filling the furnace.
5:00	Much gray dense smoke appearing on the unexposed side through joints and at the hole at the bottom of the second panel from the north end where the internal thermocouples came out. (Figure 15).
6:00	Smoke seemed to clear up.
8:00	All joints on the exposed surface flaming severely. (Figure 16 is a photograph taken through observations window.)
9:00	The color of the unexposed surface appearing to change from light buff to brown. An average temperature rise of 139°C above its initial temperature on the unexposed surface was observed.
16:00	Cotton waste, applied on the joint opening of the unexposed surface, was not ignited.
23:00	Load failure.
23:30	Gas off. (END OF TEST).
26:00	Flame through on the third joint from the north end.

Table II - Log of Roof/Ceiling Test Observations

Time Min:Sec	Observations
0:00	Start of test.
0:30	Severe cracking sound from underside of the specimen.
1:00	Light flaming on the exposed surface.
1:30	Sheet metal on exposed surface buckling.
2:00	Much smoke observed all around furnace.
3:00	Dense gray smoke puffing out through the hole where the internal thermocouple leads ran out.
8:00	Smoke seemed to clear up. About 4 inch deflection observed at center of the panel.
17:00	Load failure near center of second joint from the north end.
	Gas off.
	(END OF TEST)

NOTE:
Fifteen hours after the end of the test, the specimen, when it was dismantled, burst into flame at the east end of the second joint from the north end. The height of flame was approximately 3 ft. (See Figure 20.)

APPENDIX I

SI Conversion Units

In view of present accepted practice in this country in this technological area, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measurements which gave official status to the metric SI system of units in 1960, we assist readings interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter
1 ft = 0.3048 meter

Mass

1 pound = 0.45 kilograms

Force

1 kip = 4448 newton

Stress

1 psf = 47.88 newton/meters^2

Temperature

Temperature in °F = 9/5 (Temperature in °C) + 32°F

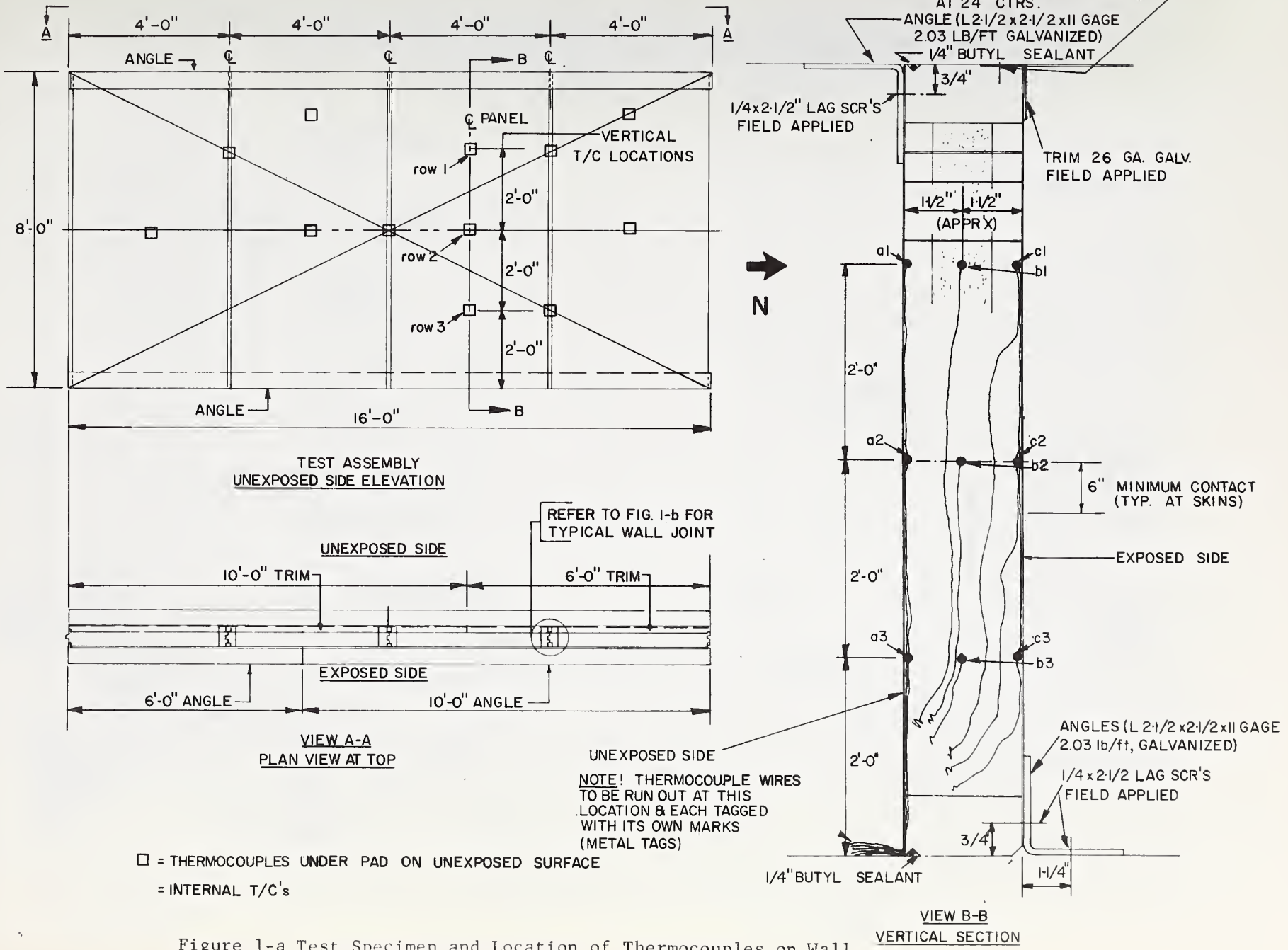

Figure 1-a Test Specimen and Location of Thermocouples on Wall Assembly.

