NATIONAL BUREAU OF STANDARDS REPORT

10 320

FIRE ENDURANCE TESTS OF UNPROTECTED WOOD-FLOOR CONSTRUCTIONS FOR SINGLE-FAMILY RESIDENCES

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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U. S. Department of Housing and Urban Development

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ABSTRACT

Fire endurance tests were performed on two full-scale and 12 small-scale wood floor constructions. The fire endurance ratings on unfinished wood joist and plywood subfloor constructions varied from 10 to 13 minutes and were mainly determined by the time to "flame through." The addition of carpeting with a hair pad delayed the time of "flame through" approximately 10 minutes. Time to "flame through" may be estimated from the thermal resistance of the construction. This may be modified by the effects of applied load or construction details such as gaps, joints, and penetrations.

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FIRE ENDURANCE TESTS OF UNPROTECTED WOOD-FLOOR CONSTRUCTIONS FOR SINGLE-FAMILY RESIDENCES

by

B. C. Son

1.0 Introduction

A series of ASTM Standard E119 fire tests were conducted to measure the fire endurance of wood floor constructions representative of those used in single family residences. The fire exposure followed the requirements of the Standard Methods of Fire Tests of Building Constructions and Materials A.S.T.M. E119-69, for floors. Tests were run on both full-scale specimens (13 1/2 by 18 ft.) with structural load, and on small-scale specimens (2 by 2 ft.).

These tests were carried out to study the relationship between the behavior of unprotected floors, over a basement or crawl space, and the "Guide Criteria" for Operation Breakthrough. Criterion A.4.1.1 of Volumes III and IV of the "Guide Criteria" states that the fire endurance of floors over a crawl space or basement should equal or exceed 10 minutes.

The constructions tested included several plywood subflooring and underlayment combinations and strip flooring directly on 2 x 8 or 2 x 10 nominal wood joists. The effect of carpeting was also examined.

The fire endurance time was usually governed by excessive temperature rise on the unexposed surface of the wood floor. Failure by flame penetration (directly through the wood or at joints) and by excessive deflection (inability to sustain the applied load) followed shortly thereafter.

Small scale test in a nominal 2' x 2' furnace was also performed to investigate a much wider range of constructions than could be tested full scale. To the extent that thermal effects principally determine fire behavior, it should be possible to predict the results of full scale tests from those of small scale tests.

In the full-scale tests, the fire endurance time was 9 minutes for a single layer 1/2 inch square edge plywood with blocked joints, and 10 minutes for a single layer of 5/8 inch plywood with tongue and groove joints. It ranged from 9 minutes and 30 seconds to 25 minutes and 50 seconds in the small scale tests covering 12 different constructions.

2.0 Preparation of Test Specimens

2.1 Construction of Full Scale Test Specimens

2.1.1 Specimen of Test #L-1

The floor was built into the 10 x 13 1/2 feet framed opening of the NBS Floor Test Furnace using nominal 2 x 10 inch Douglas Fir joists. The joists were air dried construction grade Douglas Fir. At the time of the test neither kiln dried lumber nor stress graded lumber was available in this area. The joists were spaced at intervals of 16 inches with a span of 13 1/2 feet. According to the FHA Minimum Property Standards (4) the maximum allowable span for 2 x 8 joists, on 16 in. centers, is 13 ft. Since the opening of the NBS Furnace is 13 ft. 6 in., the larger joist, nominal 2 x 10, was used in test #L-1. In test #L-2 the more typical 2 x 8 joist was used. The 2 x 10 inch solid bridging of the joists was spaced 5 feet apart and was staggered for direct nailing.

The floor specimen, consisted of a layer of 1/2 inch thick grade A-C plywood subfloor and 1/2 inch, grade C-D plywood underlayment. The use of A-C plywood, compared to a lower grade, for the subfloor probably had no effect on the fire endurance. The subfloor was nailed with 8d coated nails spaced 10" apart, starting with a full sheet in the NW corner. The underlayment was nailed with 6d coated nails. Though this is not strictly in accordance with section 817-4.3 of the FHA Minimum Property Standard (4), it is commonly used in house construction. These were spaced 12" apart starting with a full sheet in the SE corner to provide a pattern of staggered joints between layers. Gypsum board protection was provided along the edges.

One half of the specimen was covered with nylon 501 carpet (weight 66.7 oz/yd^2) over a hair pad underlayment, (weight 33.5 oz/yd^2), while the other had no finish floor, as shown in Figure 1. Figure 2 shows the underside of the floor, including joists and solid bridging, furnace thermocouples, observation windows, and gas burners. Figure 3 is a general sketch of the large floor test furnace.

To avoid overloading the joists, the lumber was assumed to be Rocky Mountain Region Douglas Fir. This has an allowable stress level of 1050 psi in bending according to Table III page 250 of the FHA Minimum Property Standards (4). A load of 63.7 lbs/ft^2, calculated to produce a working stress of 1050 psi in bending at the extreme fibers of the joists, was applied to the floor through four hydraulic jacks.

2.1.2 Specimen Test #L-2

The size of the floor and the layout of the joists was the same as in test #L-1 except that nominal 2 x 8 joists were used instead of 2 x 10's and steel-X automatic steel bridging was used along the longitudinal centerline instead of solid bridging.

In this test, two types of single-floor construction were tested. The floor was equally divided into two parts along the east-west center line. One consisted of a layer of 1/2 inch thick plywood with a square edge joint (interior grade, with exterior glue. In accordance with general practice, and with FHA Minimum Property Standards (4) requirements, the plywood was placed leaving a 1/16" joint spacing. The joint was protected by nominal 2 x 3 inch blocking. The other area consisted of a layer of 5/8 inch thick plywood tongue and groove all 4 edges (underlayment grade, sand finished, with exterior glue). Figure 4 shows a schematic picture of the floor. The floor was nailed with 8d common nails spaced 10" apart.

In this test to study the effect of a more representative live load, the applied load was reduced to a nominal 20 psf (21 lbs per square foot actual). This load, which was applied to the floor by the method used in test #L-1, represented approximately 40 percent of the working stress of the joists (see Appendix I).

The typical moisture contents of each material was measured, based on weight loss at 105°C; 10% for 5/8" thick tongue and groove plywood, 6% for 1/2" "Underlayment" plywood, 12% for 2 x 8" joist.

2.2 Instrumentation-Full Scale Test

2.2.1 Test #L-1

The instrumentation consisted of thermocouples, floor deflection indicators, smoke meters and a motion picture camera. Eighteen chromel-alumel (type K) thermocouples (.020 inch diameter wires) were placed on the top unexposed surface of the floor in such a way as to avoid contact with the loading apparatus. These were placed under 0.4 in. thick standard asbestos pads. The distribution of the thermocouples is seen in figure 1. In addition, there were five thermocouples located under the carpet at the quarter points and at the center.

The temperatures of all the thermocouples were printed out at 2 minute intervals on a Data Logger. The print out was converted to punched cards for graphing by a Calcomp Plotter.

Smoke meters with a 16 inch optical path were placed on the carpet 56 inches from the west end and 29 inches from the east-west center line in the carpeted area and at the diagonal opposite side over the bare area to measure the density of smoke accumulating above the two floor sections. The smoke meter consisted of a sheet metal canopy to collect the smoke and was arranged with a light source on one side and a vacuum phototube on the other side. An opening was provided at the bottom for air inlet and holes were provided in the top for the controlled discharge of the smoky air.

The deflection indicators consisted of wires attached to nails placed at three points; at the quarter points and midway along the longitudinal center line. The wires were terminated with small weights which kept them taut. Indicating riders were attached to the wires where they passed over a vertical scale just above the small weights. Each rider indicated the amount of movement at the corresponding point on the floor during the test.

2.2.2 Test #L-2

The instrumentation was essentially the same as in the test #L-1, indicated in section 2.2.1, however no smoke measurements were made. The locations of the thermocouples is shown in Figure 5.

2.3 Construction and Instrumentation-Small Scale Test Specimens

Twelve small scale specimens 2' x 2' nominal (25" x 25" actual) were construction on 2 x 10" joists spaced on 16 inch centers, similar to test #L-1. Joists and end blocking are shown in Figure 6. The constructions and loadings are summarized in Table 4. The instrumentations consisted of 1 thermocouple at the center at middepth, 2 thermocouples on the wood surface and, whenever the specimen was covered with a rug, there were 2 thermocouples on the rug. When the joint was protected with a nominal 2 x 4 or 2 x 3 blocking (as shown in Fig. 7) the thermocouple which was at the center was moved down on top of the blocking.

3.0 Test Procedure

3.1 Full Scale Tests

The load was applied eight minutes before the test started. The load, which is distributed through 36 steel channels, 5 by 24 in., approximates a uniform load. Details of allowable live load calulation based on full design stress are given in Appendix I.

The average temperature inside the furnace was measured by twelve protected thermocouples and was made to follow the standard A.S.T.M. E119-69 temperature-time curve by automatic control of the gas flow to the burners; which is shown in Figure 9.

The fire endurance of a construction followed by criteria of failure designated by the A.S.T.M. E119-69:

(a) The construction shall have sustained the applied load during the fire endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

(b) Transmission of heat through the construction during the fire endurance that shall not raise the average temperature on its unexposed surface more than 250°F (139°C), or 325°F (181°C) at one point, above its initial temperature.

All the following tests shall be regarded as successful if the above conditions are met.

3.2 Small Scale Test

No load was applied to the floor in Test #S-1. But a load of 40 lbs. was applied to the floor at two locations by setting the weights on the floor 4" apart from the center along the longitudinal center line. The load was increased from 40 lbs. to 240 lbs. by putting four 60 lbs. weights at four locations in Test #S-3 through Test #S-12 as shown in Figure 9.

Four protected thermocouples were used to measure the average temperature inside the furnace which was made to follow the ASTM Standard E119-69 temperature-time curve by automatic control of the gas flow to the burners.

4.0 Test Results

Please refer to Appendix II for the log of tests.

4.1 Full Scale Test

4.1.1 Test #L-1

4.1.1.1 General Observations

Flame pentration at the joint between the two sheets of plywood in the upper layer of the bare floor near the center was observed at 13min:30sec. The location where flaming occurred and the associated charred region is shown in Figure 10. There was also a load failure, as evidence by the inability to maintain hydraulic pressure at 11min:38sec.

The average temperature of the bare surface thermocouples was less than 75°C when the test was terminated after 15 minutes. On the carpet only one of the thermocouples exceeded 50°C, with a reading of 80°C. This thermocouple might have had a nail head directly underneath. The average temperatures of the bare floor and carpet are shown along with the average temperature beneath the carpet in Figure 11.

The smoke meter on the bare floor showed a sudden increase in smoke at about 9 minutes, which was more than 4 minutes before "flame through" was noticed. The smoke level indicated by the meter over the carpet was appreciably lower. The transmission of the smoke meters is given in table 1 Appendix II and Figure 12.

The deflection increased steadily as shown in Figure 13. The deflection at the center of the floor was 6.5 inches at 11:38 when the load could not be maintained. The deflections are tabulated in table 2 Appendix II.

There were a few small scorch marks on the hair pad due to heat conduction through the nails. At some locations this continued into the burlap backing of the nylon carpet leaving scorch spots up to 1 inch in diameter.

4.1.2 Test #L-2

4.1.2.1 General Observations

Flames penetrated the 1/2" plywood floor near the quarter point along the longitudinal center line between the blocked joints at 11min:00sec. About 50 seconds later flames were noticed along the tongue and groove joint near the center on the south west side.

Figure 14 illustrates average temperature rises on the unexposed surface. The temperature failure was 9 minutes for the 1/2" plywood floor and 10 minutes for the 5/8" plywood floor.

Figure 15 is the temperature history of the 6 specially arranged thermocouples. The slow rise in temperature of thermocouple C illustrates the effectiveness of the blocking in protecting the joint.

The deflections are tabulated in table 3 Appendix II and shown graphically in Figure 16.

4.2 Small Scale Tests

4.2.1 Test #S-1

4.2.1.1 General Observations

Some difficulties with the furnace control occured at the beginning of this test and so the furnace temperature-time curve was below the standard temperature-time curve (see Fig. 17). The corrected time of flame through, according to the correction formula stated in ASTM E119-69, was 18min:10sec. This compares quite well with the 17min:21sec of test #S-2 which was a duplicate of #S-1 excepting that a light load of 10 psf was applied to #S-2.

The corrected time to flame through was 5 minutes longer than in the full scale test. The probable reason for this difference was that no load was applied to produce bending and opening of the joints.

4.2.2 Test #S-2

4.2.2.1 General Observations

The rate of "burn through" was only one minute less than in Test #S-1. Since no bending was observed either upward or downward throughout the test, it is clear that this weight (10 psf) was not enough to produce downward bending. The difference of 1 minute between test #S-1 and #S-2 is probably not significant.

4.2.3 Test #S-3

4.2.3.1 General Observations

The time to reach "Flame Through" was considerably decreased. As indicated in "Observation During Test" of test #S-2 it took about 4 minutes to produce a definite "flame through" after the subfloor burned out; but in this test it took only one-half a minute.

The applied load did not appear to influence the behavior of the specimen unduly. This load, however, was used as a standard procedure for the remaining small tests.

The locations and shapes of "flame through" were rather localized along the joint, compared to previous tests, as shown in Figure 18.

4.2.4 Test #S-4

4.2.4.1 General Observations

The "flame through" region covered a large portion of the floor and originated in the same area as in test #S-3. The "flame through" in the test #S-3 was primarily through the artificially open joint. In test #S-4 the fire burned a large hole all at once. The surface charred over a large area during the last 3 minutes 50 seconds of test and then the surface ignition suddenly took place over the char region. This was taken as the "flame through" time.

4.2.5 Test #S-5

4.2.5.1 General Observations

"Flame through" was also originated at tongue and groove joint (see Fig. 19).

4.2.6 Test #S-6

4.2.6.1 General Observations

"Flame through" region was situated at the quarter points, i.e., directly through the plywood and carpeting.

The 2 x 4" blocking, besides protecting the joint thermally also acted like a stiffening beam and changed the pattern of the deflection from that in test #S-4. Figures 20, 21 and 22 show the pattern of deflection at 17.5 minutes and "flame through" at the north (left) side, and the flaming regions.

4.2.7 Test #S-7

4.2.7.1 General Observations

The "flame through" occurred in the same location as in Test #S-6.

4.2.8 Test #S-8

4.2.8.1 General Observations

The charring and "flame through" occurred in a same manner and location as in test #S-4.

4.2.9 Test #S-9

4.2.9.1 General Observations

The "flame through" occurred on the tongue and groove joint near the center.

4.2.10 Test #S-10

4.2.10.1 General Observations

The "flame through" and associated char region was located near the north-south quarter areas and not at the protected joint as in Test #S-7.

4.2.11 Test #S-11

4.2.11.1 General Observations

The "flame through" region covered a large portion of the floor near the center and originated in the same area as in test #S-9.

4.2.12 Test #S-12

4.2.12.1 General Observations

The charring and "flame through" occurred in a same manner and location as in test #S-5.

4.2.13 Test Results on Small Scale Tests

Figure 23 and 24 shows the temperature changes at half depth for the small scale tests. In Figure 24 the slope of curve 7-1 is flatter than the others, which is explained by the blocking under the joint protecting the joint from the fire.

The temperature changes on the bare floor and on the carpet surface are shown in Figures 25, 26, and 27.

5.0 Summary of Results

5.1 Comparison of the results from the full scale and from small scale tests.

Experiments were carried out to measure the time of "flame through" of the different floor constructions subjected to the conditions of the standard fire endurance test.

Structural failure of unprotected wood floors generally occures at approximately the same time as failure by excessive temperature rise or "flame through." In test #L-1, the load to produce the design stress (63.7 psf live) on the nominal 2 by 10 joists, produced load failure at 11:38 and "flame through" at 13:30. It was not possible to continue the test to excessive temperature failure. To obtain a better measurement of temperature transmission failure, and to simulate a more representative live floor load, it was decided to use 20 psf for test #L-2. Temperature failure occurred between 9 and 10 minutes, "flame through" occurred between 11 and 12 minutes, and load failure occurred at 13 minutes. No direct comparison is possible with the small scale tests since the joists were not loaded.

It is believed, that, as the supporting joists in the full scale test are gradually destroyed by charring, cracks form at the extreme highly stressed fibers on the bottom surface. This increases the deflection and accelerates the rate of flame penetration through increased joint separations. There are differences in pressures in the large and small-scale furnaces which may also have an effect on the results.

As previously mentioned in test #S-3, the 1/8" fixed gap on the underlayment joint reduced the time of "flame through" by 4.5 minutes. For both the large scale and small scale tests the temperature rise on the unexposed surface was nearly the same. It may be that the artificial gap on small scale test #S-3 corresponded to the cracks made on the exposed surface due to the load in the full scale test #L-1.

Furthermore, the time of "flame through" of the small scale test on the 5/8" plywood with tongue and groove joint or the 1/2" plywood with square edge joint protected with 2" x 3" blocking are in agreement with those of the full scale test.

Considering the criterion of temperature failure, it is interesting that the temperature failures were seen a few minutes earlier than the "flame through" failures in most cases. Table 4 includes different types of failure on various constructions, loading conditions and total thermal resistance.

Thermal resistance is calculated from a thickness and coefficient of thermal conductivity as follows:

$$\text{Thermal Resistance} = \frac{\text{Thickness}}{\text{Coefficient of thermal Conductivity}}$$

The thermal properties which form the basis for the computed thermal resistances (See Table 5) were obtained from a standard reference source [2].

5.2 Effect of Carpeting

It was obvious that the carpeting delayed the time of "flame through" by 8 to 12 minutes. Since the carpet itself did not add any strength to the floor, there was not much difference in the deflections between the floor sections with or without carpet.

5.3 Estimation of the time of "flame through."

Figure 28 illustrates the influence of the thermal conductivity of various materials on the time of "flame through" under free convection conditions and at room temperature. It is apparent that construction #4 (1/2" + 1/2" + 1/8" gap + carpet) has the largest value of thermal resistance and requires the longest time for the flame to penetrate through the floor. It can be seen in figure 28, that emperically there is a linear relation between the thermal resistance and the "flame through" time. The slope is K = 0.133 (BTU/°F).

For instance, a 1/8" vinyl asbestos tile will add a thermal resistance (R) of 0.05 (HR °F/BTU) to the floor. The additional time for the flame to pass through the tile with a resistance of R = 0.05 (HR °F/BTU) will be 24 seconds. The flame through time of 11 minutes was observed by experiment on 1/2" plywood with 2 x 3" blocking. Thus, the total time required for "flame through" on the floor construction of 1/2" plywood with 2 x 3" blocking, finished with 1/8" vinyl asbestos tile can be estimated as 11.4 minutes.

5.4 Estimation of "Load Failure" by Excessive Deflection

There are no deflection requirements on ASTM E-119 to indicate "load failure."

Based on a survey of laboratory fire endurance tests on representative constructions, the requirement was proposed that both a maximum deflection $D > \frac{L^2}{800d}$, and a maximum hourly deflection rate $R > \frac{L^2}{150d}$ be exceeded as an indication of load failure [3]. Taking L = 12' 10" as the span between supports and d = 9 5/8 in (0.80 ft) as the distance between the upper and lower extreme fibers of the critical fire exposed member (joist), load failure may be considered to have occurred at 10:05 min in test #L-1, and with d = 7 5/8 in (0.64 ft), load failure may be considered to have occurred at 5:36 min. in test #L-2.

6.0 Conclusions

Bare wood floor constructions conforming to the FHA Minimum Property Standards (4) are marginally able to meet a fire endurance time requirement of 10 minutes. This includes single-floor plywood constructions 1/2 in. and 5/8 in. thick. Strip flooring (25/32" softwood and 13/16" hardwood) directly over joists have a fire endurance time in the range of 10 to 13 minutes.

The addition of a separate finish floor should increase the fire endurance time by an amount dependent on its additional thermal resistance. This is estimated to be approximately 1/2 minute for 1/8 in. vinyl asbestos tile to approximately 10 minutes for carpeting over a hair pad.

For example, the time of flame through for the (1/2" + 1/2" + 1/8" gap + carpet) construction, which has total thermal resistance of 2.40 (HR °F/BTU), is almost 4 times that for the (1/2" + 2 x 4 blocking) construction with total thermal resistance of 0.62 (HR °F/BTU).

The total thermal resistance of the floor construction can be used as a factor for estimation of "flame through" time. This would be modified by the effects of the applied load or the gap size.

7.0 REFERENCES

1. Standard Methods of Fire Tests of Building Construction and Materials, American Society for Testing and Materials Designation E 119-69.

2. "Handbook of Fundamentals, Heating, Refrigerating, Ventilating and Air Conditioning" Published by ASHRAE, 1967.

3. J. V. Ryan and A. F. Robertson, "Proposed Criteria for Defining Load Failure of Beans, Floors, and Roof Constructions During Fire Test," Journal of Research of the National Bureau of Standards - C. Engineering and Instrumentation, Vol. 63C, No. 2, October-December 1959.

4. "Minimum Property Standards For One and Two Living Units FHA No.300, U.S. Department of HUD, FHA, Rev. January 1970.

APPENDIX I

LIVE LOAD CALCULATION

Allowable design stress for Douglar fir construction grade joist with 2 x 10" and 2 x 8" in cross-section on full scale test.

According to the stress equations

$$f_b = \frac{M}{I/C} \qquad (1)$$

and

$$M = \frac{WL^2}{8} \qquad (2)$$

Allowable bending stress

$$f_b = 1050 \text{ psi}$$

Section modulus

$$I/C = 24.44 \ (\text{in}^3) \text{ for } 2 \times 10\text{" joist}$$

$$I/C = 15.23 \ (\text{in}^3) \text{ for } 2 \times 8\text{" joist}$$

From Equation (1)

$$M_{2 \times 10} = 1050 \times 24.44 = 25{,}700 \ (\text{lb-in}) = 2140 \ (\text{lb-ft})$$

From Equation (2)

$$W_{2 \times 10} = \frac{8\ (2140)}{(13.52)} = 94.0\ (lb/ft)$$

Above value is for unit length on the joist. Therefore, the working load corresponding to unit area can be converted by multiplying by the factor (12/16).

$$W_{2 \times 10} = 94.0 \times 12/16 = 70.5\ (psf)$$

Live load = Total allowable load - Dead load.

Dead load =	carpet	1.0 psf
	plywood (1" thick)	3.0 psf
	+ joist (2 x 10" cross-section)	2.8 psf
	total dead load	6.8 psf

therefore,

Live load/2 x 10 = 70.5 - 6.8 = 63.7 (psf)

Same manner

$$W_{2 \times 8} = 52\ psf$$

Dead load = plywood (5/8 inch thick)

= 1.87 psf

therefore,

Live load/2 x 8 = 52 - 1.87 = 50.1 (psf)

NOMENCLATURE

M = Bending Moment

f_b = Bending Stress

I/C = Section Modulus

w = Load

c = Half depth of joist

Subscript 2 x 10 = 2 x 10 inch joist

Subscript 2 x 8 = 2 x 8 inch joist

APPENDIX II

LOG OF TESTS

TEST #L-1

Observation During Test

min:sec.	
1:00	Joist ignited, crackling sounds, smoke escaping between joists and plywood deck around the edge of the floor.
2:00	Fire-exposed plywood surfaces all scorched.
3:00	Inside of furnace filled with smoke and flame. Whole underside on fire.
4:00	West side of fire-exposed plywood burned more than east side.
5:00	Smoke increasing through the cracks at the perimeter, but no smoke directly from upper surface.
8:00	Crackling sounds were more severe.
10:00	Appreciable smoke around T/C #8 pad on bare floor.
11:38	"Load Failure" (could not sustain hydraulic load).
12:30	Load off. At least 2 joists were broken.
13:30	Flame through at joint.
15:00	Gas off. END OF TEST

Table 1

TEST #L-1 SMOKE DEVELOPMENT

Time min:sec.	Over plywood T(%)	O.D.*	Over carpet T(%)	O.D.*
0:00	100	0	100	0
1:00	99.5	0	100	0
2:00	99.5	0	99	0
3:00	96	0.01	96.5	0.01
4:00	97.5	0.01	97.5	0.01
5:00	97	0.01	95.5	0.01
6:00	97.5	0.01	97.5	0.01
7:00	93.5	0.037	91.5	0.04
8:00	88	0.053	89	0.053
9:00	78	0.1	86.5	0.06
10:00	11.2	0.93	80.5	0.09
11:00	4.5	1.35	78	0.1
12:00	12.4	0.9	72	0.2
12:30	Readings discontinued			

*Over 16 in. optical path.

Table 2

TEST #L-1 DEFLECTION MEASUREMENTS

Measurements of deflections were made at three points on the longitudinal center line; at the North (N) and South (S) quarter points, and at dead center (C).
Readings in inches.

	N	C	S
Before load	0	0	0
After load	.18	.20	.20
min:sec.			
1:00	.20	.20	.20
2:30	.45	.50	.20
5:00	.6	.75	.6
6:00	.6	.95	.7
7:00	.9	1.25	.9
8:00	1.1	1.6	1.1
9:00	1.5	2.3	1.5
10:00	1.8	3.0	1.8
10:30	2.1	3.6	2.1
11:10	2.4	4.5	2.8
11:38	2.7	6.5	3.3

Load off (unable to maintain pressure)

TEST #L-2

Observation During Test

Time min:sec.	
0:40	Joist started flaming on the south side.
1:00	Joist started flaming on the north side.
1:30	Smoke on unexposed surface.
3:00	Large sheet of flames formed on under side of floor.
4:00	Formation of black char at a few spots on the top surface.
11:00	"Flame through" on 1/2" plywood floor.
11:50	"Flame through" on 5/8" plywood floor.
13:00	Load failure (floor broke through).

Table 3

TEST #L-2 DEFLECTION MEASUREMENTS

Time min:sec.	N	C	S
0:00	0	1	0.5
1:00	0	1.25	1.0
2:00	0	1.5	1.25
3:00	0	2	1.5
4:00	1	2.5	2
5:05	2.5	5	3.5
7:00	4	8	5
10:00	4	14	9
12:00	7	18	12
13:00	Wire broke	19	

TEST #S-1

Observations During Test

Time min:sec.	
6:45	Joists and exposed plywood surface ignited.
10:20	Tendency of center part of joint to bend upward due to thermal stress. Smoke coming out through joint.
18:00	Fire inside furnace seen through the opening of joint.
19:30	Small fire coming through the joint.
20:00	Noticable difference in height between plywood sections at center of joint.
21:43	"Flame through."
(18:10)	(Corrected time for flame through, see General Observations of test #S-1).

TEST #S-2

Observations During Test

Time min:sec.	
1:00	Inside the furnace was filled with flame and smoke.
1:20	Joists started flaming.
13:30	Fire inside the furnace seen through the opening of the joint. (Subfloor burned through).
14:00	Along the edge of the joint, dehydration phenomena and black char appeared.
17:21	"Flame Through."

TEST #S-3

Observations During Test

Time min:sec.	
1:10	Joists started to burn.
5:30	Smoke from joint.
12:15	The furnace fire appeared through the gap. (Subfloor burned through).
12:45	"Flame Through."

TEST #S-4

Observations During Test

Time min:sec.	
1:00	Joist on fire
7:00	Gray smoke filtering through the carpet, and the center part of the unexposed surface was covered with moisture.
14:00	Fire reached underlayment. (thermocouple indication)
21:00	Deflection due to the load was observed near center.
22:00	Black char on the carpet started to be formed.
25:00	Load was relaxed. (Could not sustain the weights).
25:50	"Flame through."

TEST #S-5

Observations During Test

Time min:sec.	
1:00	Joist started to burn.
6:00	Exposed surface under thick flame.
9:00	Smoke was noticed around T and G joint near the north end. At the same time its color became charcoal black, and sagging and opening at this joint was observed.

9:30	The fire inside furnace was seen through the opening.
10:30	"Flame through" at the joints. The locations of "flame through" and openings at joints are seen in Figure 19.

TEST #S-6

Observations During Test

Time min:sec.	
1:00	Joist started to burn.
8:00	Gray smoke filtering through the carpet and moisture noted on the unexposed surface.
14:50	Black char on the carpet surface. An appreciable deflection was observed midway between dead center and north and south end.
18:15	"Flame through."

TEST #S-7

Observations During Test

Time min:sec.	
1:06	Ignition of joist.
7:00	Smoke started to appear on unexposed surface.
8:00	The top surface became dark near north end.
9:25	"Flame through."

TEST #S-8

Observations During Test

Time min:sec.	
1:05	Joist ignited.
6:15	Appearance of gray smoke through the carpet at the middle of the joint.
17:00	Deflection occurring at center.
19:10	Formation of the char region near center of the carpet surface.
20:20	Deflection was severe.
24:00	"Flame through" near center.

TEST #S-9

Observations During Test

Time min:sec.	
1:00	Ignition of joist.
4:00	Smoke was seen above tongue and groove joint.
6:00	Formation of dark char on the edge of the joint near center.
9:40	Flames were seen through the opening made on the joint.
11:35	"Flame through."