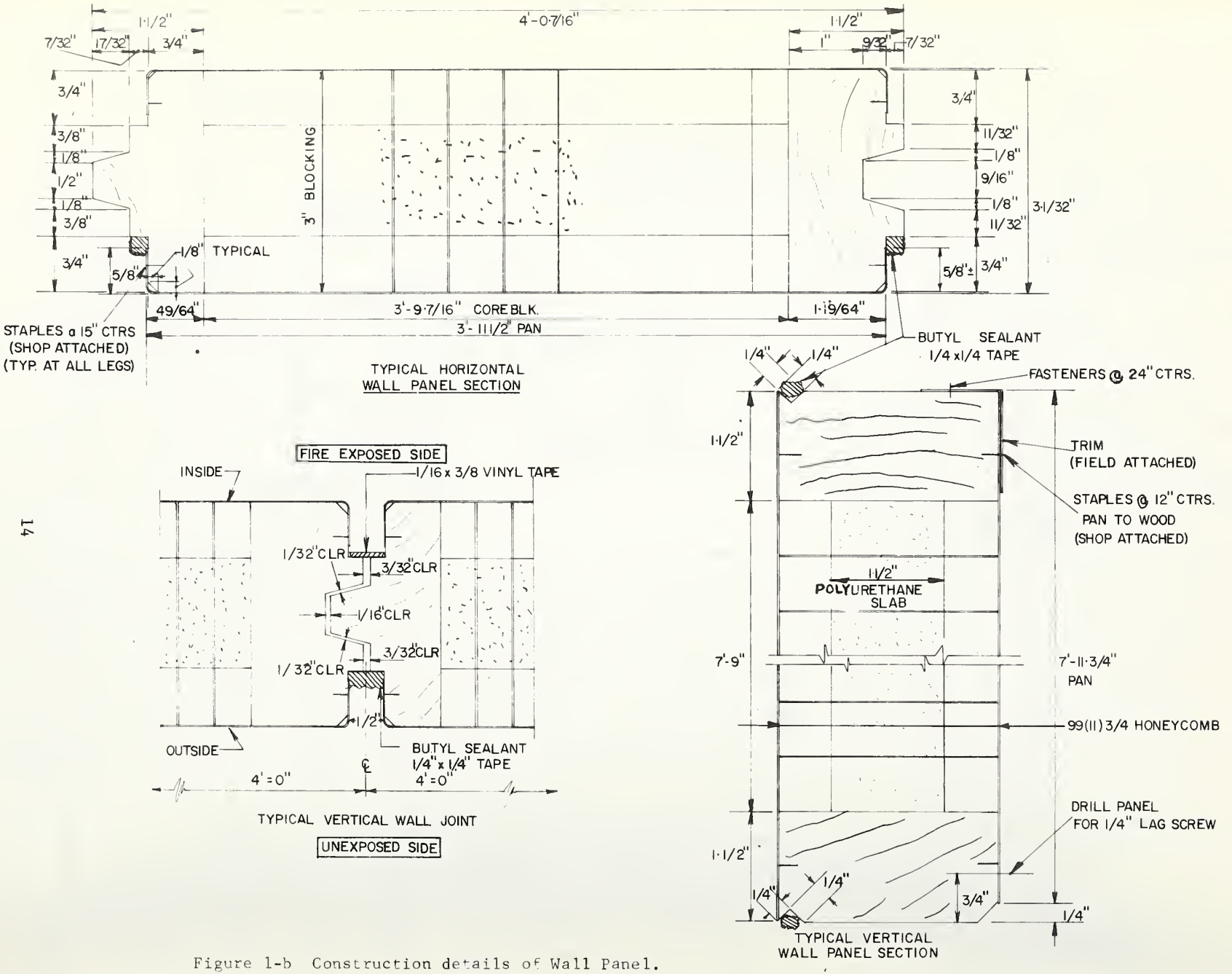

Figure 1-b Construction details of Wall Panel.

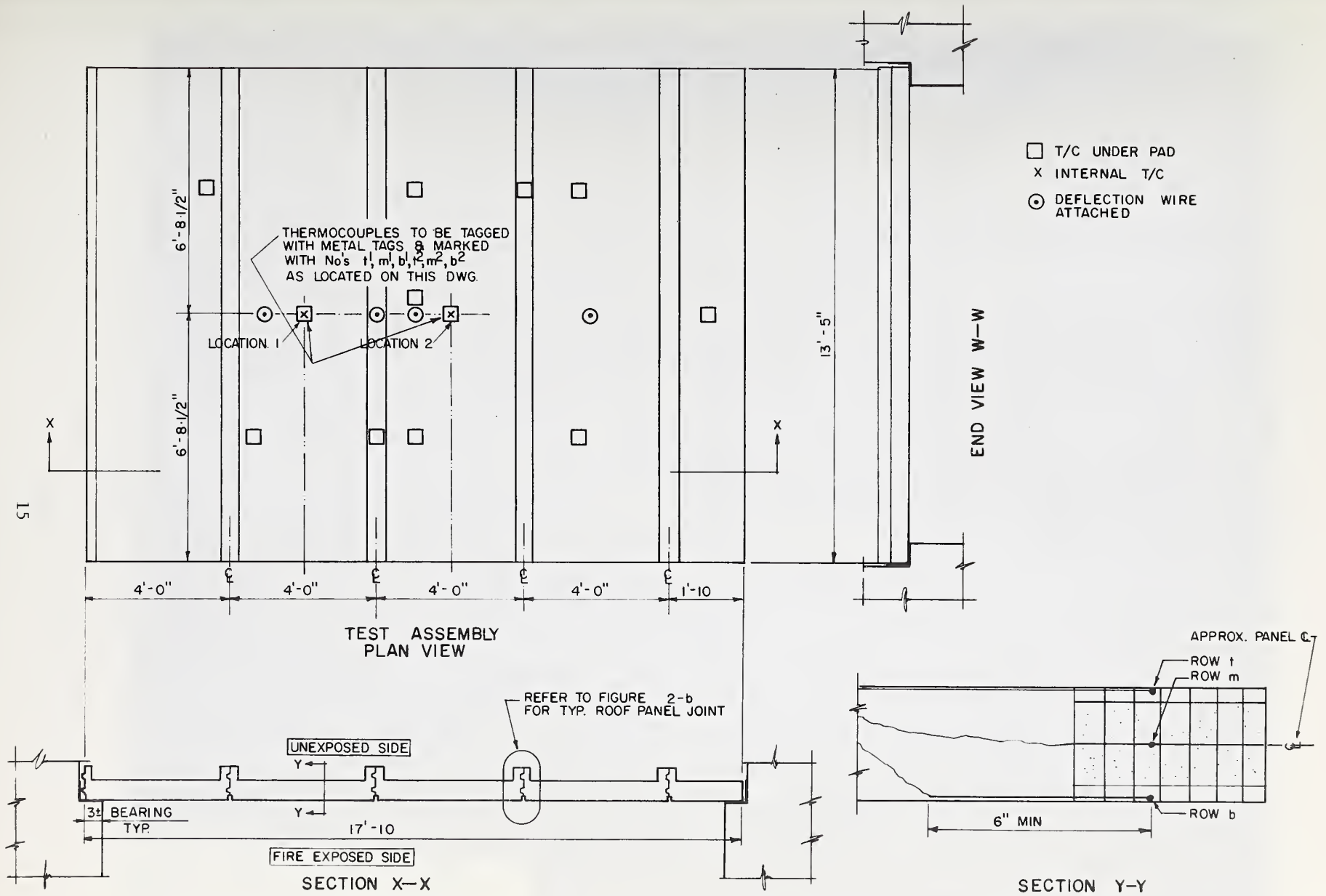

Figure 2-a Test Specimen and Location of thermocouples on Roof/Ceiling Assembly.