TEST #S-10

Observations During Test

Time min:sec.	
1:00	Joist started to burn.
7:40	Char forming on the unexposed surface near north quarter area.
10:25	Fire inside furnace was seen throug the opening made where the char was formed.
11:00	"Flame through."

TEST #S-11

Observations During Test

Time min:sec.	
1:03	Joist started to burn.
7:00	Gray smoke and moisture was observed on the unexposed surface near the center.
15:00	Black char forming. Deflection was noted.
18:00	Deflection severe. The charred region about three inches in diameter.
19:20	"Flame through."

TEST #S-12

Observations During Test

Time min:sec.	
1:00	Joist on fire.
3:00	Dehydration phenomena was clear on the edge of the wood.
4:00	Droplets of moisture were formed on top of the unexposed surface.
10:30	Sagging was observed near north end where tongue was broken during construction.
11:00	The sagging resulted in a small opening.
12:00	Fire inside furnace was seen through the opening.
13:21	"Flame through" when the broken tongue existed.
14:10	"Flame through" at a normal joint.

TABLE 4

FIRE ENDURANCE TIMES FOR VARIOUS FLOOR CONSTRUCTIONS

COMPARING SMALL AND FULL SCALE TEST

TEST	CONSTRUCTION	SMALL SCALE (2'x2')				FULL SCALE (13 1/2'x18')				THERMAL RESISTANCE HR°F/BTU
		LOAD LB/ft²	FLAME THRU (MIN)	LOAD FAIL. (MIN)	TEMP.FAIL. (MIN)	LOAD LB/ft²	FLAME THRU (MIN)	LOAD FAIL.* (MIN)	TEMP.FAIL. (MIN)	
1	1/2"+1/2" (plywood)	None	21:43	---	17:10	---	---	---	---	1.25
2	1/2"+1/2"(plywood)	10	17:21	---	----	63.7	13:30	11:38	>15:00	1.25
3	1/2"+1/2"+1/8" gap (plywood)	60	12:45	---	---	---	---	---	---	1.25
4	1/2"+1/2"+1/8" gap + carpet (plywood)	60	25:50	---	20:00	63.7	not reached	11:38	not reached	2.48
5	25/32" with T & G (pinewood)	60	10:30	---	---	---	---	---	---	0.98
6	1/2"+2"x4" Blocking & carpet (plywood)	60	18:15	---	11:30	---	---	---	---	1.85
7	1/2"+2"x4" Blocking (plywood)	60	9:25	---	8:00	---	---	---	---	0.62
8	1/2"+1/4"+1/8" gap & carpet (plywood)	60	24:00	---	22:30	---	---	---	---	2.16
9	5/8" with T & G (plywood)	60	11:35	---	10:24	21	11:50	13:00	10:00	0.78
10	1/2"+2x3" Blocking (Plywood)	60	11:00	---	6:30	21	11:00	13:00	9:00	0.62
11	5/8" with T & G & carpet (plywood)	60	19:20	---	17:15	---	---	---	---	2.01
12	13/16" with T & G (oak)	60	14:10	---	13:00	---	---	---	---	0.56

* Unable to maintain load application due to excessive rate of deflection.

TABLE 5

THERMAL RESISTANCE OF VARIOUS FLOOR MATERIALS

MATERIAL	DENSITY LB/FT^3	CONDUCTIVITY BTU/HR FT °F K	CONDUCTANCE BTU/HR °F c	THICKNESS INCH L	THERMAL RESISTANCE HR °F/BTU R
OAK	51.5	1.2		13/16	0.65
PINE	34	0.8		25/32	0.98
PLYWOOD		.80		1/2	0.62
CARPET plus hair pad			.8		1.2
VINYL asbestos tile			20.0	1/8	0.05

$$R = \frac{L}{K} = 1/c$$

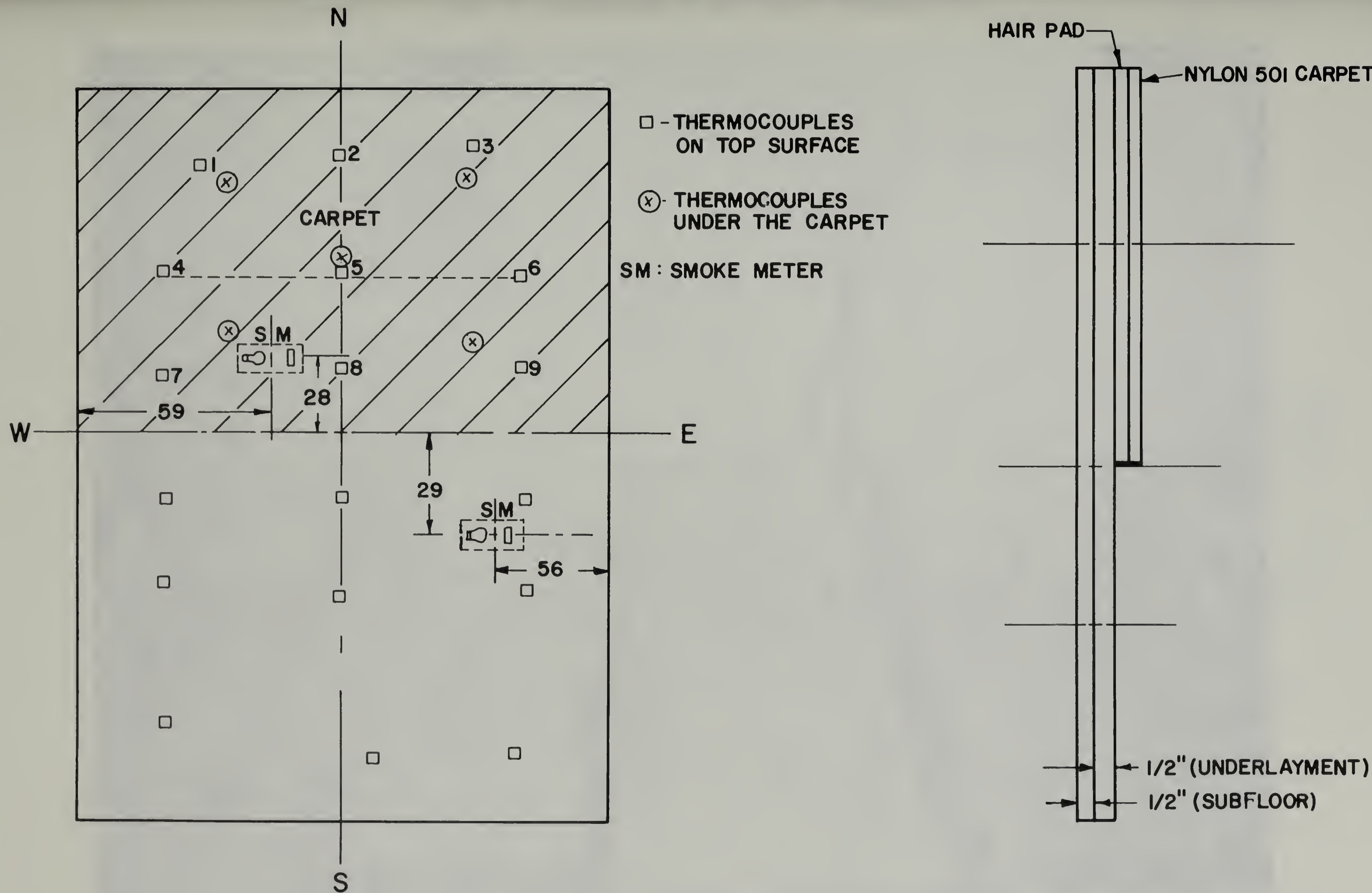


Fig. 1. Locations of Thermocouples and Smoke-Meters

Fig. 2. Underside of the Floor Construction

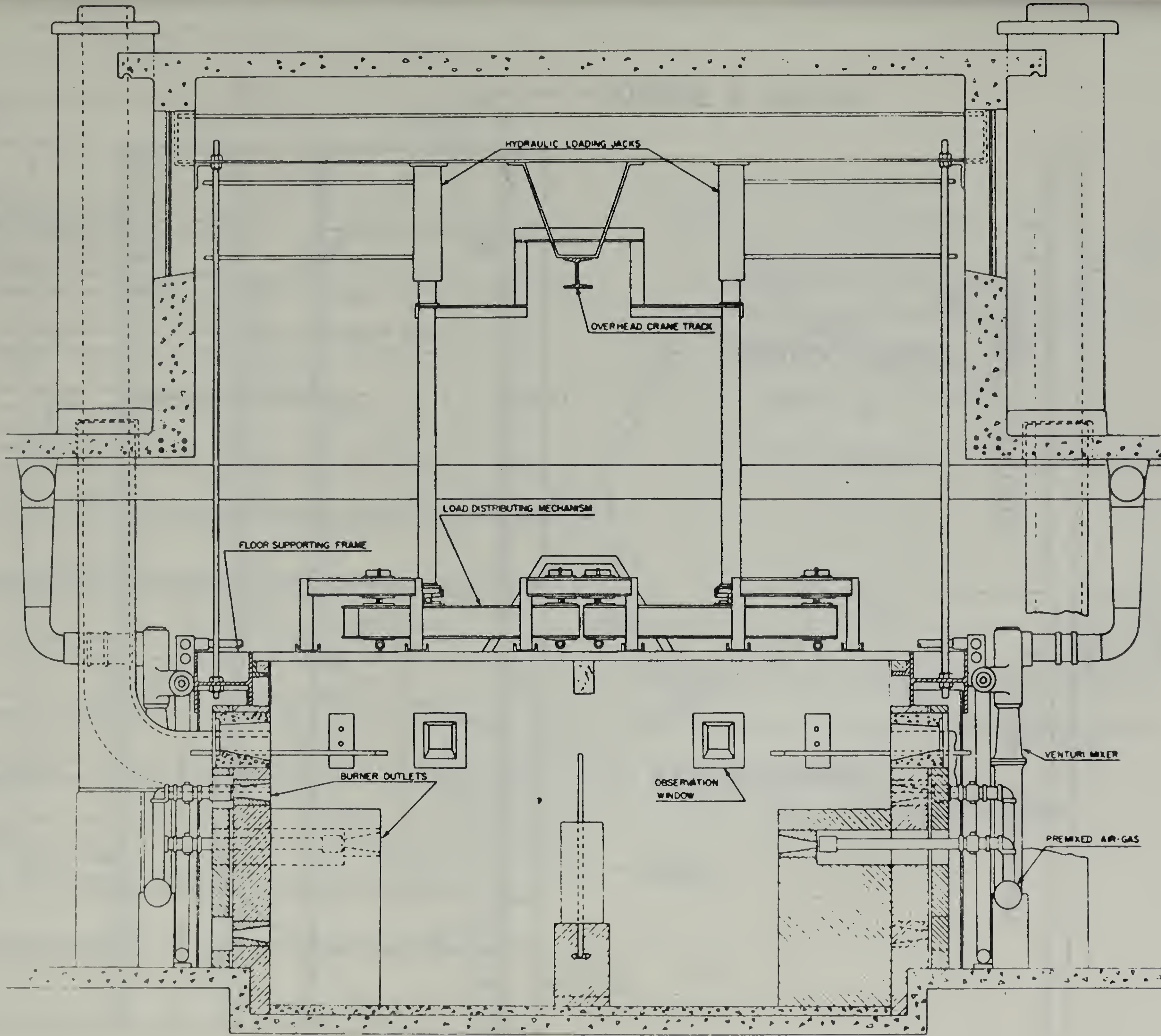


FIGURE 3. Section of the large floor-test furnace at NBS.

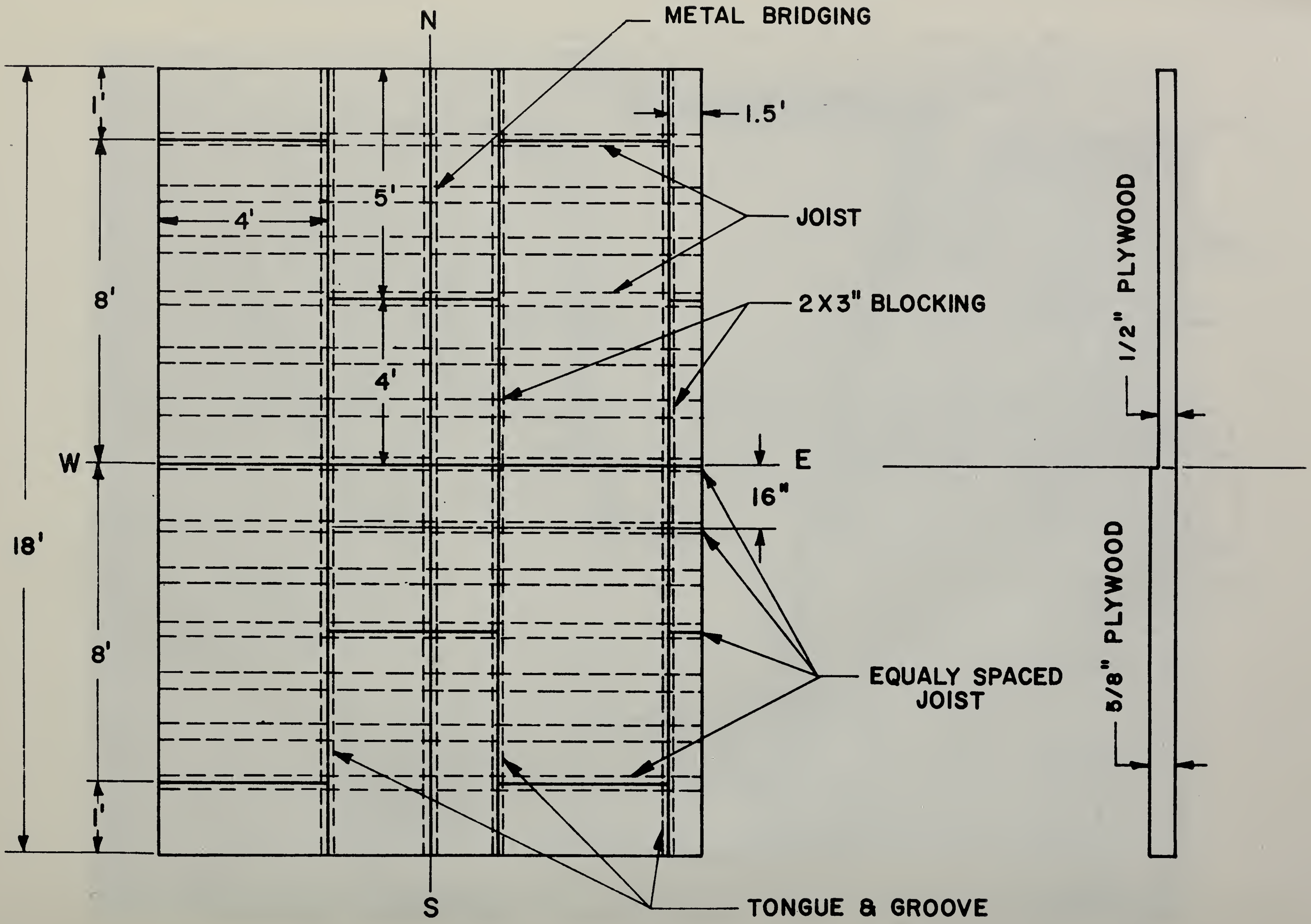


FIGURE 4. Floor Speciman of Test #L-2

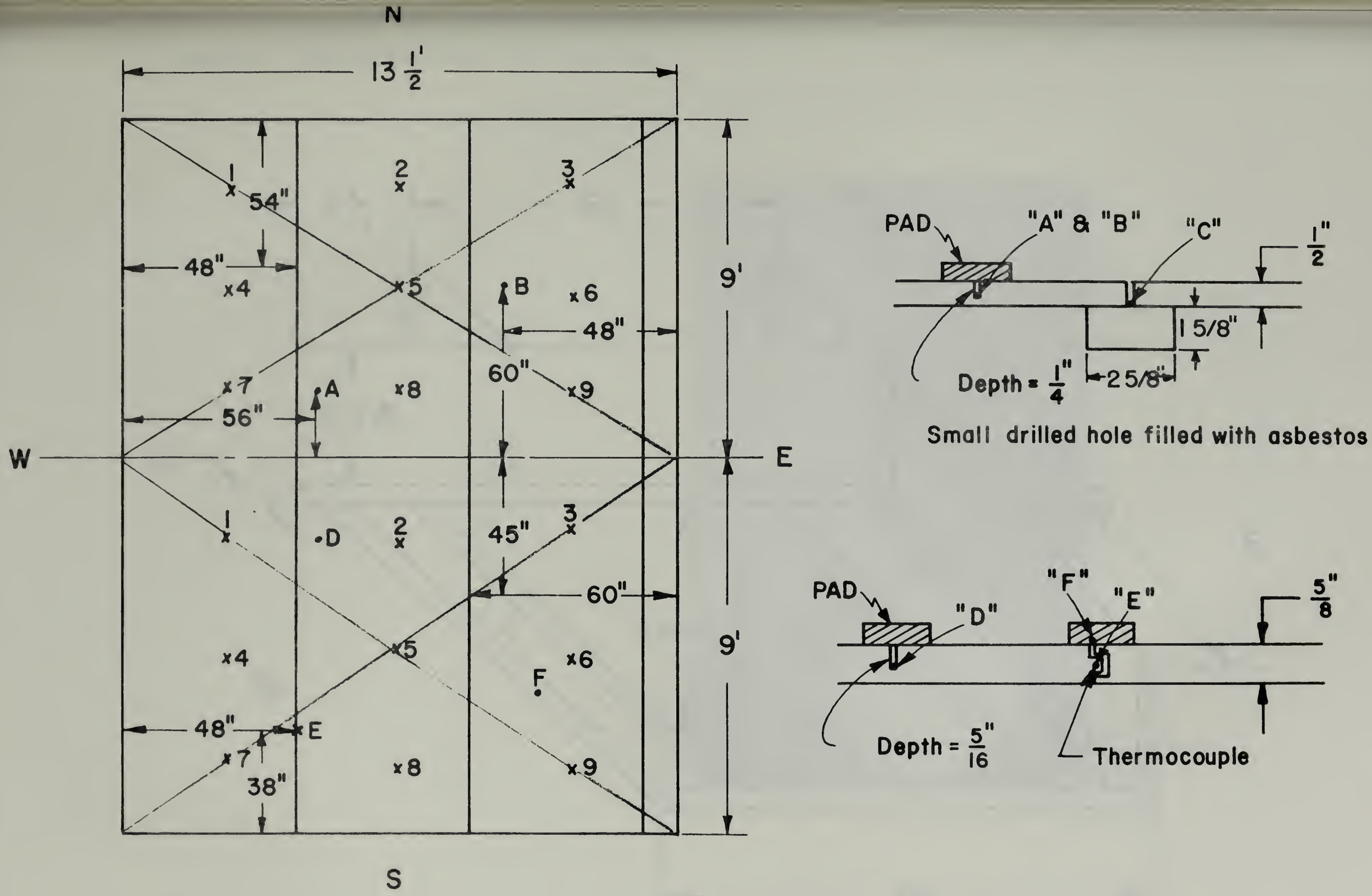


FIGURE 5. Locations of Thermocouples of Test #L-2

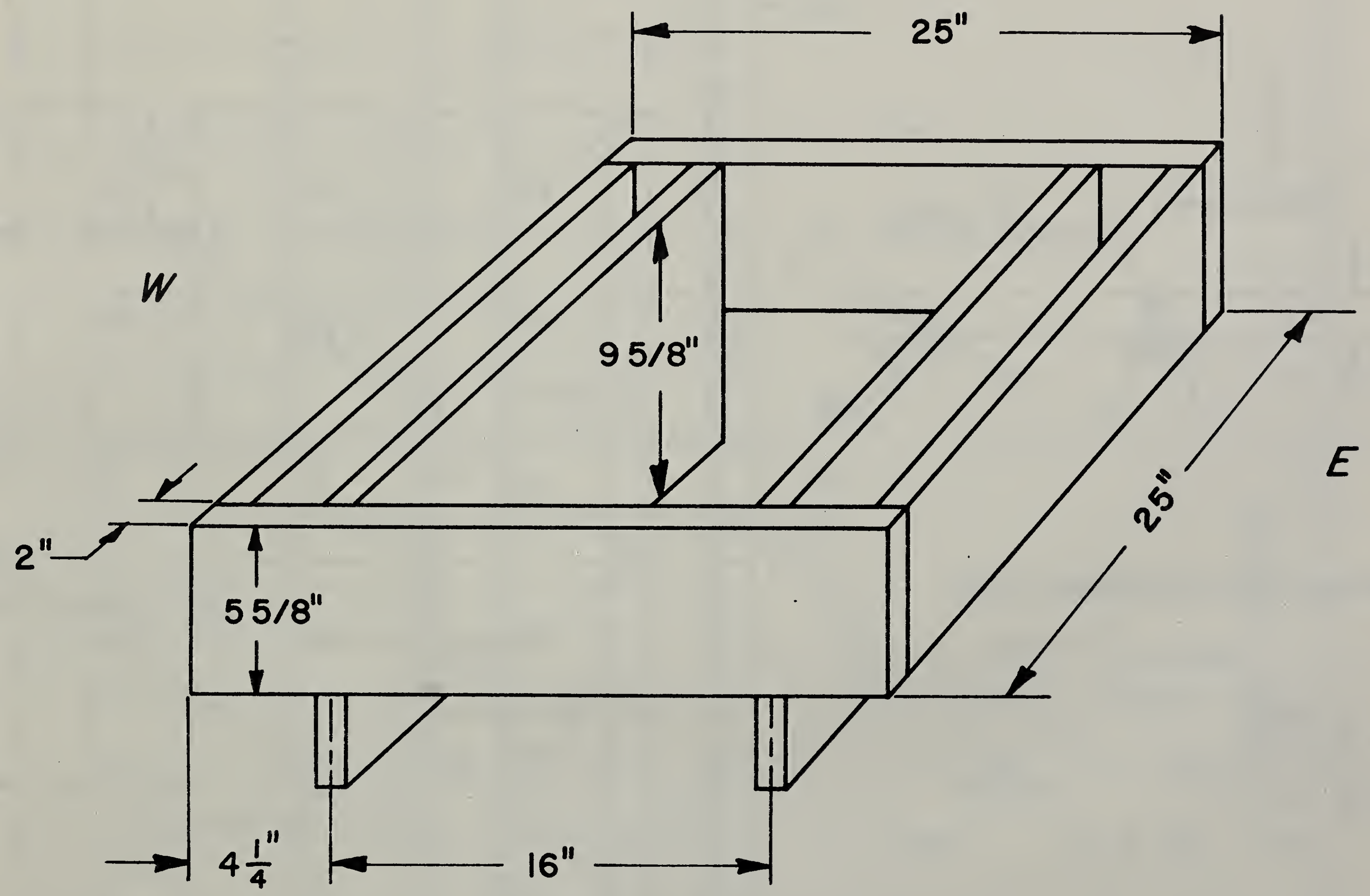


FIGURE 6. Framing for Small Scale Specimen

Figure 7 Location of Weights
Test #S-3

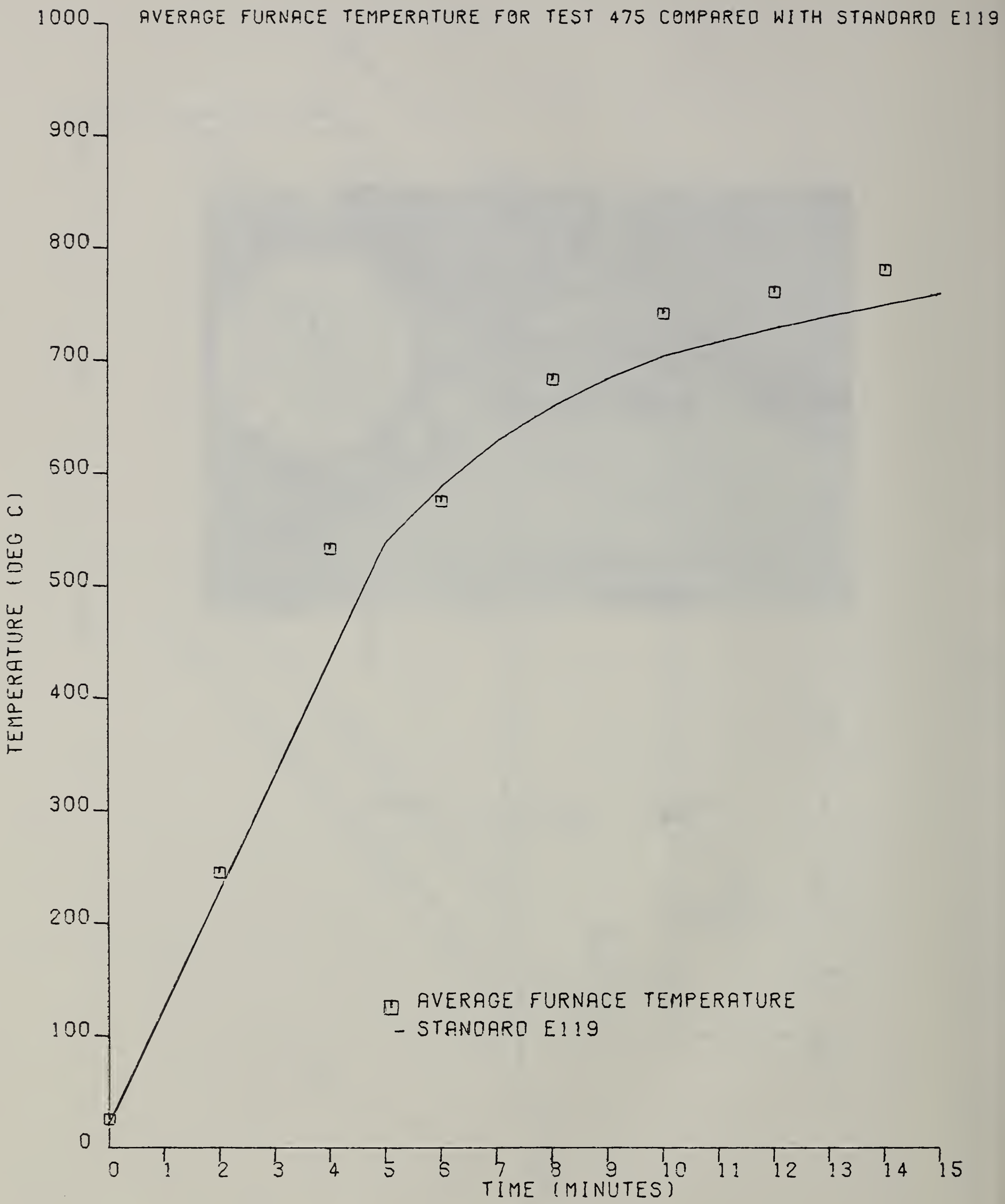

AVERAGE FURNACE TEMPERATURE FOR TEST 475 COMPARED WITH STANDARD E119
TEMPERATURE (DEG C)
0
100
200
300
400
500
600
700
800
900
1000
TIME (MINUTES)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
AVERAGE FURNACE TEMPERATURE
- STANDARD E119

FIGURE 8.