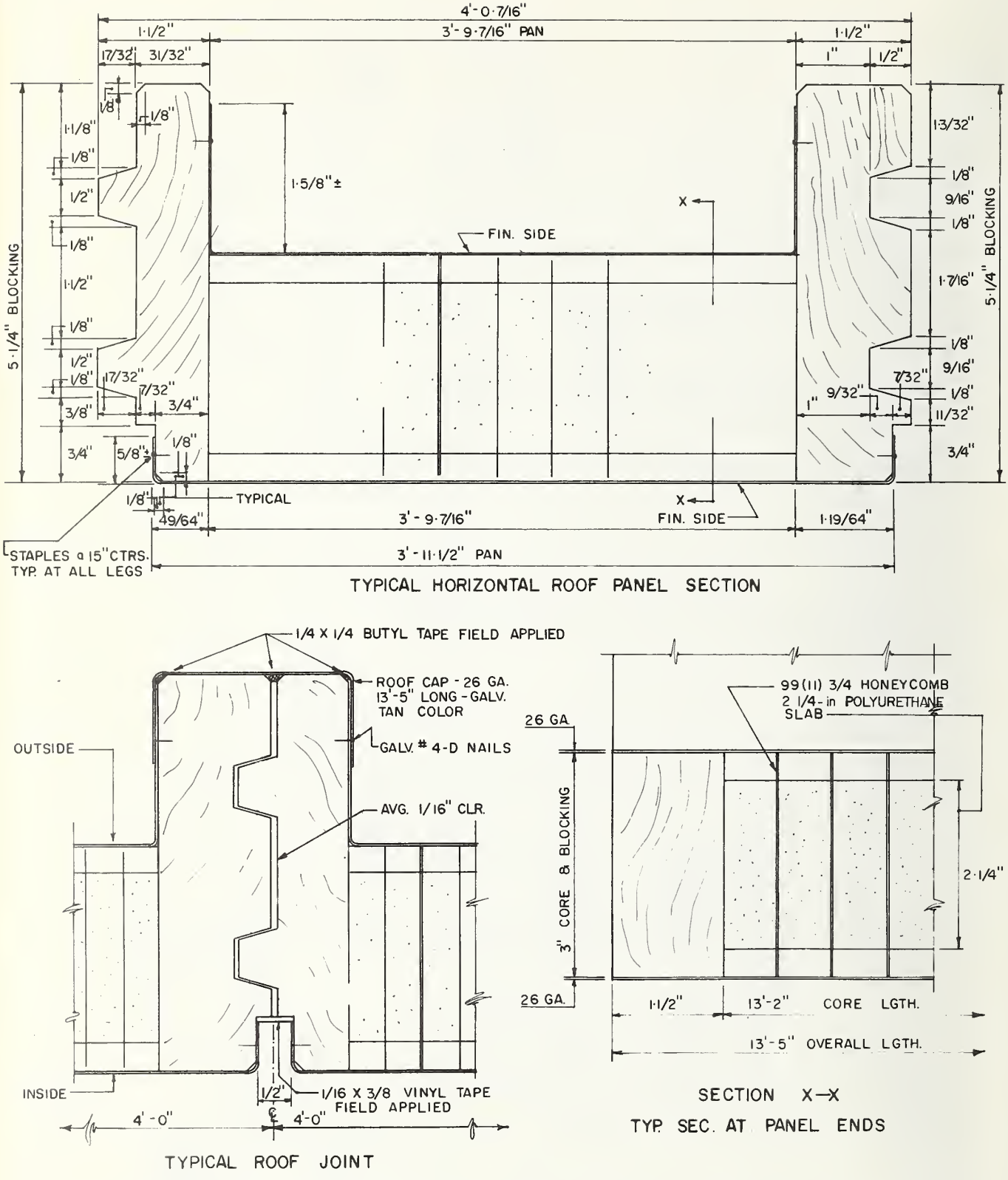

Figure 2-b Construction details of Roof/Ceiling panel.

Figure 3. Second joint from the north end on the exposed side before the test (roof/ceiling assembly).

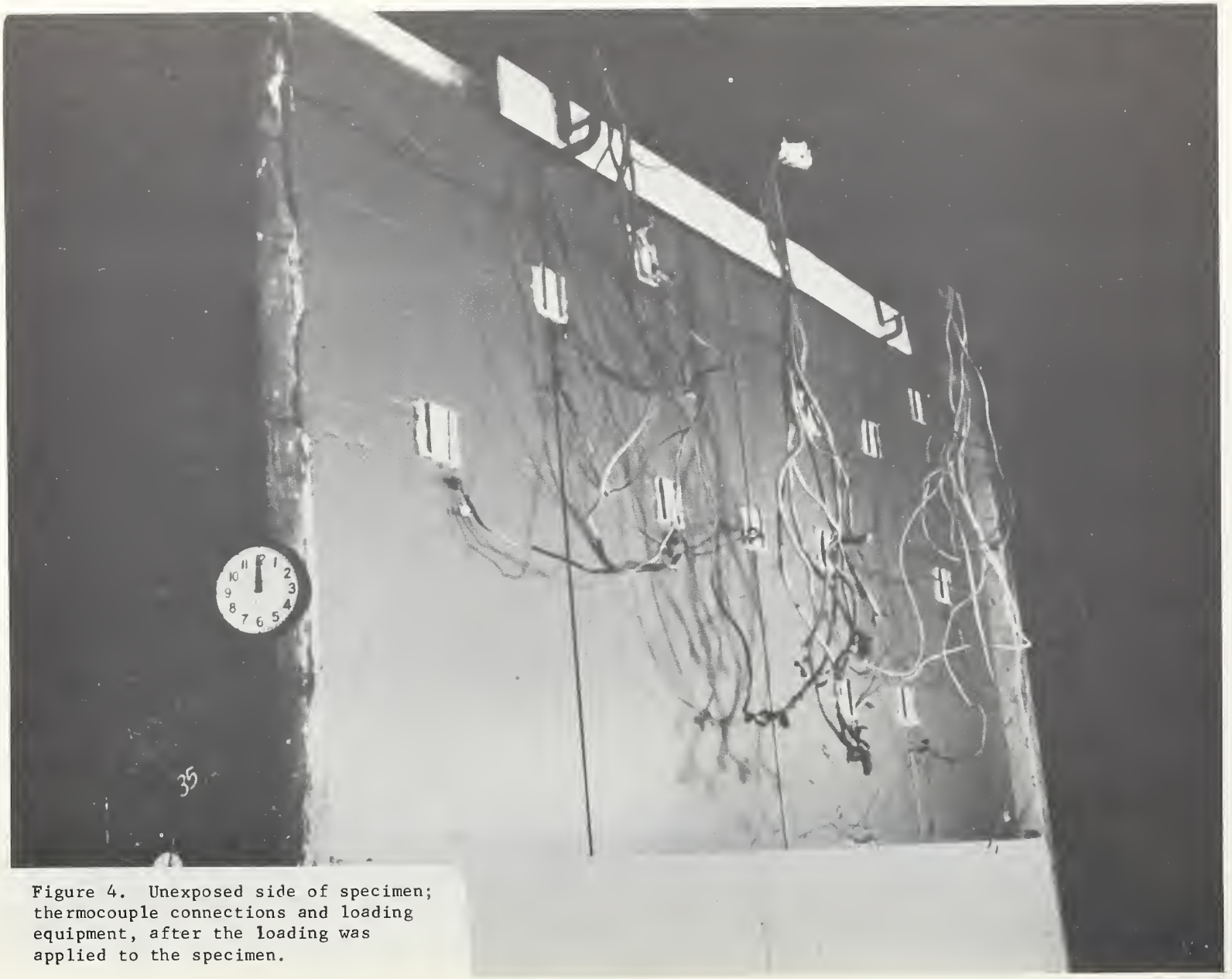

Figure 4. Unexposed side of specimen; thermocouple connections and loading equipment, after the loading was applied to the specimen.