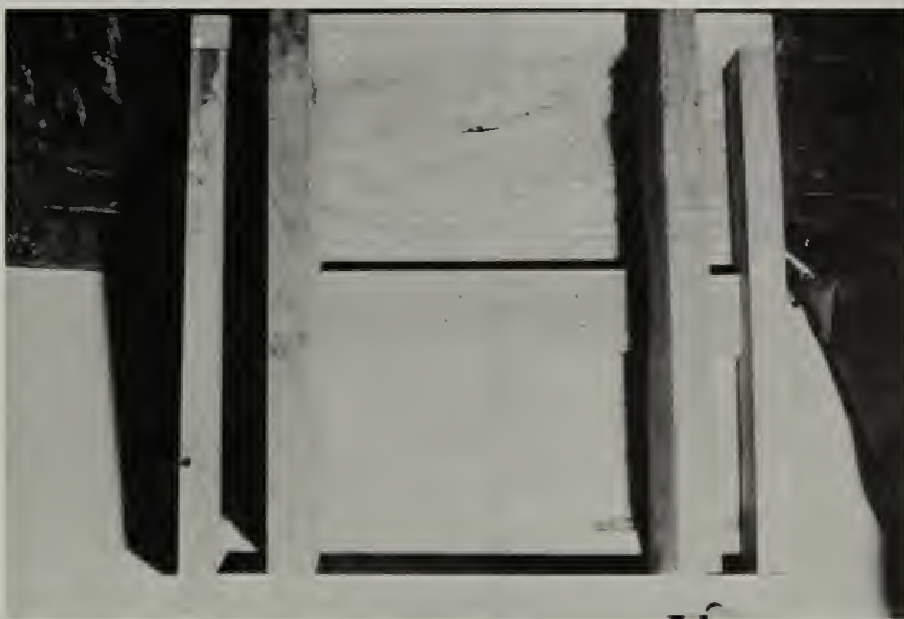


Figure 9 Underside of Specimen in
Test #S-6

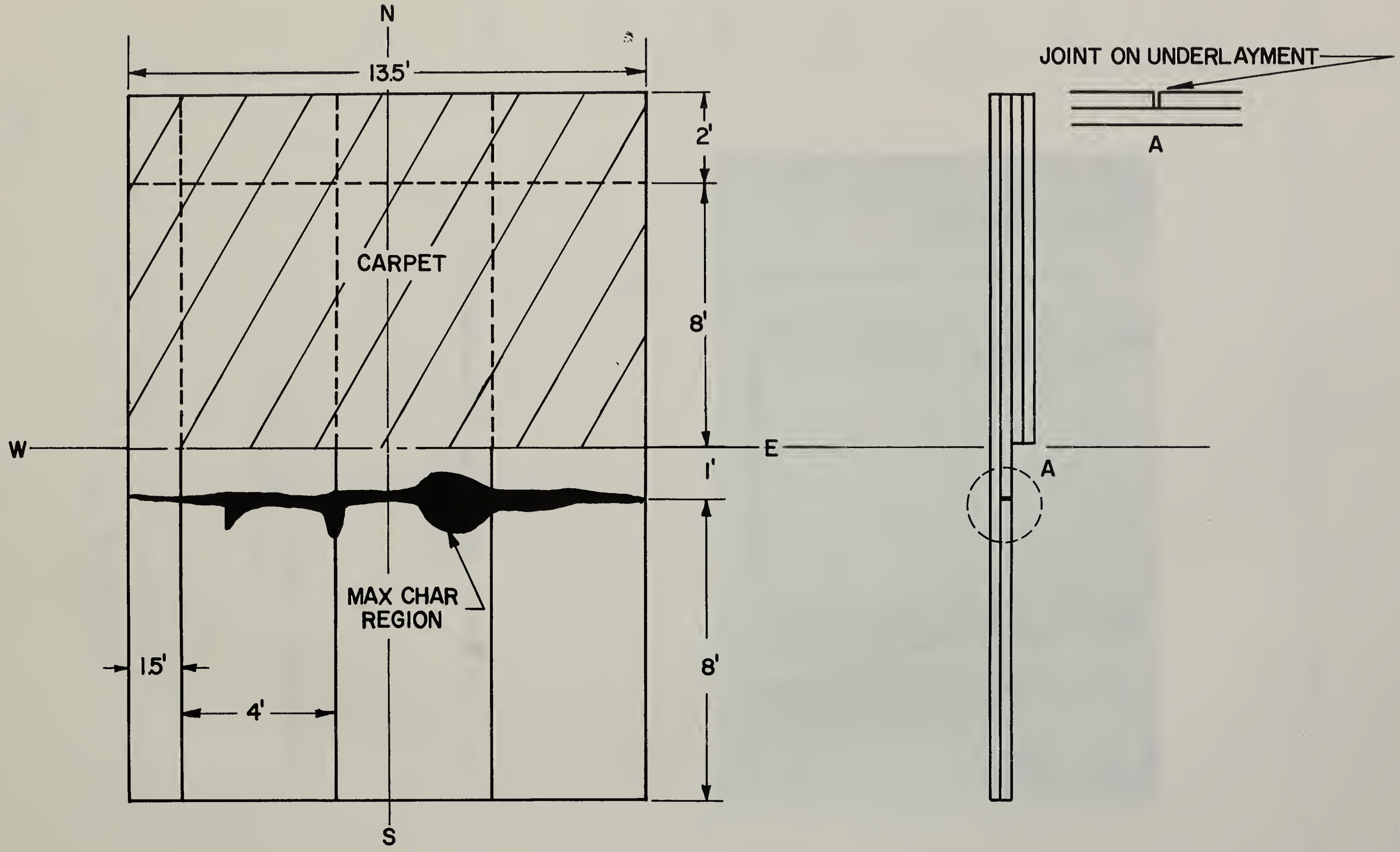


FIGURE 10. Char Region on Unexposed Surface after Test #L-1

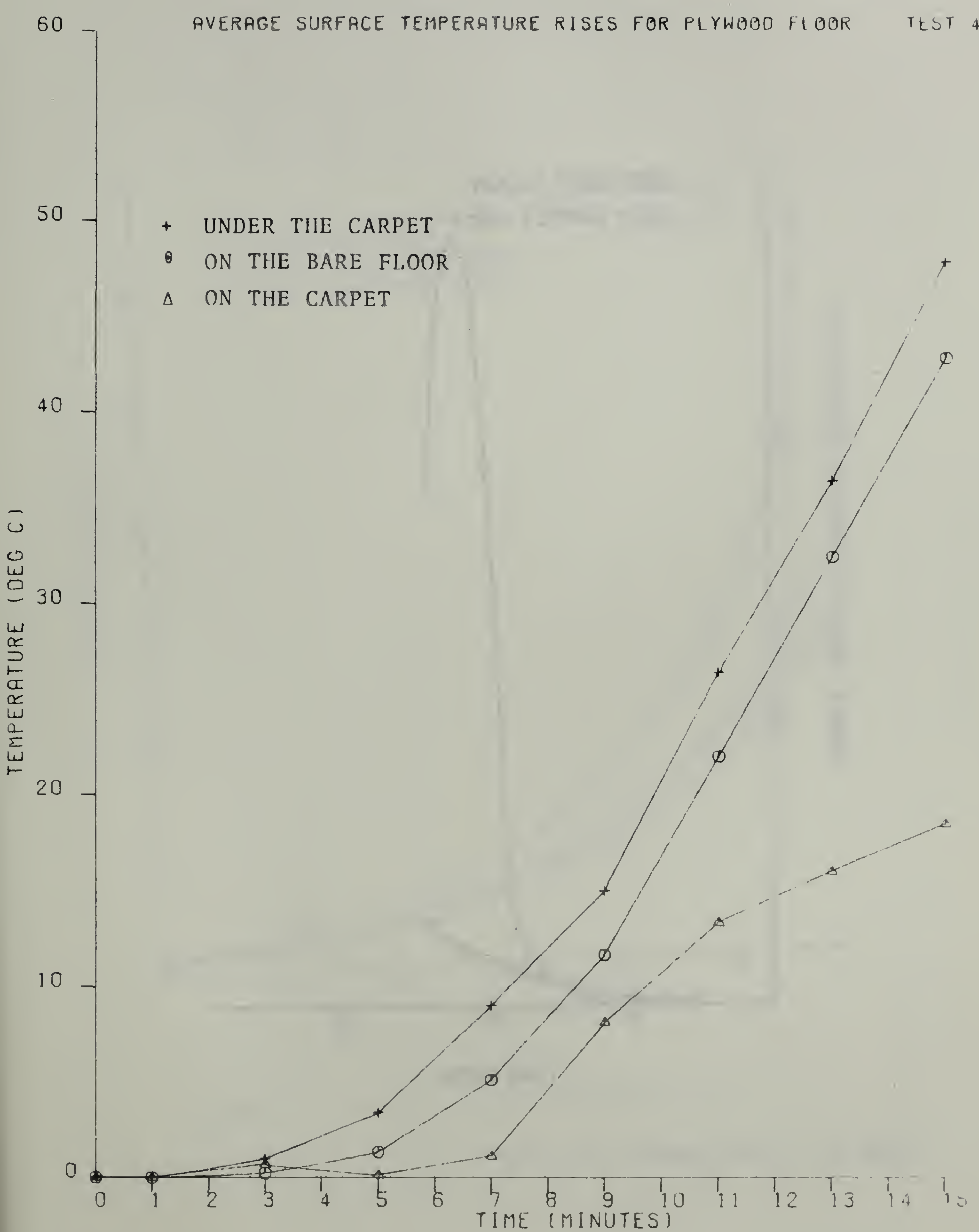

AVERAGE SURFACE TEMPERATURE RISES FOR PLYWOOD FLOOR TEST 475
UNDER THE CARPET
ON THE BARE FLOOR
ON THE CARPET
TEMPERATURE (DEG C)
TIME (MINUTES)
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

FIGURE 11.