Figure 5. The unexposed surface of the roof/ceiling assembly with the loading rig in place. (After load failure).

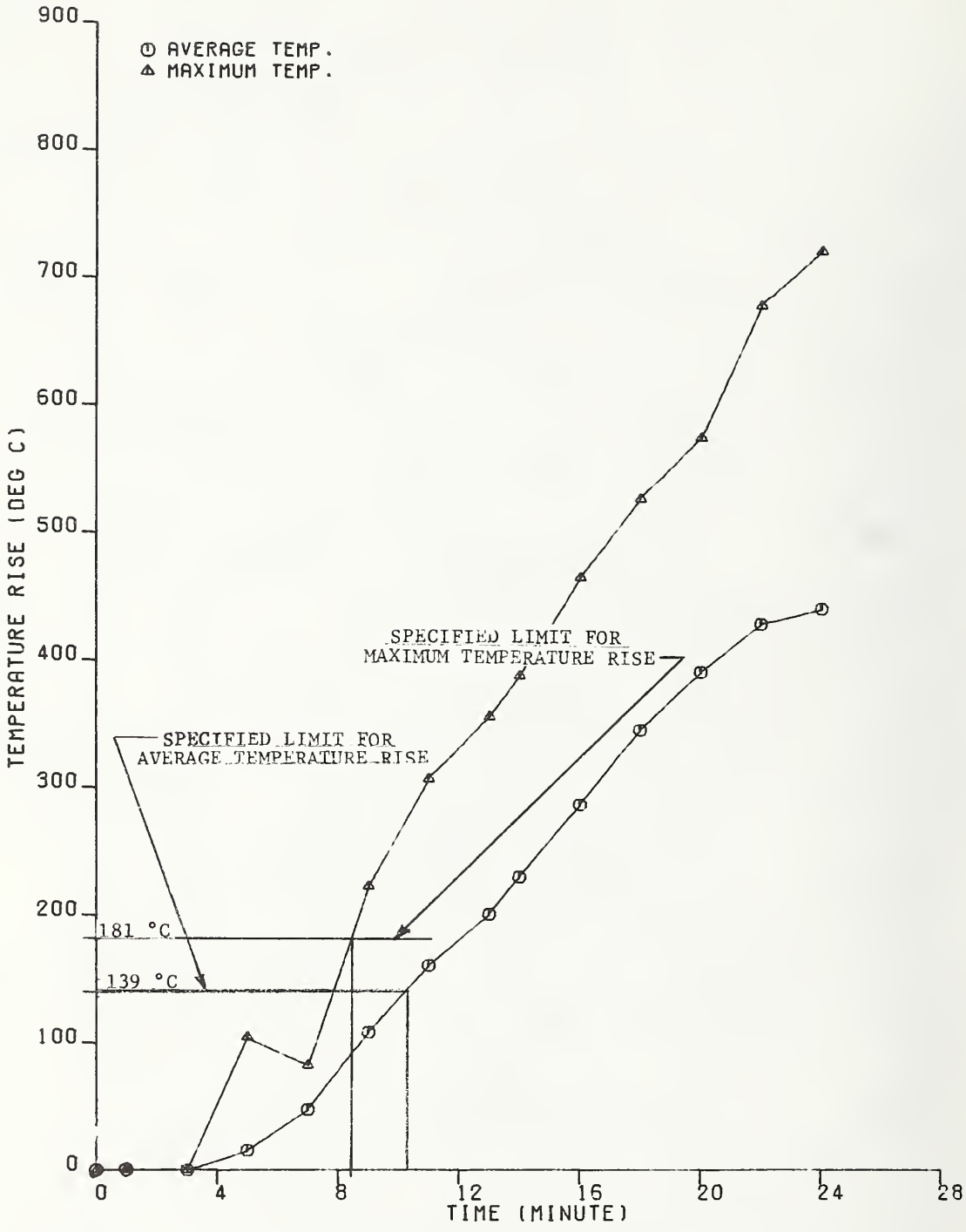

Figure 6.

MAXIMUM AND AVERAGE SURFACE TEMPERATURE Roof/Ceiling Assembly

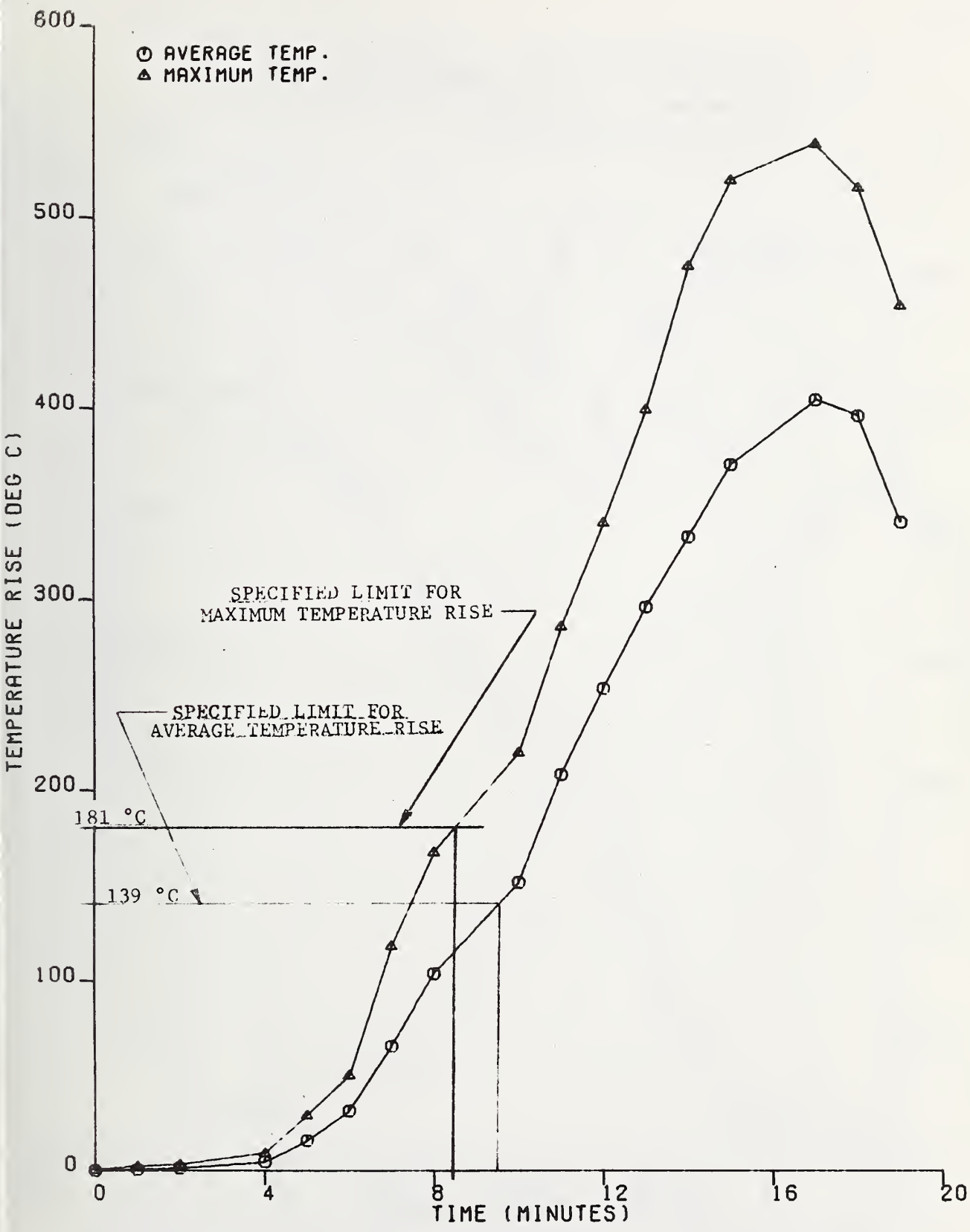

Figure 7.

MAXIMUM AND AVERAGE SURFACE TEMPERATURE RISE-Wall Assembly

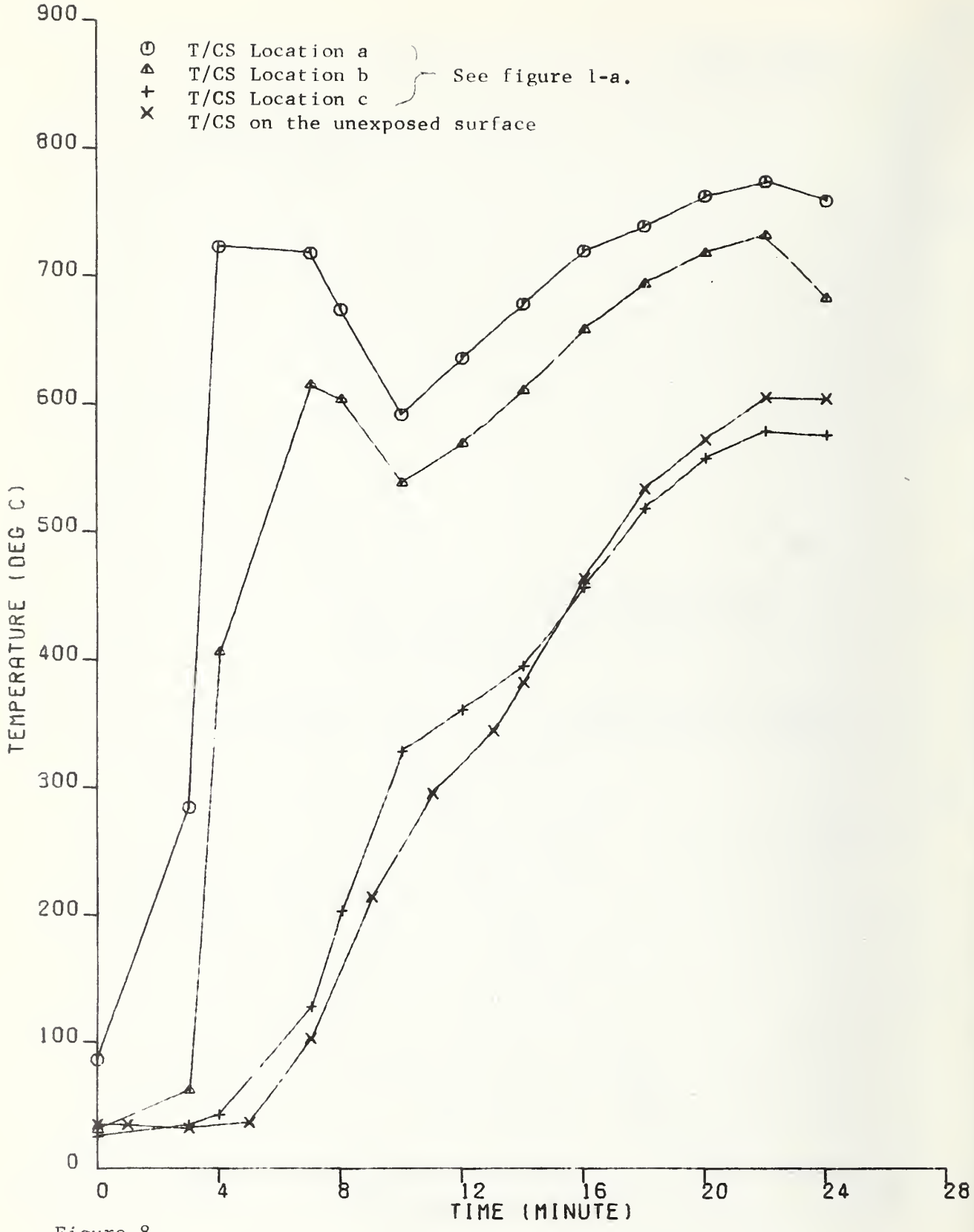

Figure 8

TEMPERATURE GRADIENT ACROSS THE WALL PANEL (TEST 489)

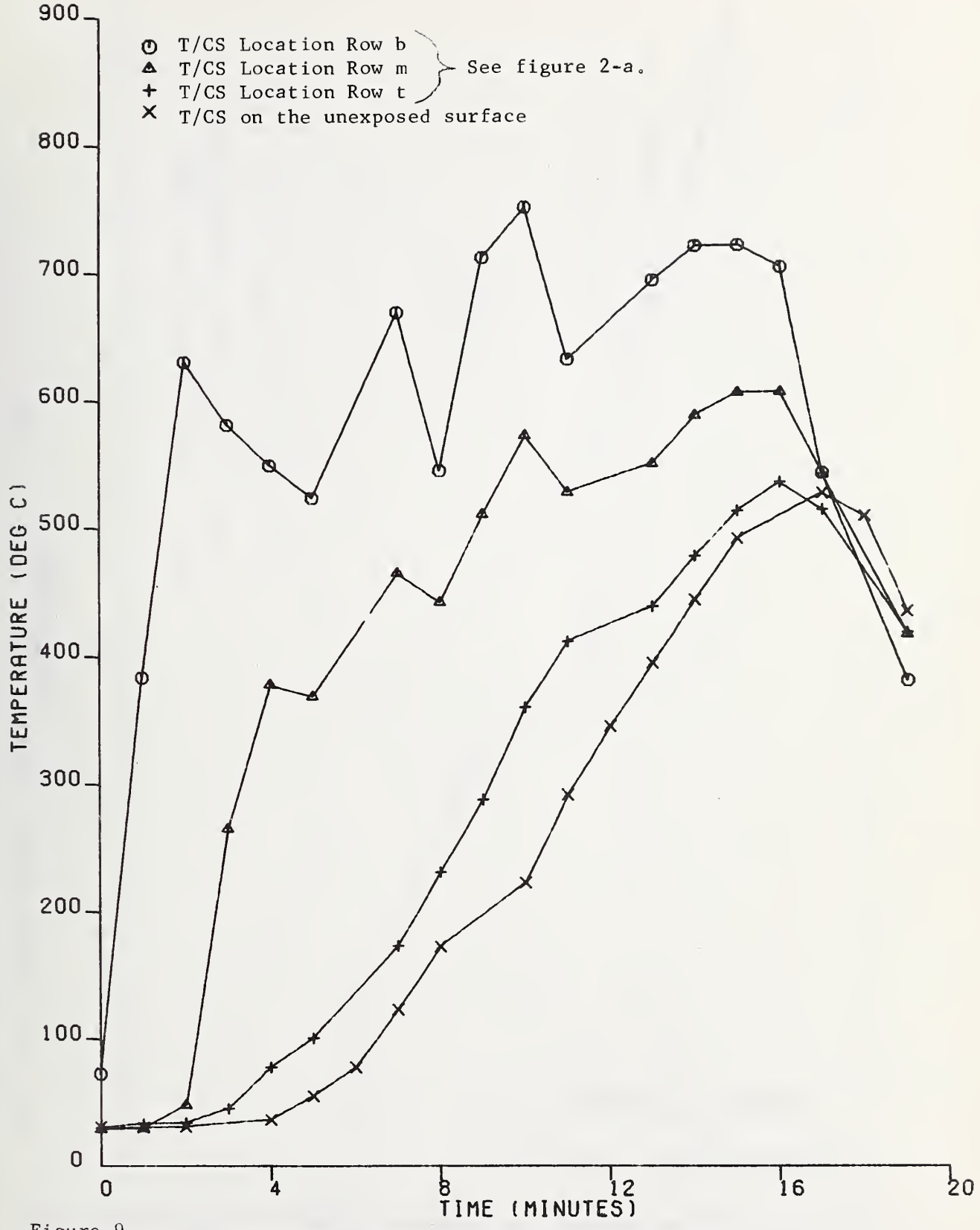

Figure 9.
TEMPERATURE GRADIENT ACROSS THE FLOOR/CEILING ASSEMBLY (TEST 490)

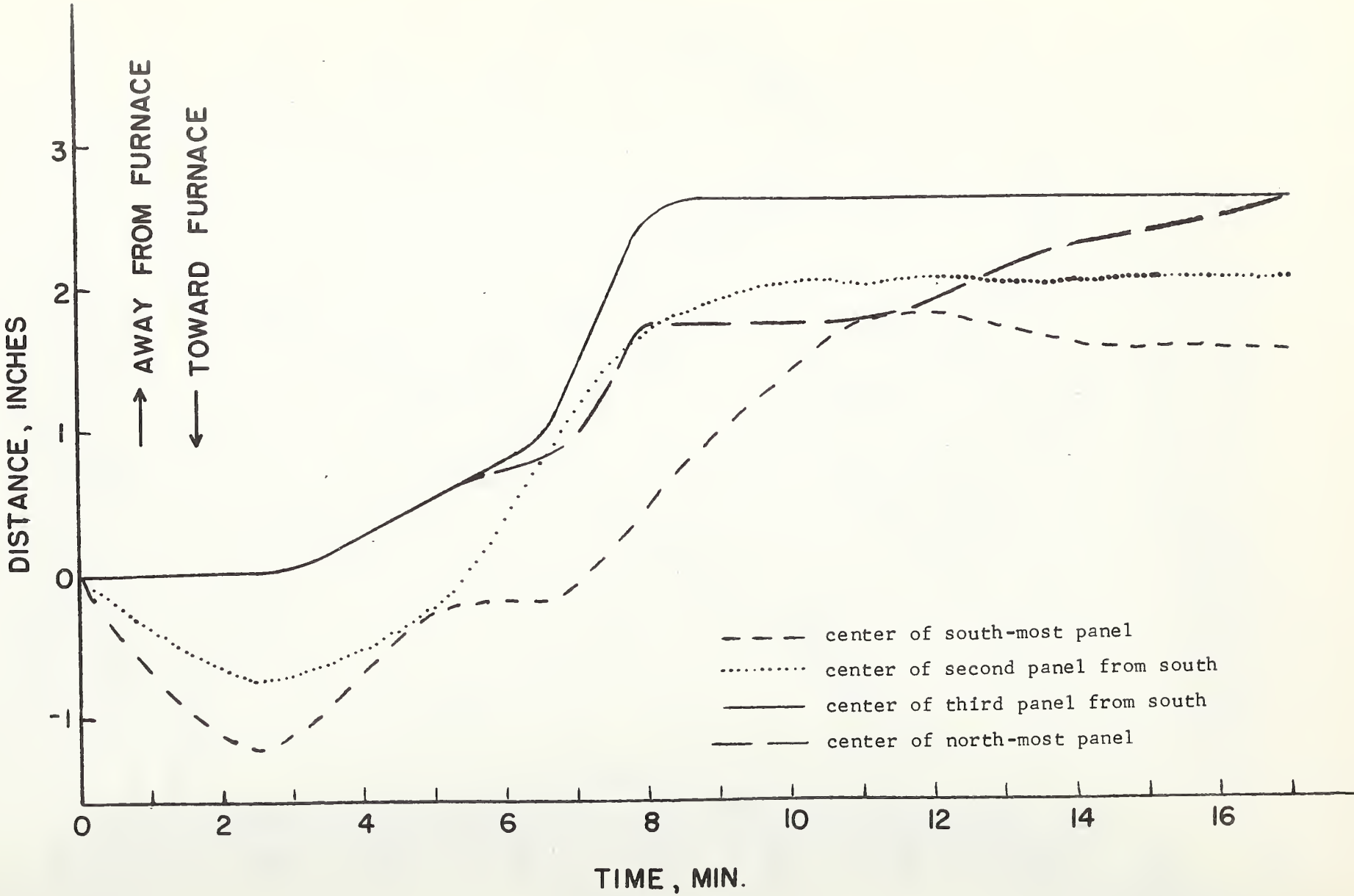

Figure 10. DEFLECTIONS ON THE UNEXPOSED SURFACE, WALL ASSEMBLY.

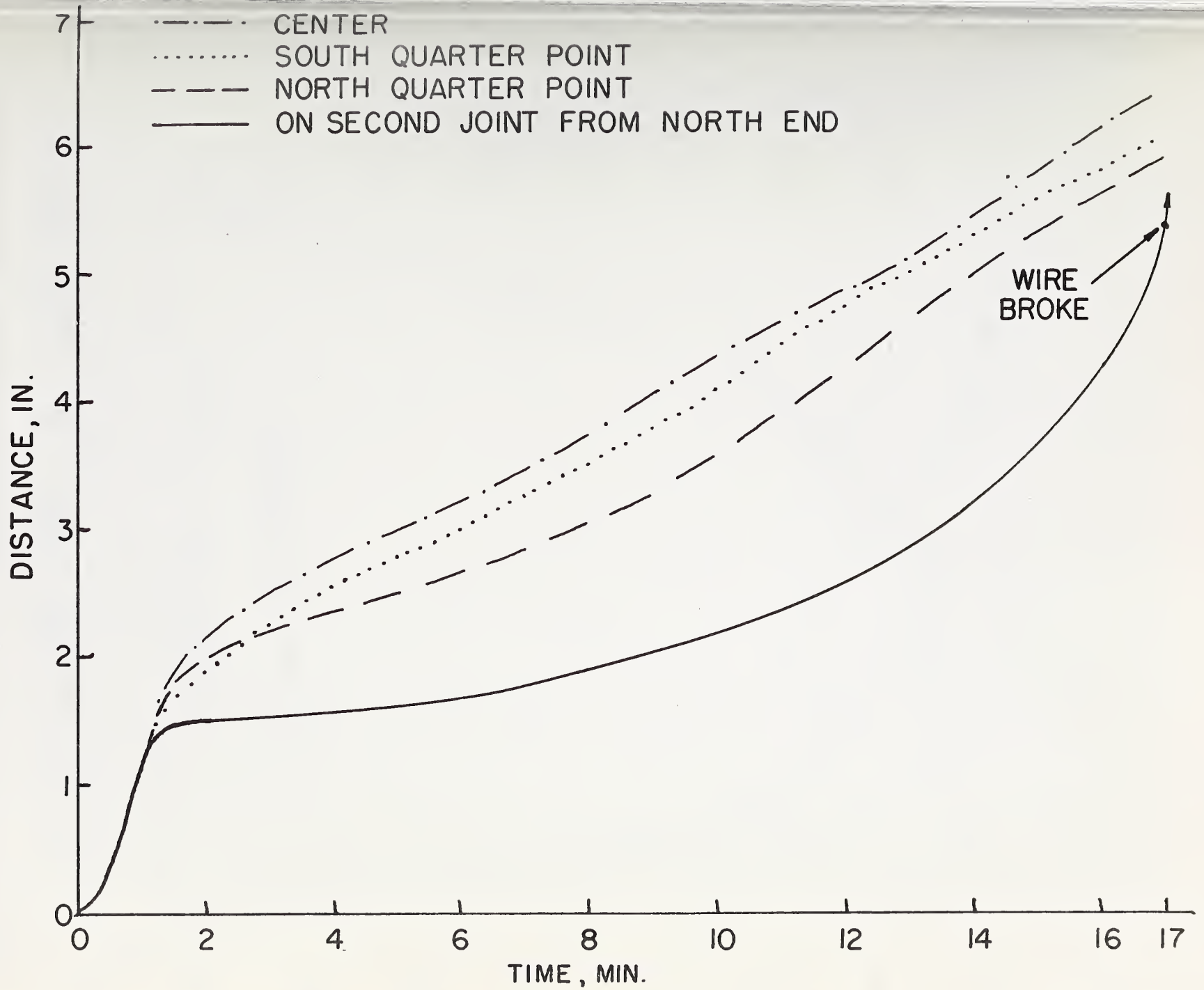

Figure 11. DEFLECTIONS OF THE 4 POINTS ON THE UNEXPOSED SURFACE. ROOF/CEILING ASSEMBLY.

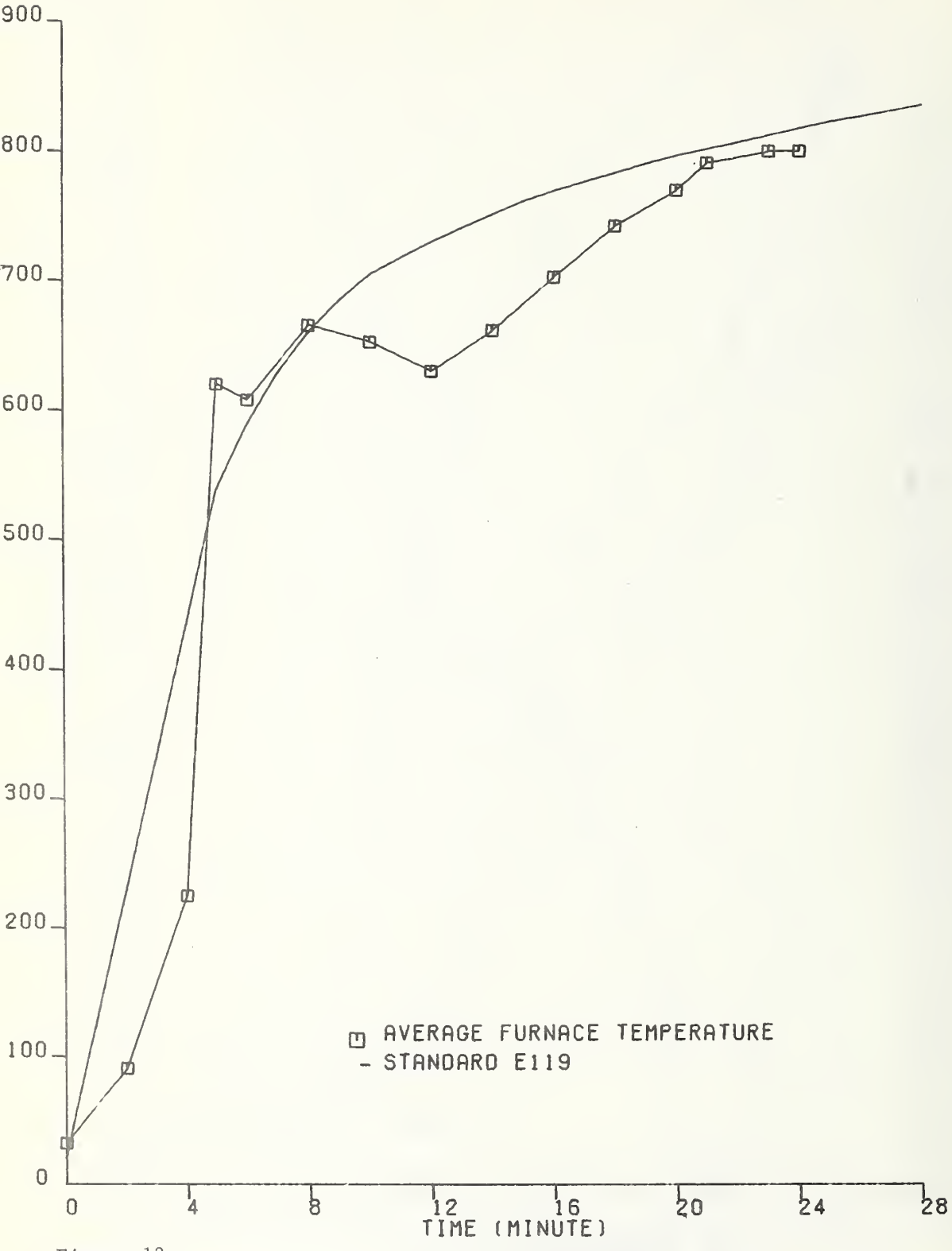

Figure 12.

AVERAGE FURNACE TEMPERATURE FOR WALL TEST COMPARED WITH STANDARD E119 TIME-TEMPERATURE CURVE

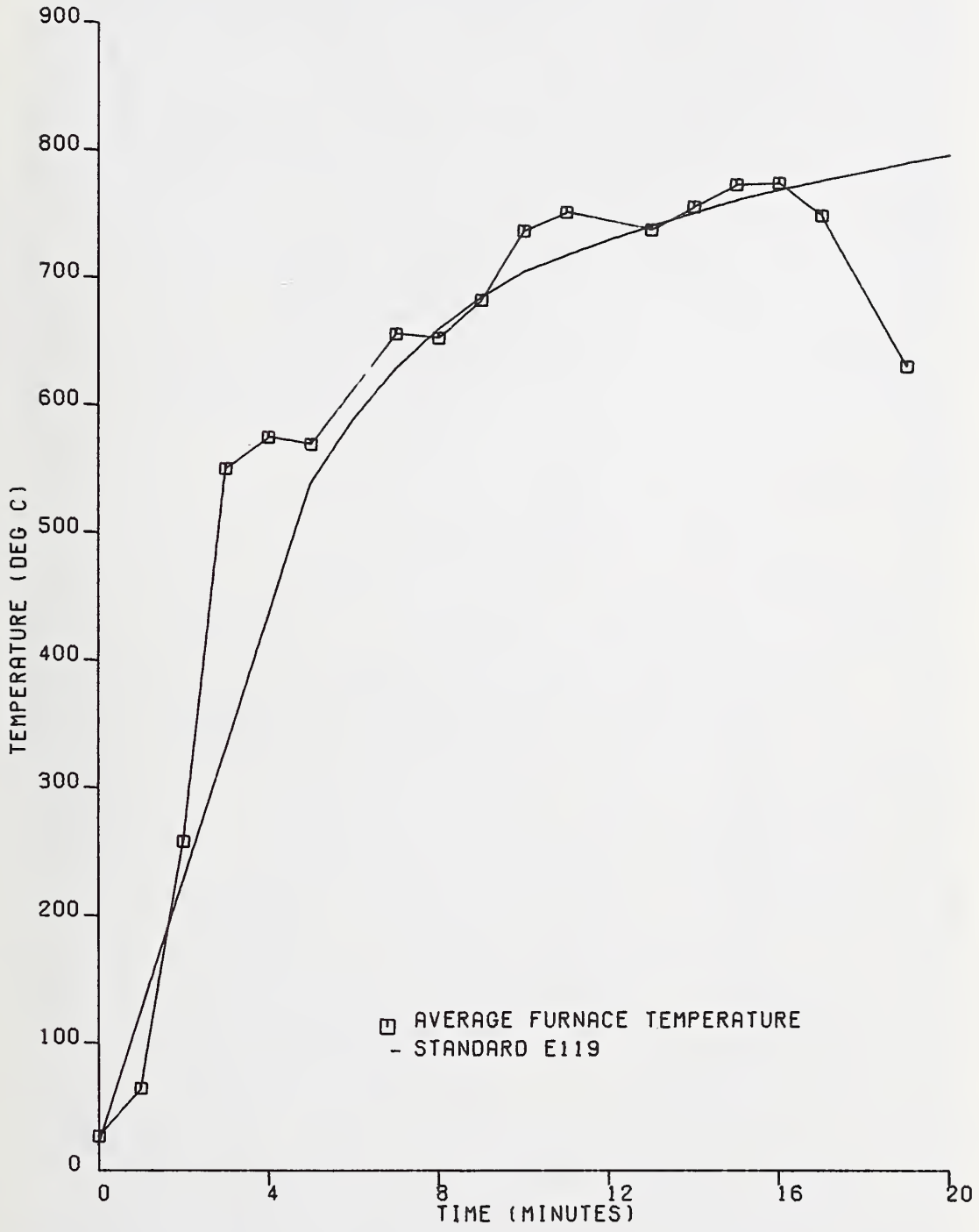

Figure 13.

AVERAGE FURNACE TEMPERATURE FOR ROOF/CEILING TEST COMPARED WITH STANDARD E119 TIME-TEMPERATURE CURVE.

Figure 14. Smoke appearing on top of the unexposed side of the wall. Test time of 2 min.

Figure 15. Smoke on the unexposed side of the wall. Test time of 5 min.

Figure 16. All joints on the exposed surface of the wall panel burning. Test time of 8 min. (Inside furnace)

Figure 17. The fire side of the wall panel after it was removed from the surface just before extinguishment of the fire.

Figure 18. The unexposed surface of the roof/ceiling assembly after the loading rig was removed at the end of the test.

Figure 19. The exposed surface at the failed joint (second joint from the north) of roof/ceiling assembly at the end of the test.

Figure 20. Fire re-occurring 15 hours after the end of the test (Roof/Ceiling Assembly).

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

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The test method was in accordance with the requirements of ASTM E 119, Standard Methods of Fire Tests of Building Construction and Materials, for loadbearing structures. The applied live load was 237 pounds per linear foot (plf) for the wall assembly and 28.6 pounds per square foot (psf) on a 13 ft 5 in. span for the roof/ceiling assembly. The results of these tests are valid only for walls and roof/ceilings of such constructions described in this report and loaded at or below the stress levels developed by these loadings.

The fire endurance of the wall assembly was 7 minutes 50 seconds; and the roof/ceiling, 9 minutes 09 seconds. In both cases, the failure was due to a maximum temperature rise of 181°C (325°F) above the initial temperature on the unexposed surface.

17. KEY WORDS (Alphabetical order, separated by semicolons) Exterior wall; fire endurance; fire test; housing systems; Operation BREAKTHROUGH; paper honeycomb; roof/ceiling assembly; structural sandwich panel.

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