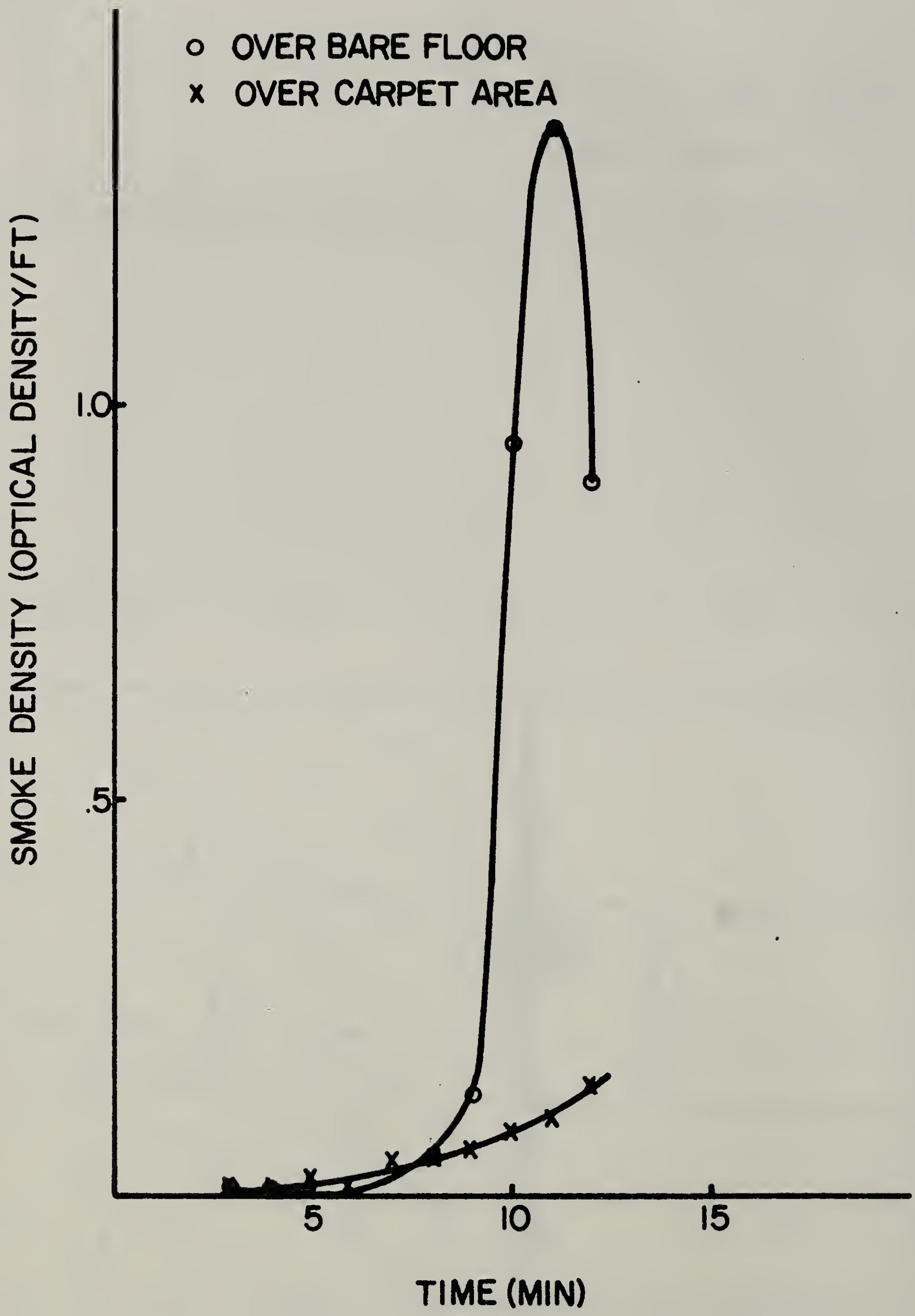


FIGURE 12. Smoke Density, Test #L-1

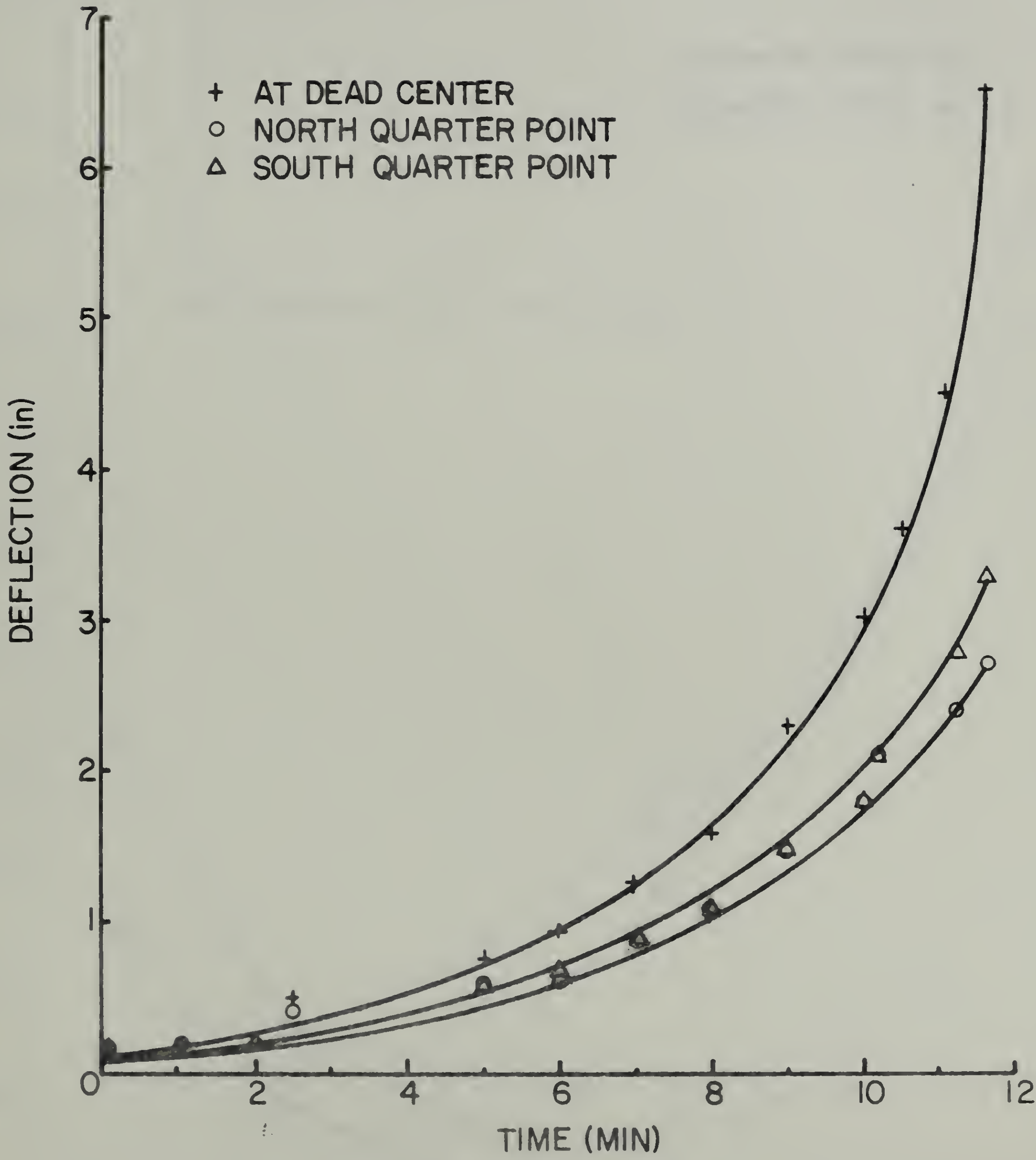


FIGURE 13. Deflection Measurements Test #L-1

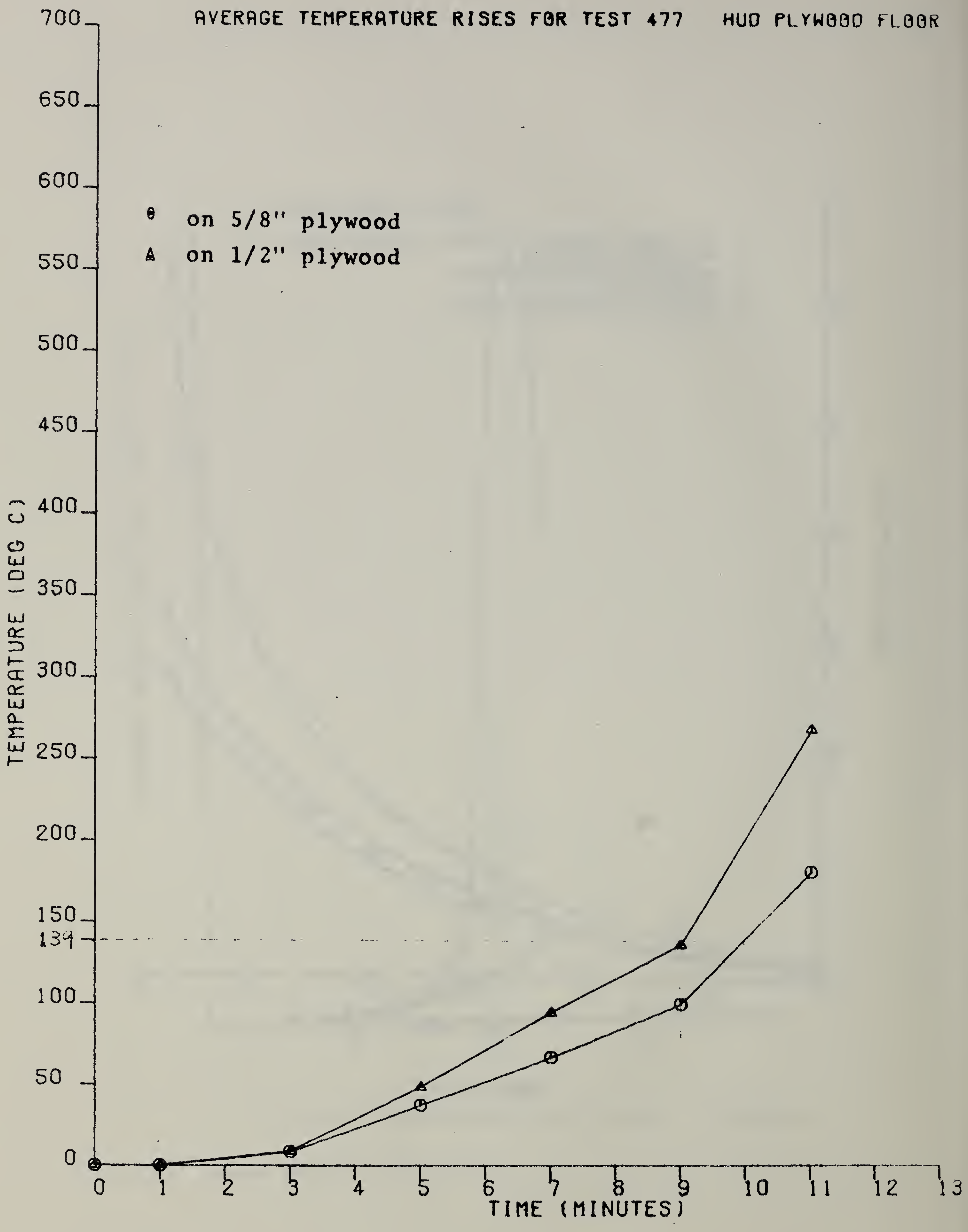

AVERAGE TEMPERATURE RISES FOR TEST 477 HUD PLYWOOD FLOOR
on 5/8" plywood
on 1/2" plywood
TEMPERATURE (DEG C)
TIME (MINUTES)
700
650
600
550
500
450
400
350
300
250
200
150
134
100
50
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13

FIGURE 14.

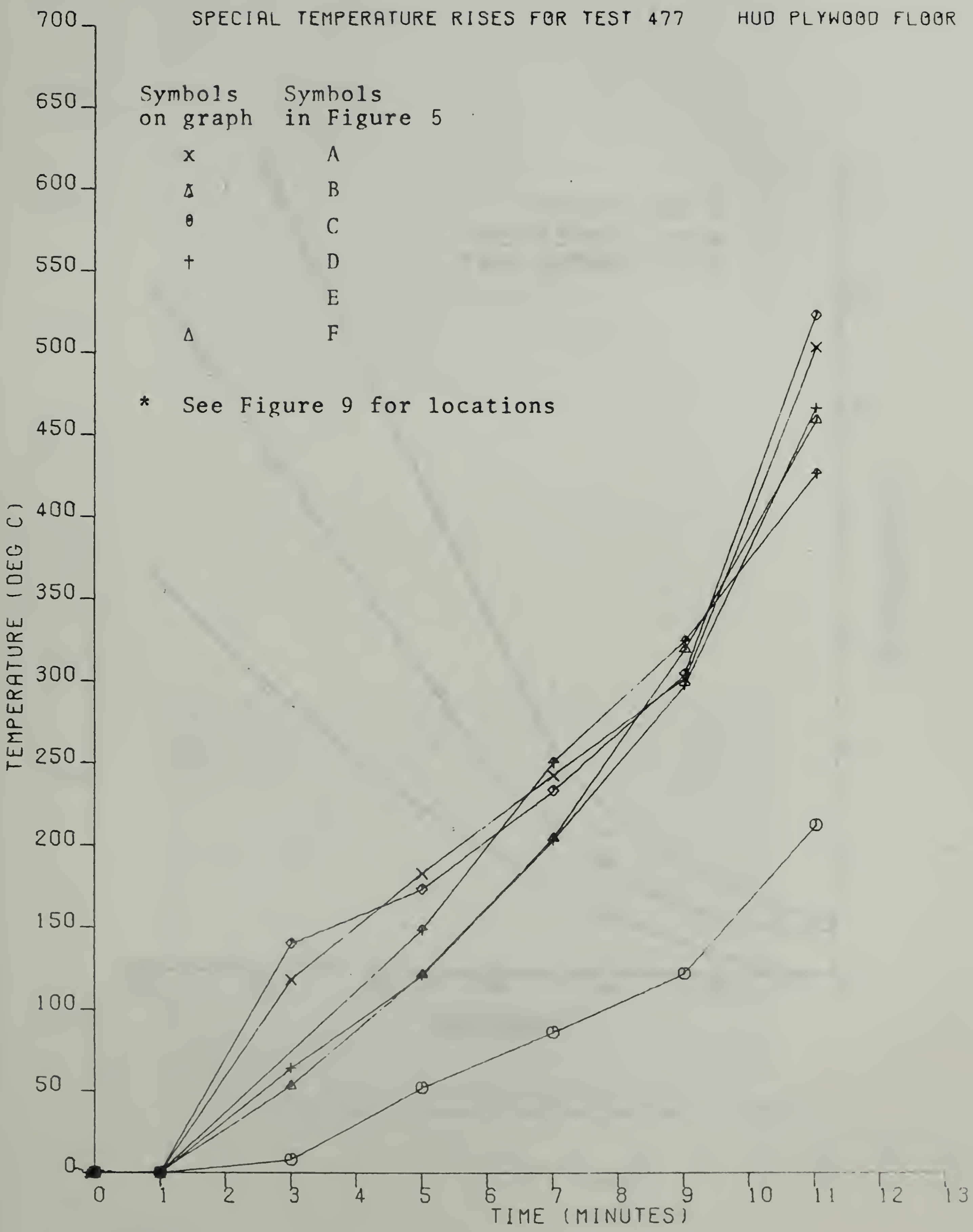

SPECIAL TEMPERATURE RISES FOR TEST 477 HUD PLYWOOD FLOOR
Symbols on graph
Symbols in Figure 5
x A
B
C
+ D
E
Δ F
* See Figure 9 for locations
TEMPERATURE (DEG C)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (MINUTES)

FIGURE 15.

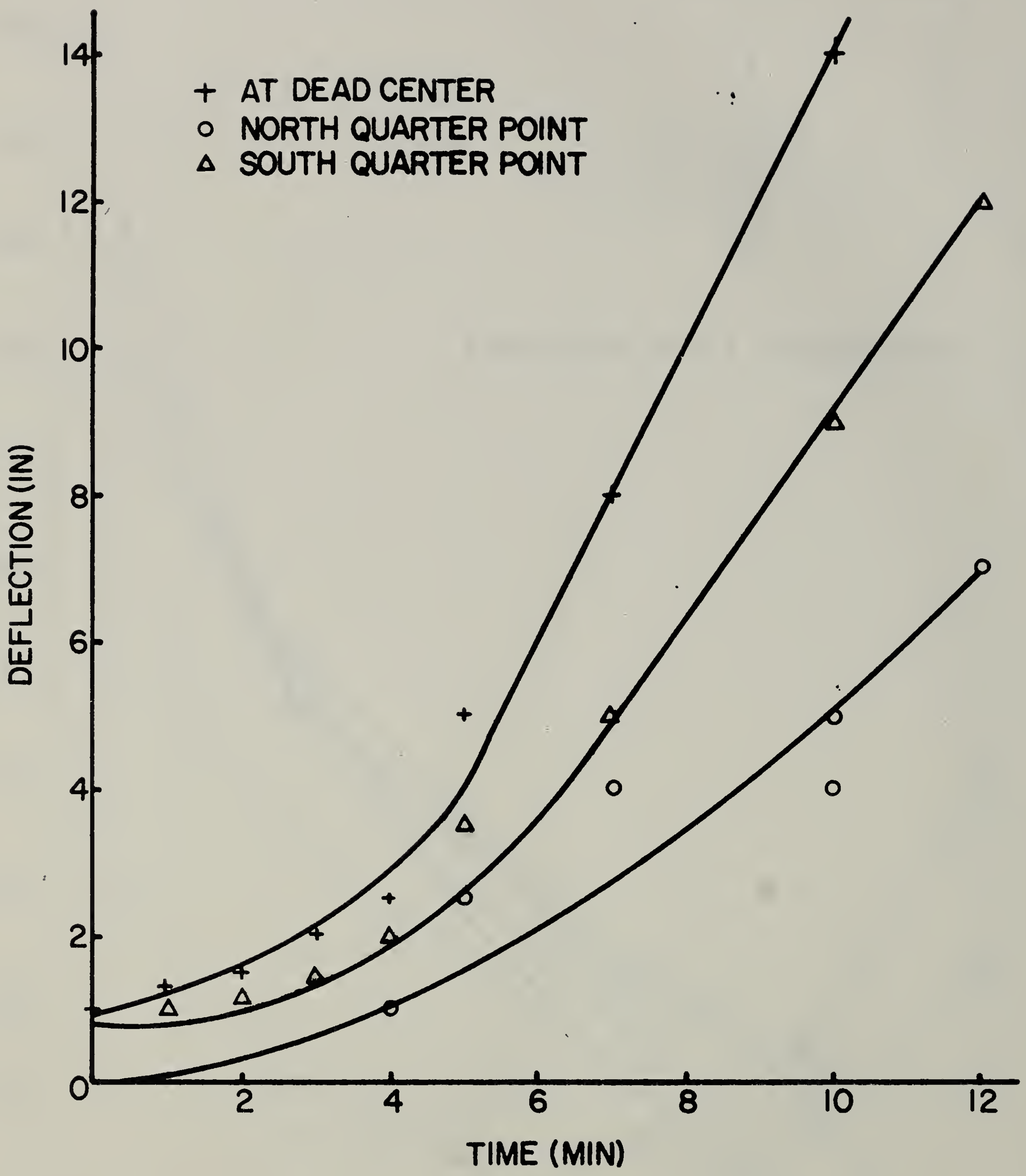


FIGURE 16. Deflection Measurements, Test #L-2

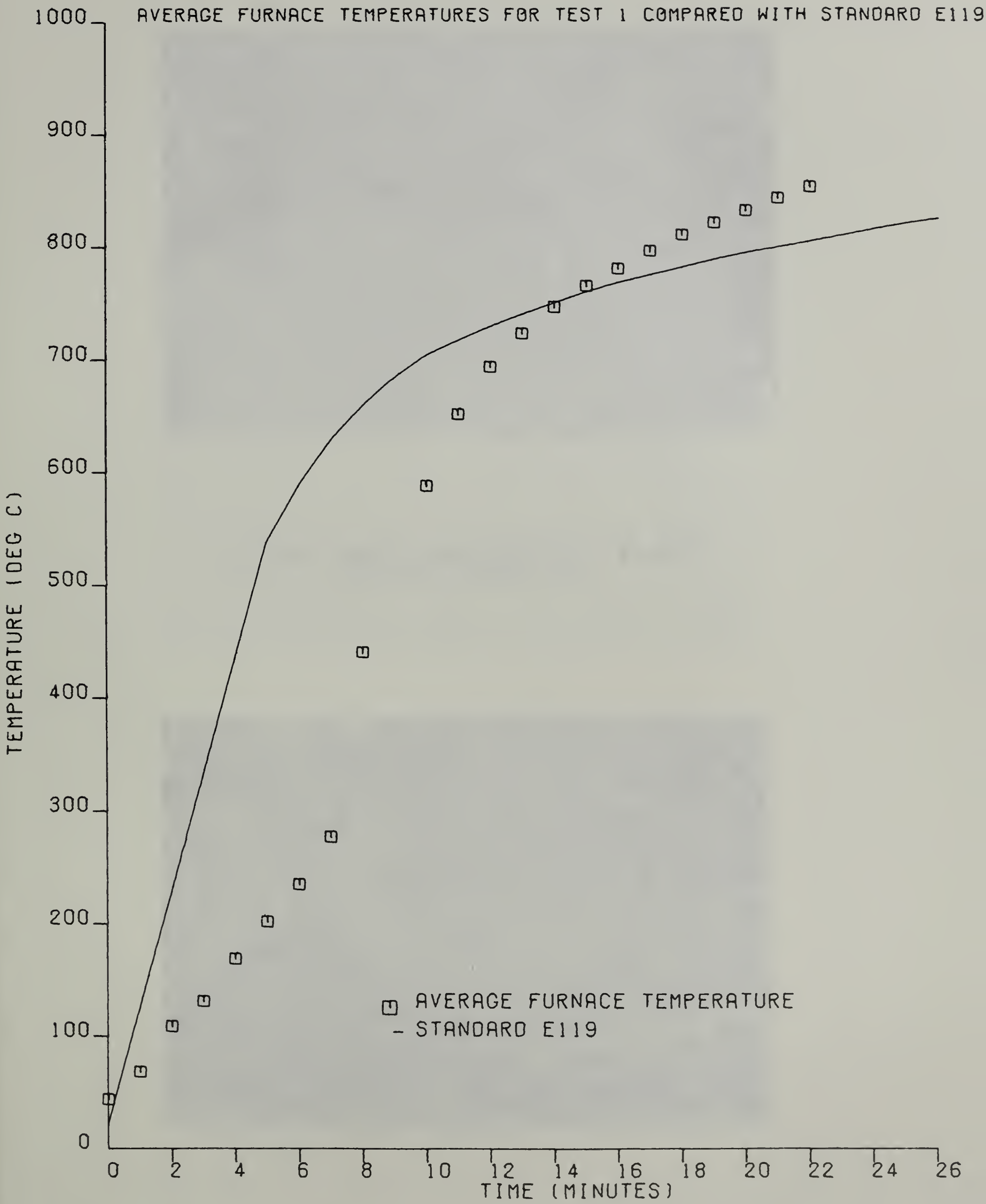

AVERAGE FURNACE TEMPERATURES FOR TEST 1 COMPARED WITH STANDARD E119
TEMPERATURE (DEG C)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME (MINUTES)
AVERAGE FURNACE TEMPERATURE
STANDARD E119

FIGURE 17.

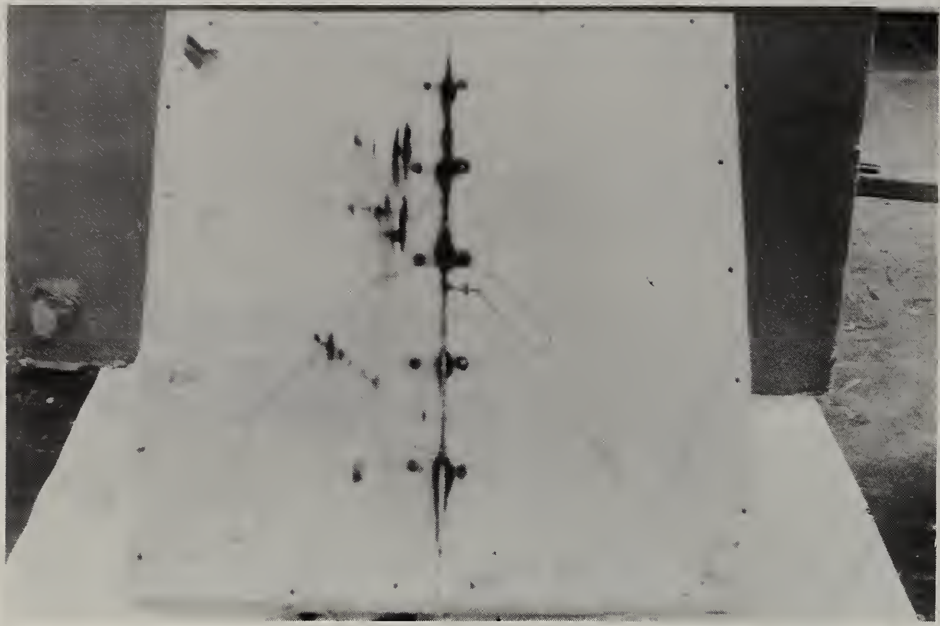


Fig. 18. Flame Through and Associated Char Region Test #S-3

Fig. 19. Locations of Flame Through Openings at Joint (after removing load) Test #S-5

Fig. 20. Smoke at 17.5 min. Test #S-6

Fig. 21. Flame Through. Test #S-6

Fig. 22. Flaming Region Before
Extinguishment. Text #S-6

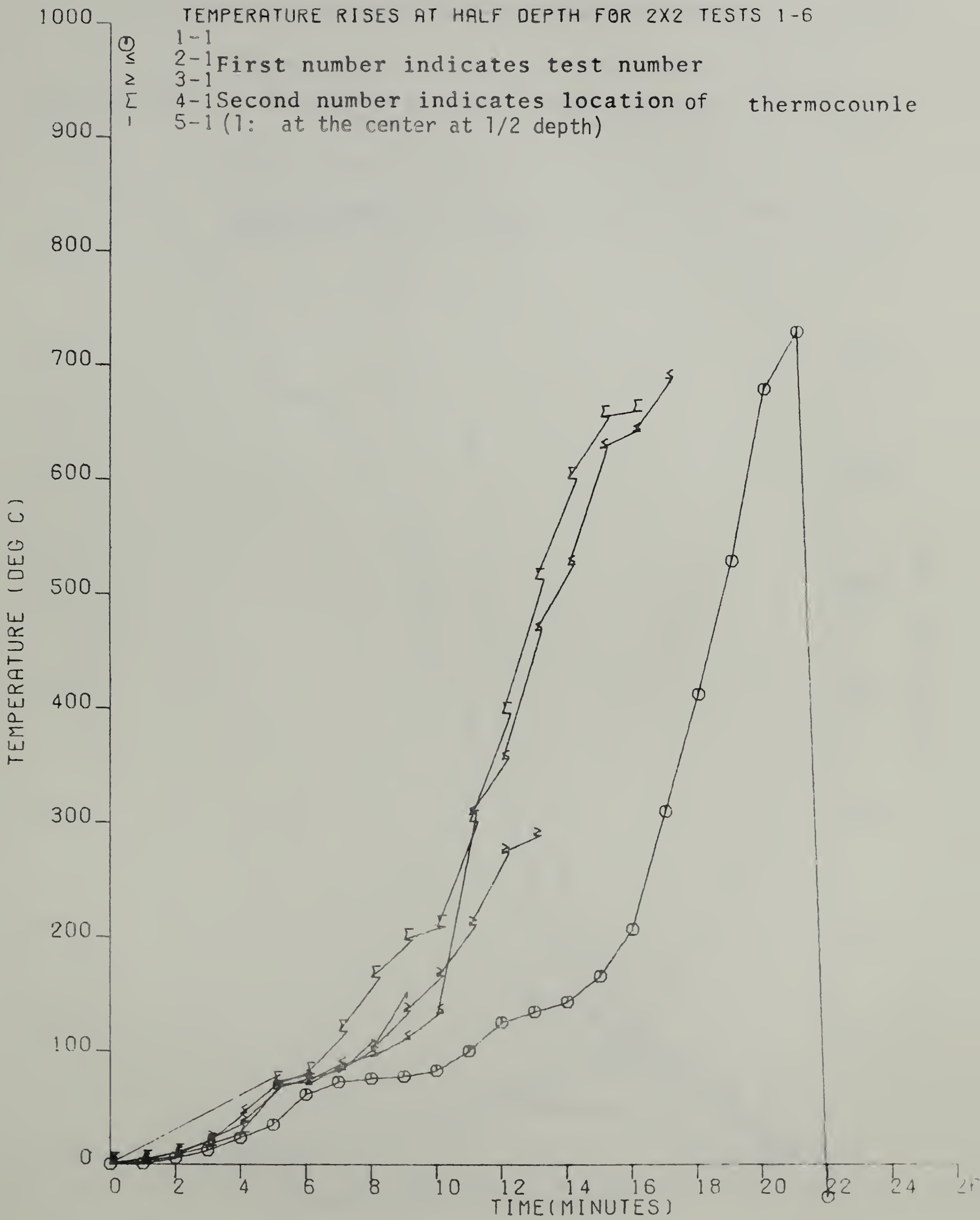

TEMPERATURE RISES AT HALF DEPTH FOR 2X2 TESTS 1-6
1-1
2-1 First number indicates test number
3-1
4-1 Second number indicates location of thermocouple
5-1 (1: at the center at 1/2 depth)
TEMPERATURE (DEG C)
TIME(MINUTES)
0
100
200
300
400
500
600
700
800
900
1000
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig. 23

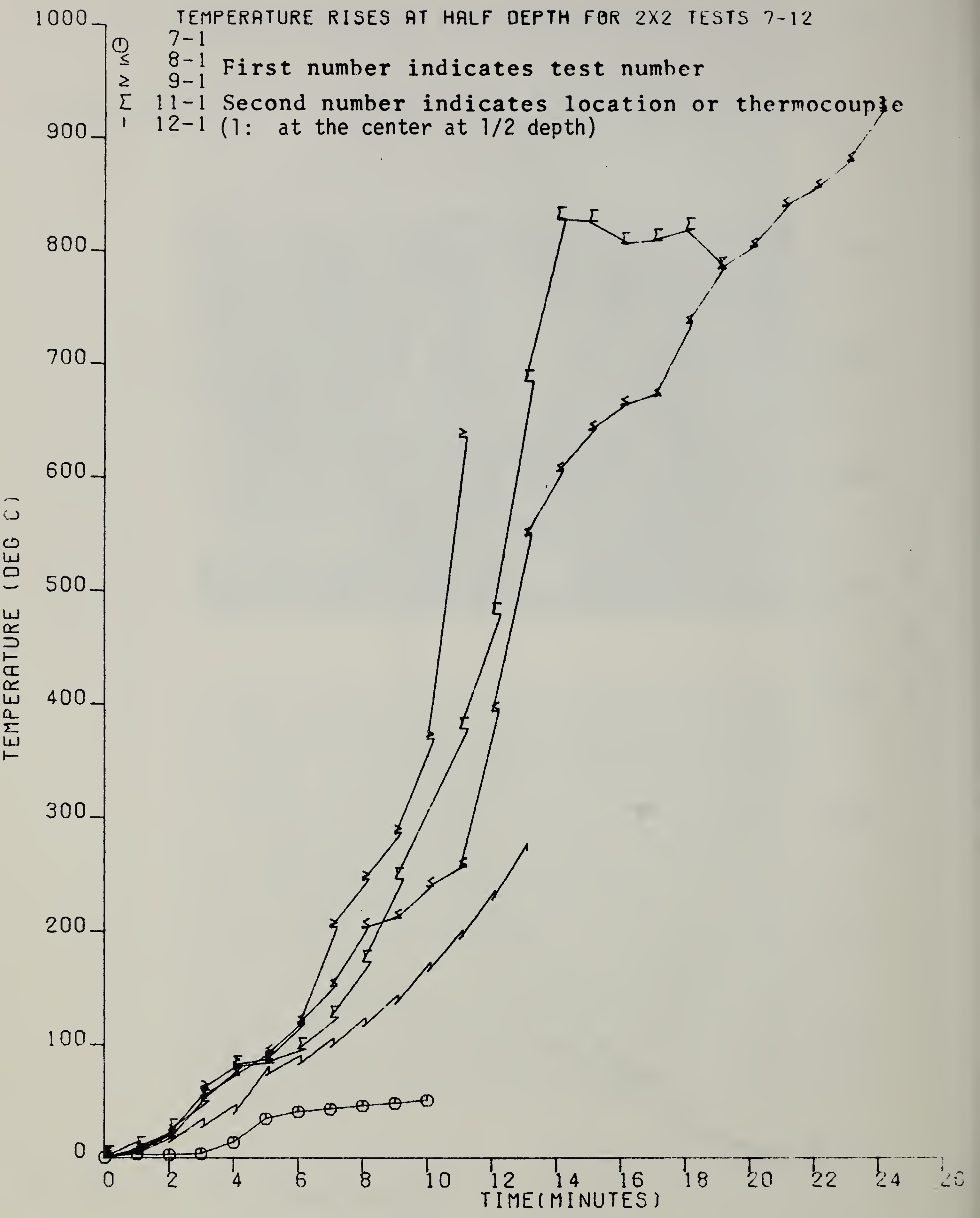
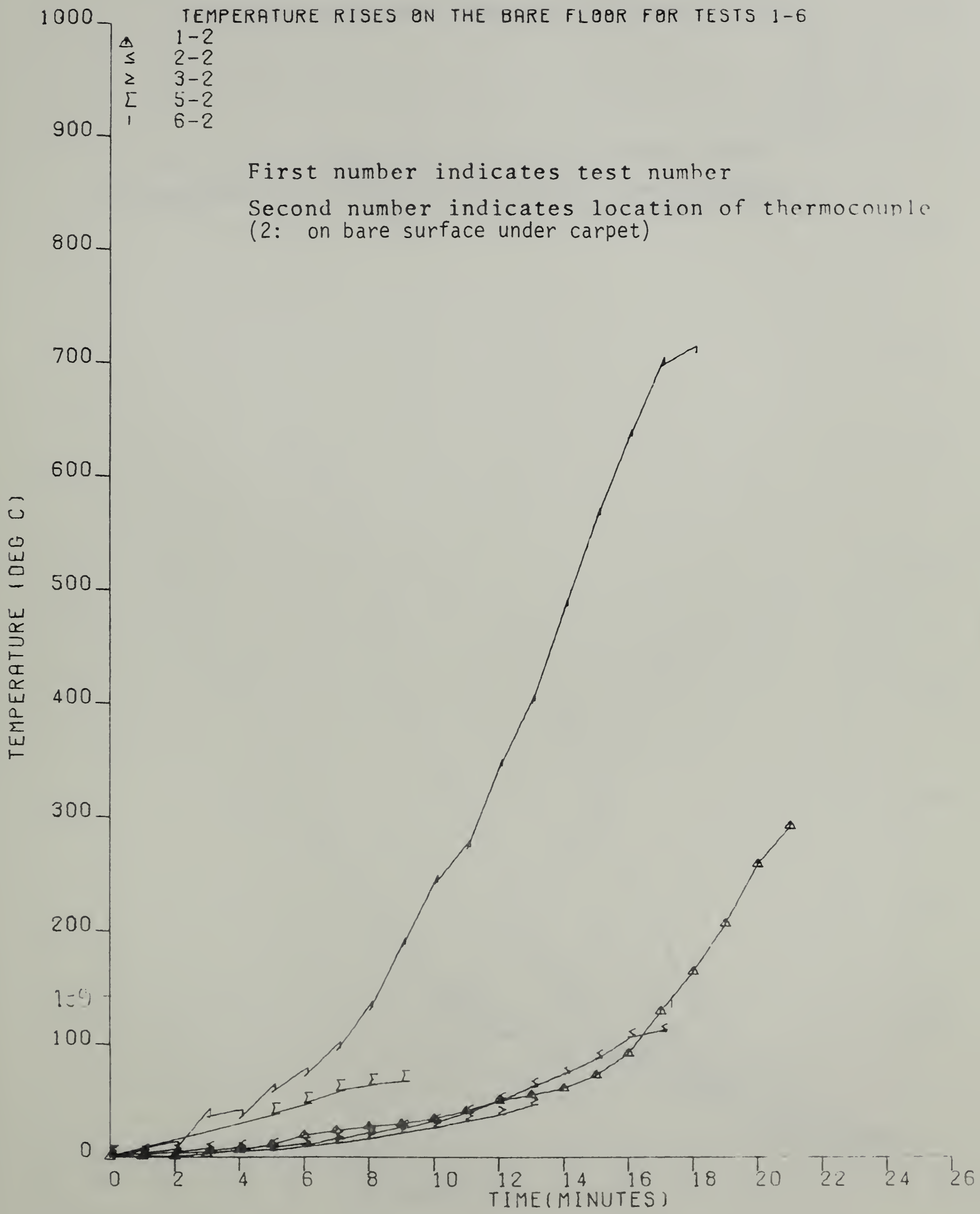

TEMPERATURE RISES AT HALF DEPTH FOR 2X2 TESTS 7-12
7-1
8-1
9-1
11-1
12-1
First number indicates test number
Second number indicates location or thermocouple
(1: at the center at 1/2 depth)
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (DEG C)
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME(MINUTES)

Fig. 24.



TEMPERATURE RISES ON THE BARE FLOOR FOR TESTS 1-6
1-2
2-2
3-2
5-2
6-2
First number indicates test number
Second number indicates location of thermocouple
(2: on bare surface under carpet)
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (DEG C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME(MINUTES)

Fig. 25.

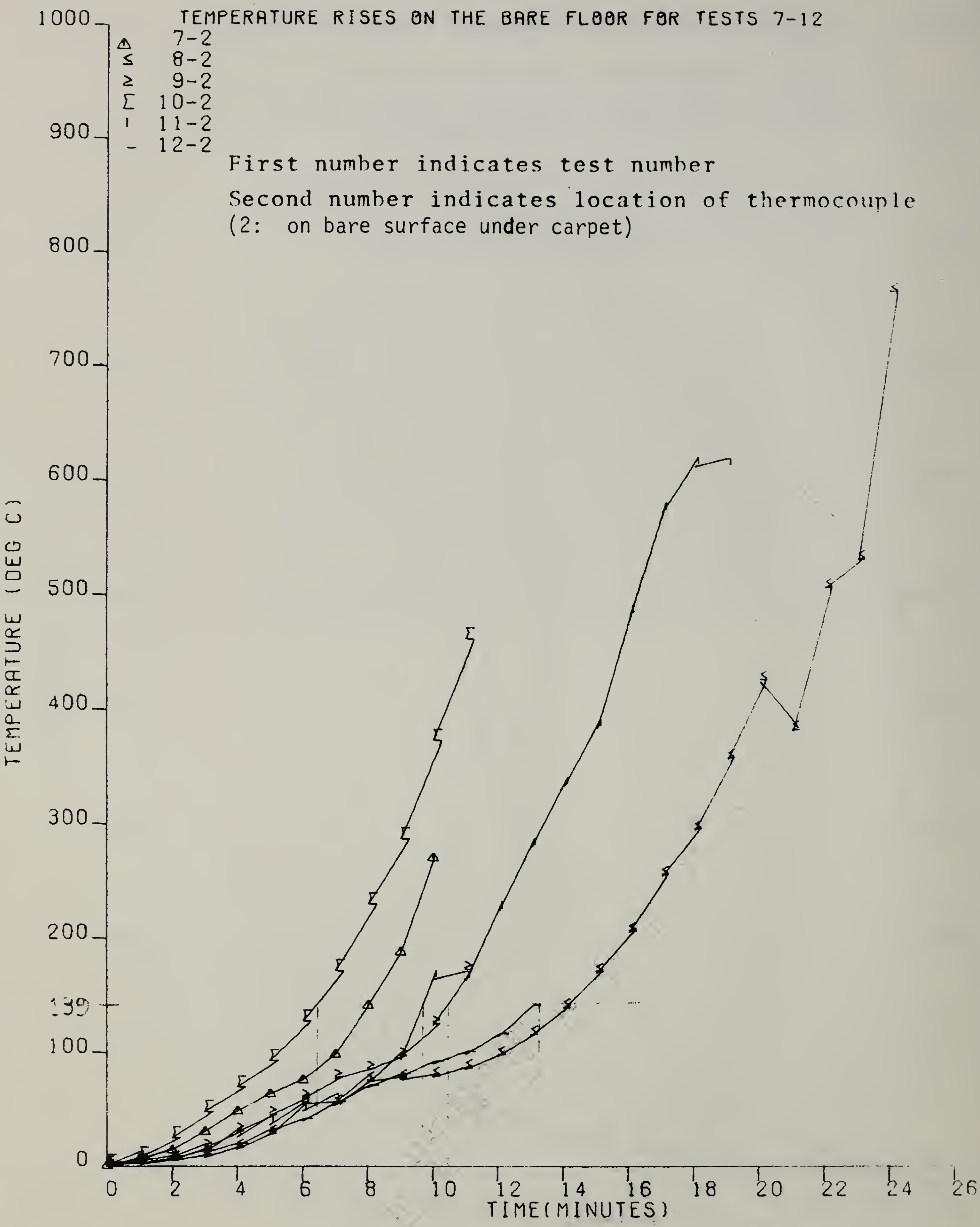

TEMPERATURE RISES ON THE BARE FLOOR FOR TESTS 7-12
Δ 7-2
≤ 8-2
≥ 9-2
Σ 10-2
ˈ 11-2
- 12-2
First number indicates test number
Second number indicates location of thermocouple
(2: on bare surface under carpet)
TEMPERATURE (DEG C)
1000
900
800
700
600
500
400
300
200
139
100
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME(MINUTES)

Fig. 26.

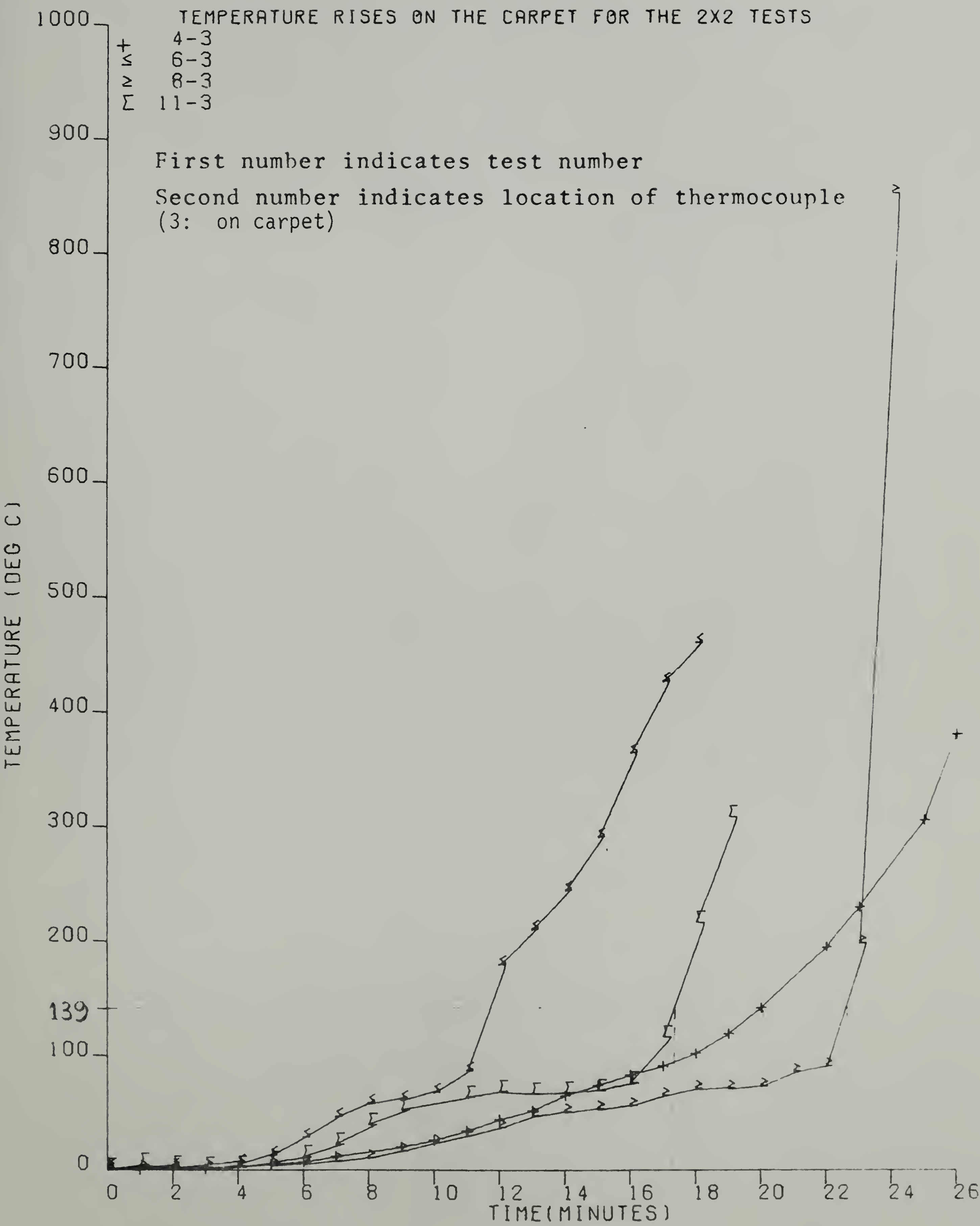

TEMPERATURE RISES ON THE CARPET FOR THE 2X2 TESTS
+ 4-3
≤ 6-3
≥ 8-3
Σ 11-3
First number indicates test number
Second number indicates location of thermocouple
(3: on carpet)
TEMPERATURE (DEG C)
1000
900
800
700
600
500
400
300
200
139
100
0
TIME(MINUTES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26

Fig. 27.

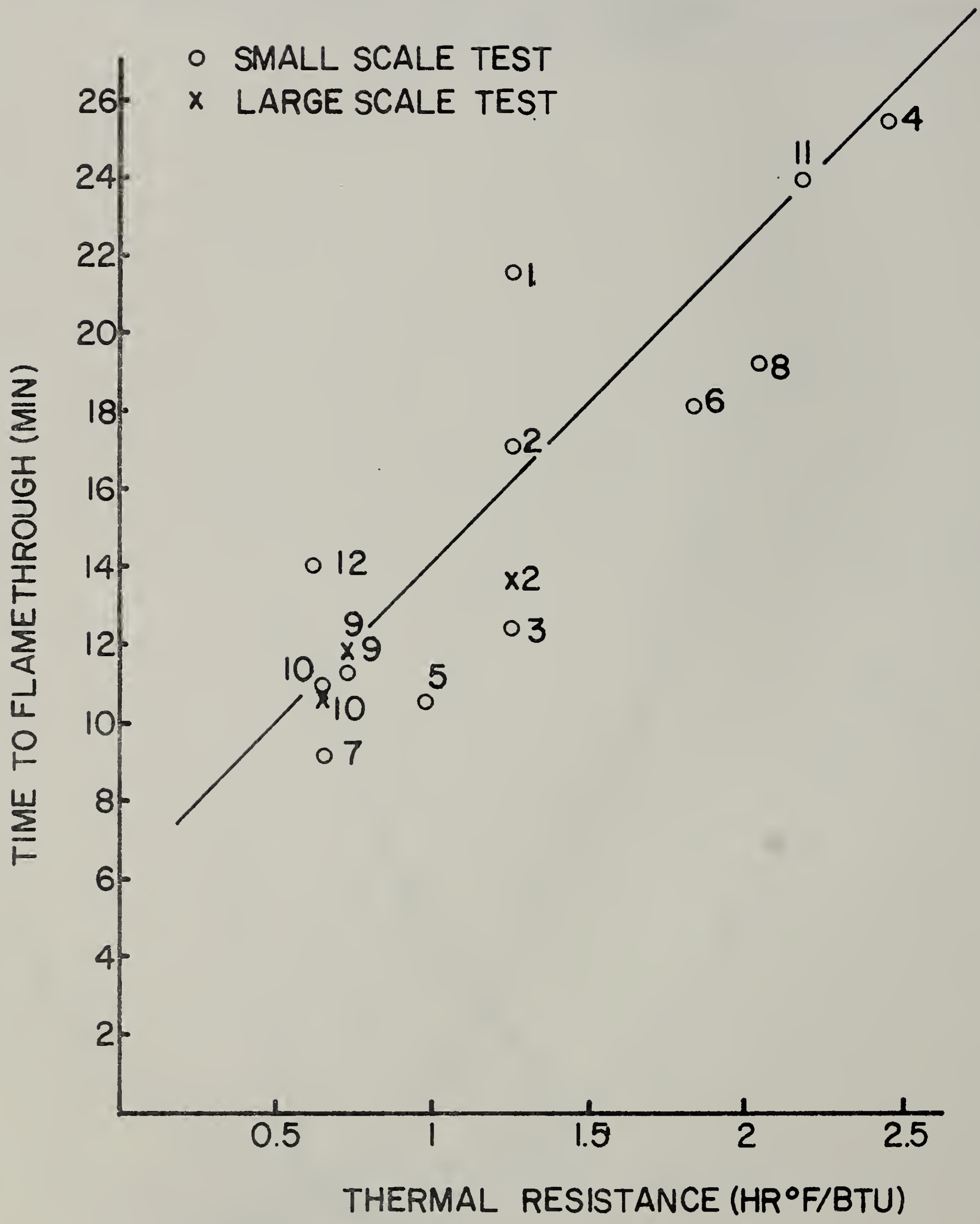


Fig 28 Thermal RESISTANCE of Floor Construction Vs Flamethrough Time

DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS