NATIONAL BUREAU OF STANDARDS REPORT

10 677

FIRE ENDURANCE TEST OF AN INTERDWELLING WALL

Sponsored by

The Gypsum Association

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

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Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information [3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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FIRE ENDURANCE TEST OF AN INTERDWELLING WALL

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Sponsored by:

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ABSTRACT

In a research study sponsored by the Gypsum Association, a double wall assembly was subjected to a standard fire endurance test in accordance with ASTM E119-69. The Fire Research Section, NBS, monitored the construction of the assembly and witnessed the test, which was conducted at the National Gypsum Company Fire Test Laboratory, Buffalo, New York, on September 23, 1971. The wall assembly consisted of two parallel and identical wall panels separated by an air space. Each panel contained a 5/8 inch Type X gypsum board nailed to each face of a nominal 2 x 4 inch wood stud (actual 1-1/2 by 3-1/2 inch) on 16 inch centers. Each panel was separately loaded to represent field construction.

The fire resistance of the first (fire-exposed) panel was 68 minutes, based on structural failure.

The fire resistance of the complete assembly was 118 minutes. The initial mode was a structural failure, followed immediately by "flame through" at the resultant cracks.

No hose stream test was conducted.

INTRODUCTION

A standard fire test was conducted to measure the fire endurance of a wall construction made from two separate wall panels. This test was carried out as a research program sponsored by the Gypsum Association at National Gypsum Company Fire Test Laboratory, Buffalo, New York on September 23, 1971 and was witnessed by personnel from NBS.

The wall assembly consisted of two identical 10 ft x 10 ft panels, parallel to each other with a one inch air space between the two panels. Each panel consisted of 5/8 inch Type X gypsum board on each face of 2 x 4 (nominal) wood studs on 16 inch centers. The two parallel wall panels constitute an assembly, which could represent an inter-dwelling wall between two single family attached units. They were investigated for both the structural and thermal fire endurance of the assembly. It was necessary to apply a load separately on each panel to be a representative of field construction.

The fire exposure followed the requirements of the Standard Methods of Fire Tests of Building Constructions and Materials, ASTM E119-69, for load-bearing walls.

A commercial device is identified in this report in order to adequately describe the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards.

TABLE OF CONTENTS

DESCRIPTION OF TEST ASSEMBLY

The wall assembly consisted of two identical 10 foot by 10 foot panels, parallel to each other with a one inch air space between the two panels. Each panel consisted of a layer of 5/8 inch Type X gypsum board faces applied to the face of 2 x 4 (nominal) wood studs on 16 inch centers. The wood studs in the first and the second wall panel were staggered. Fire stops, consisting of 2 x 4 (nominal) wood block, were placed at the mid-height of the panel and were staggered for direct nailing using #8 common nails. The top of the panel was closed by a single 2 x 4 (nominal) header and the bottom was closed by a double 2 x 4 (nominal) sill. See Figure 1 for the construction details.

The wood members used in this assembly were "Select Structural" 2" x 4" x 14' Douglas Fir S-Dry (1-1/2" x 3-1/2" net). These were inspected by a representative of the Western Wood Products Association on September 15, 1971 in accordance with the 1970 standard grading rules for Western lumber as published by the Western Wood Products Association. The lumber bears the association grading department identification stamp, WWP-12. Each wood member was weighed and the moisture content was measured with a solid wood Moisture Detector manufactured by Delmhost Instrument Co. (Model #RC-2) and supplied by NBS. The average measured weight and moisture content of the wood members were 1.248 LB/FT and 11.68%.

Three different brands of 5/8 inch Type X gypsum boards were used to form the gypsum faces of the panels. The three brands were "Gold Bond" by National Gypsum Company, "Sheet Rock" by U.S. Gypsum Company, and "Best Wall" by Georgia Pacific Company. See Figure 2 for the locations of the different brands.

Joints between gypsum boards were tapered and filled with "Gold Bond" STA-Smooth joint compound and reinforced with paper tape.

The gypsum boards were attached with cement coated cooler nails (6d, 1-7/8 inch long) on 16 inch centers horizontally and on 7 inch centers vertically.

The average measured end thickness and taper, and weights of each of the brands of gypsum board were as follows:

Brand	End Thickness	Taper	Weight
	(inch)	(inch)	(LB/FT^2)
Gold Bond	0.619	0.5838	2.40
Sheet Rock	0.6257	0.59	2.42
Best Wall	0.6219	0.5728	2.39

In the details of construction the assembly was considered representative of field construction. Construction of the assembly was started on September 20, 1971 and completed on September 22, 1971. The temperature and humidity in the construction and storage area were not controlled and so were the same as the ambient contitions.

INSTRUMENTATION

A total of 33 bare thermocouples, of which 16 were chromel-alumel and 17 were iron-constantan, were installed in the assembly. As is shown in Figure 2, four thermocouples were located on each of the four faces identified in Figure 1 and five between studs and the unexposed side of face 3.

Nine ASTM surface thermocouples under standard 6 x 6 x 0.4 in felted asbestos pads were placed on the unexposed surface.

The lateral deflections of the unexposed surface were measured from a horizontal reference wire which was strung at the mid-height of the assembly and 4-1/2 inch from the unexposed surface. The variations of the distances from the wire to the unexposed surface were measured periodically during the test with a ruled stick.

The vertical movements of each wall panel during the test were measured by four dial gages, which were located at the quarter points at the bottom of each loading frame, as shown in Figure 3.

DESCRIPTION OF TEST

The panel assembly was mounted in a 10 foot by 10 foot frame of the wall test furnaces at National Gypsum Co., Buffalo, New York. Five minutes before the test started the design load of 2020 LB/stud was applied. This design load was governed by the crushing strength of the sill which was lower than the strength of the stud. The load was applied to each panel independently through 4 hydraulic jacks. The calculation of the design load is shown in Appendix 1. Figure 3 shows the unexposed surface of the specimen; the thermocouple connections, loading equipment, and the lateral and the vertical deflection measuring devices. Figure 4 shows the back side of the furnace, gas lines and recorders.

The temperature inside the furnace was measured by 11 ASTM thermocouples enclosed in sealed 1/2 inch wrought iron pipes placed 6 inches from the exposed face of the specimen. The furnace temperature was constrained to follow the standard ASTM E119 temperature-time curve by manual control of the chimney opening. The actual furnace time-temperature curve and the standard curve are shown in Figure 5. The criteria for the fire endurance of a bearing wall construction in ASTM procedure E119-69 are as follows:

a. The wall or partition 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 wall or partition during the fire endurance test shall not have been such as to 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.

A test shall be regarded as successful if the above conditions are met.

The furnace was operated in accordance with standard National Gypsum Co. test practices. An exhaust blower in the chimney flue is operated for the first 5 minutes, then turned off. Measurements of furnace pressure were made using iron pipe probes located at three vertical positions. At an elevation corresponding to one-third height of the assembly, the pressure was varied between minus .08 and 0. inch H_2O (negative).

TEST OBSERVATION

min:sec	Observations
00:00	Start Test
01:05	Paper on the exposed face ignited (Fig. 6).
03:00	Flame spread over the entire exposed face.
04:00	Paper tape used to reinforce the joint compound beginning to fall off (Fig. 7).
06:00	Combustion of the paper on the exposed face completed.
16:00	No smoke observed on the unexposed surface.
23:00	Joint spackling falling down. The horizontal joint appears to be charring on the exposed face.
30:00	Joints on the exposed face beginning to open up.
35:00	Small flames from the combustion of the wood stud were coming through the joint opening.
40:00	On the exposed face, the individual gypsum boards were buckling between the joint line. (Fig. 8)
50:00	Flaming at the joint openings becoming more severe.
57:00	No smoke observed on the unexposed surface, probably because the furnace pressure was negative.
62:00	The horizontal gypsum joints opened wide and bowed out and the gypsum boards at the joints appeared ready to fall down. (Fig. 9)
63:00	Pieces of the exposed face falling down. (Fig. 10)
65:00	The second gypsum face of the first wall panel was visible.
68:00	Load failure of first wall (See Table 1 for the vertical movement of the first wall).

70:00	The second gypsum face of the first wall beginning to fall in.
75:00	Large openings forming on the second gypsum face of the first wall.
77:00	Paper burning on the exposed gypsum face of the second wall.
90:00	Most of the first wall had fallen into the furnace. The horizontal joint on the exposed gypsum face of the second wall beginning to blacken and open up. (Fig. 11)
93:00	Flames from the wood studs coming through the joint openings on the exposed face of the second wall. Crackling sounds from the burning of wood studs in the second wall.
103:00	The horizontal gypsum joint on the exposed face of the second wall opened wide and bowed down and seemed ready to fall in.
110:00	Severe flaming from the large hole (about 1 foot square) which formed near the center of the north quarter portion on the exposed face of the second wall.
115:00	The unexposed side still appeared sound. (Fig. 12)
118:00	Load failure followed by flame through at the resultant crack formed at mid-height near the north quarter point of the assembly. (Fig. 13) End of Test

TEST RESULTS

The average temperature rise of the unexposed surface and the maximum temperature rise during the test are shown in Figure 14. The average temperature gradients across the double wall assembly, the north half of the assembly and the south half of the assembly are shown in Figures 15, 16, and 17.

The structural failure of the first wall occurred at 68 minutes of test time, as shown in Table 1.

The structural failure of the second wall occurred at 1 hour: 58 minutes of test time and was followed by flame through. Figures 13 and 18 are photographs showing the front view of the unexposed surface and the view of the north end after test. Note the large crack that formed on the unexposed gypsum board face at the north end of the panel. Fig. 19 shows the condition of the fire side of the assembly (the first gypsum face of the second wall panel) after it was removed from the furnace and before the application of water from a fog nozzle. All the gypsum joints were open, the boards were buckled and the surface was blistered.

In the second panel most of the wood studs were either charred or consumed and had lost their structural strength. A photograph of three wood studs from the center and quarter points near the mid-height of the panel is shown in Fig. 20. This picture shows that the wood stud at the north quarter point was more severly burned than those at the center and south quarter point. This occurred when the lower vertical joint, on the second wall, near the north quarter point opened up during the test. See Fig. 19.

The lateral deflection at the mid-height of the unexposed surface varied from zero to one inch away from the furnace. The vertical movement of the first wall exceeded the 1 inch range of the dial gages at 68 min. The horizontal and vertical movements of both wall panels are shown in Table 1.

COMMENTS ON TEST

The construction of the specimen, as shown in Figures 1 and 2, was symmetrical except for the locations of the joints, so that if the opposite side would have been exposed to the fire it would have provided the same fire resistance.

The one inch air space between the two wall panels in this assembly was smaller than the 2-1/2 inch air space commonly found in conventional construction. This smaller air space was used in order to emphasize any mechanical damage of the second wall by the structural failure of the first wall. During this test there was no evidence of such damage. This difference in thickness of the air space is thought to have little or no effect on the thermal performance of the assembly.

The 118 minute fire endurance of the assembly is close to 175 percent of that of the first wall, ie. 68 x 1.75 = 119 minutes. This is in agreement with the average results of several different loaded double wall tests performed under Operation BREAKTHROUGH. This relationship applies when the quality of each wall in the double wall configuration is similar and when the wall surfaces that face the air space between the two walls.

APPENDIX I

Loading Calculation

Type lumber: Select Structural Douglas Fir

Structural properties of the studs:

Modulas of Elasticity:	$E = 1{,}800{,}000$ psi
Actual Unit Stress for fiber in Bending:	$f_b = 2{,}100$ psi
Allowable unit stress in compression perpendicular to grain:	$F_{c\perp} = 385$ psi
Allowable unit stress in compression parallel to grain:	$F_c - 1{,}600$ psi
Cross section area:	$A = 3.5\times1.5 = 5.25$ in^2
Length:	$L = 115.5$ inch
Depth:	$d = 3.5$ inch
Total concentrated load:	$P =$ lbs

a) Using Column Formula;

$$P/\text{stud} = \frac{0.3\ EA}{(L/d)^2} = \frac{0.3\times1.8\times10^6\times5.25}{(115.5/3.5)^2} = 2{,}600\ \text{LB/stud}$$

b) Load calculation based on bearing plate compression;

$$P/\text{stud} = F_{c\perp}\times A = 385\times8.25 = 2{,}020\ \text{LB/stud}$$

Allowable load per stud:

The allowable load is the lesser of (a) and (b) above.

Allowable live load = 2,020 LB/stud.

Total Allowable live load per wall; 9 studs in each wall

Load/wall = 2,020 x 9 = 18,180 LB/wall

The load is applied on each wall through 4 jacks.

Load/jack = 18,180/4 = 4,550 LB/jack.

Since the cross section area of the rod in the jack is 12.57 in^2, the gauge pressure can be obtained, as

$$\text{Gage pressure} = \frac{4{,}550}{12.57} = 362\ \text{psi}$$

Actual pressure = 370 psi

$$\text{The percentage difference} = \frac{370-362}{300}\times 100 \approx 2\%$$

APPENDIX II

Official Observers

H. Carlsen	Gypsum Association, Chicago, Illinois
D. Brackett	Gypsum Association, Chicago, Illinois
R. Friedheim	National Gypsum Co., Buffalo, New York
B. Son	National Bureau of Standards, Washington, D.C.

Deflection Record During Test

TIME (Minutes)	LATERAL UNEXPOSED SURFACE			VERTICAL FIRST WALL		VERTICAL SECOND WALL	
	SQ*	CENTER	NQ*	SQ	NQ	SQ	NQ
Before Load Applied	0	0	0	0.00	0.00	0.00	0.00
After Load Applied	0	0	0	0.109	0.100	0.045	0.087
5 Min. Later Load Applied							
Test Time 0	0	0	0	0.20	0.20	0.20	0.20
5	1/8	1/8	1/8	0.205	0.208	0.207	0.204
10	1/8	1/8	1/8	0.210	0.212	0.210	0.206
15	1/8	1/8	1/8	0.221	0.222	0.213	0.206
20	1/8	1/8	1/8	0.228	0.228	0.215	0.206
25	1/8	1/8	1/8	0.238	0.237	0.215	0.206
30	1/8	1/8	1/8	0.264	0.258	0.218	0.206
35	1/8	1/8	1/8	0.305	0.294	0.219	0.206
40	1/8	1/8	1/8	0.354	0.334	0.221	0.206
45	1/8	1/8	1/8	0.397	0.371	0.226	0.208
50	1/4	1/4	3/16	0.451	0.418	0.230	0.208
55	1/4	1/4	1/4	0.527	0.485	0.235	0.208
60	1/4	1/4	1/4	0.600	0.551	0.239	0.209
65	1/4	1/4	1/4	0.800	0.725	0.244	0.210
68	3/8	1/4	1/4	↓	↓		
70	1/4	1/8	1/8			0.246	0.210
75	1/4	1/8	1/8			0.246	0.209
80	1/4	1/8	1/8			0.249	0.209
85	1/4	1/8	1/8			0.253	0.209
90	1/4	1/8	1/8	LIMIT (failure)	LIMIT (failure)	0.259	0.210
95	1/4	1/4	1/4			0.266	0.212
100	1/4	1/4	3/8			0.282	0.232
105	3/8	7/16	5/8			0.308	0.272
110	1/2	3/4	1			0.345	0.327
115	3/4	1	1-1/2			0.405	0.365
118	↓	↓	↓			↓	↓

* SQ: South Quarter Point
* NQ: North Quarter Point

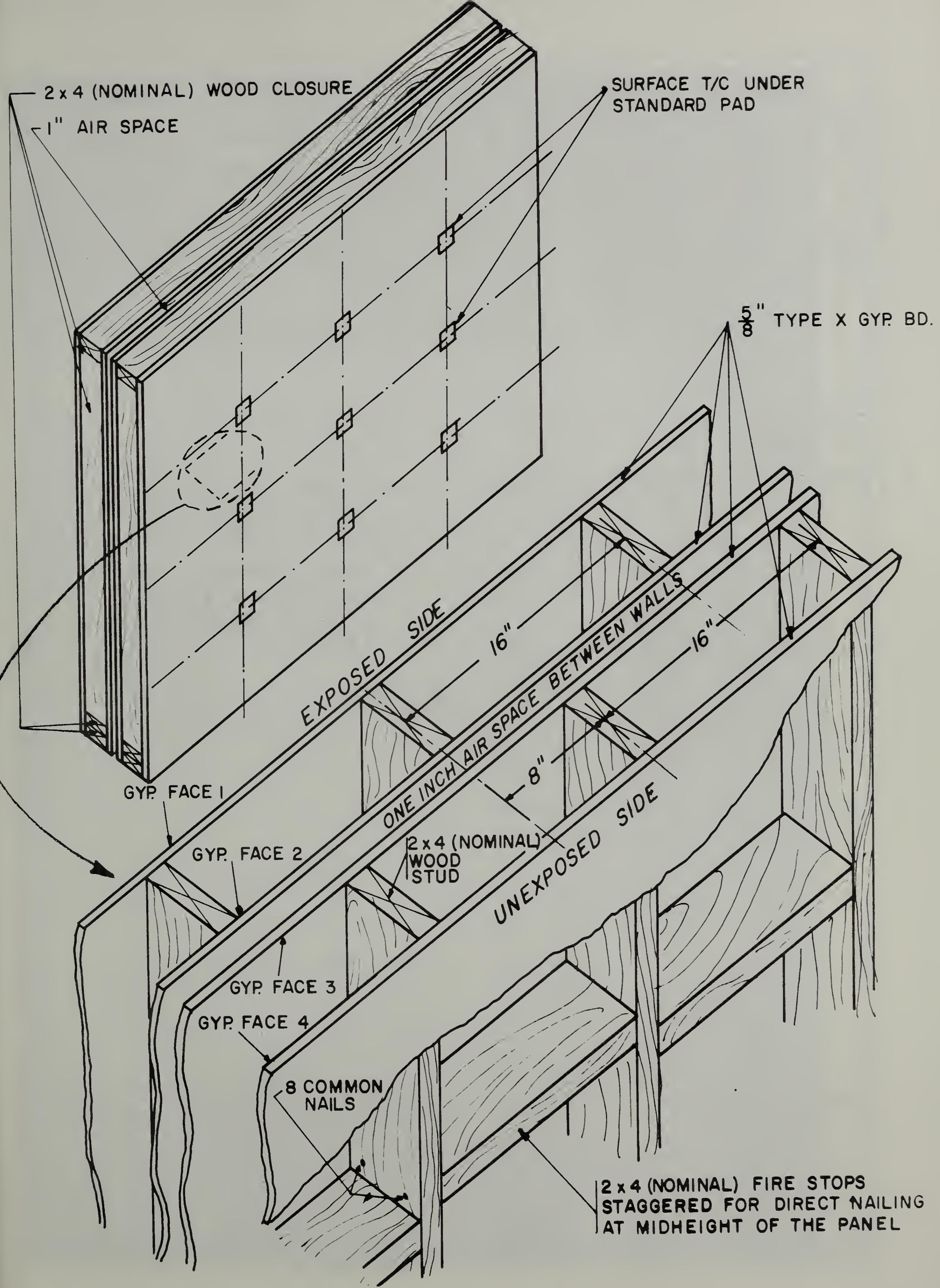


Figure 1. Construction Details

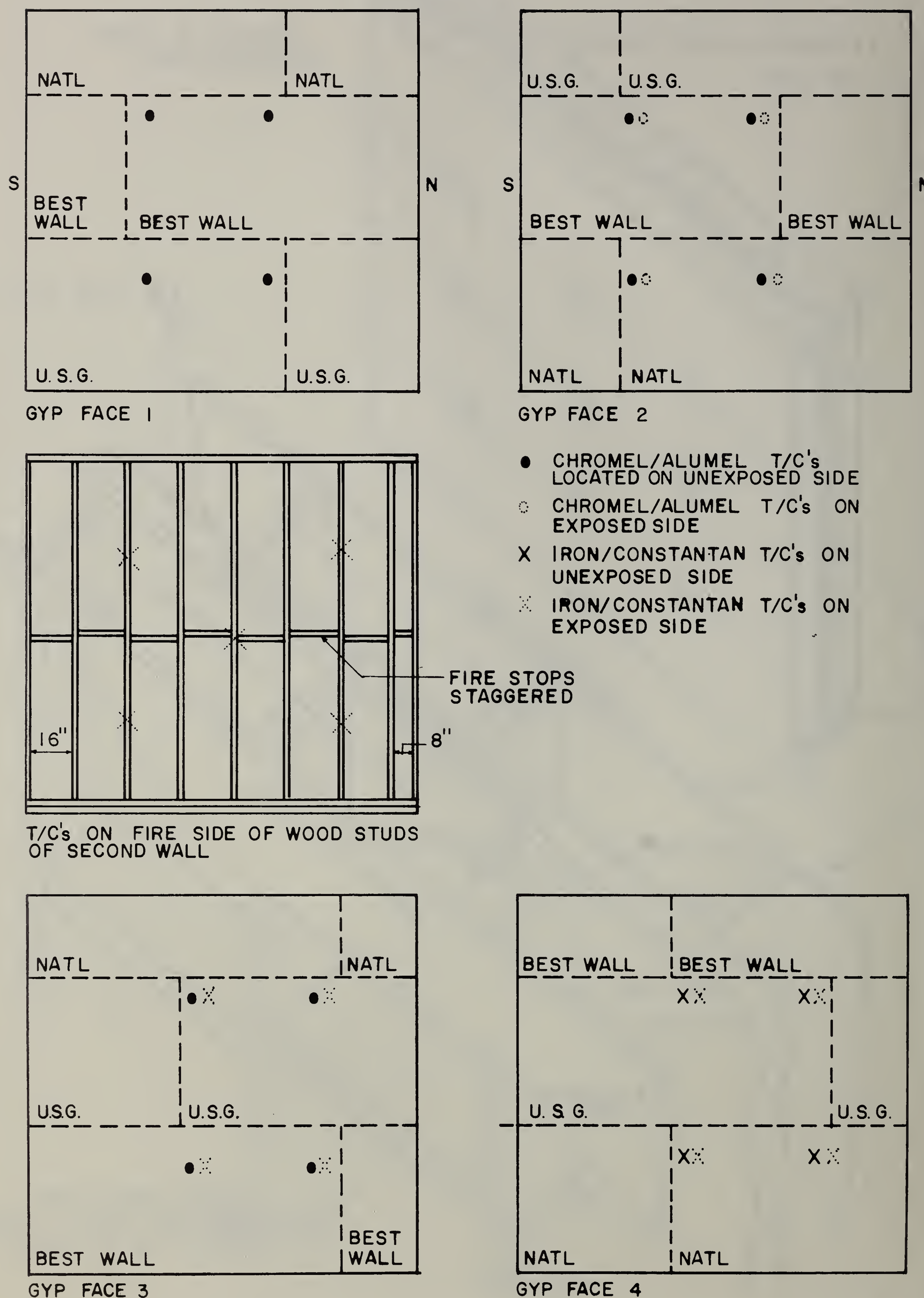


Figure 2. Locations of gypsum boards and thermocouples

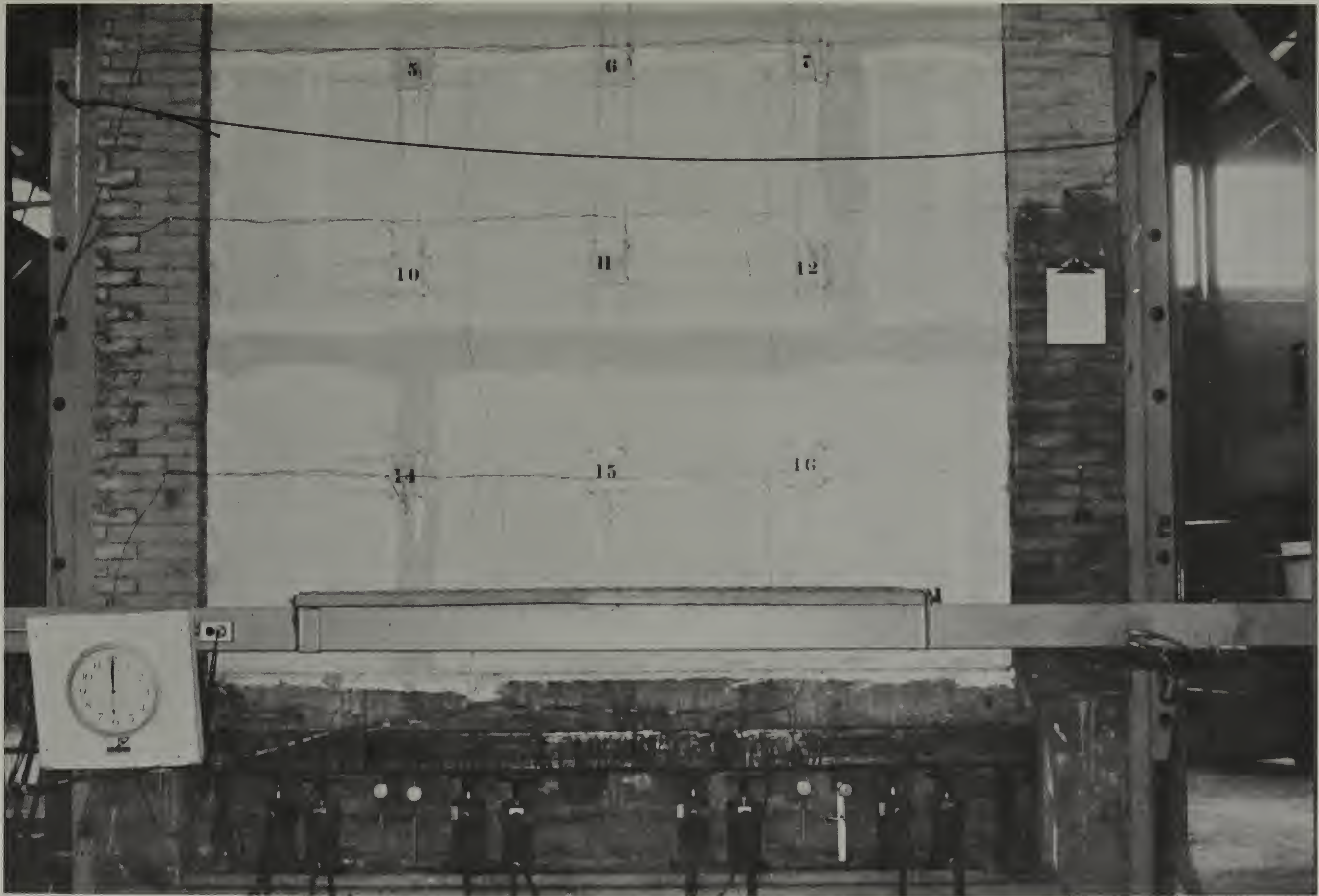


Figure 3. The unexposed side of the assembly; the thermocouple connections, loading equipment, the lateral and the vertical deflection measuring device.

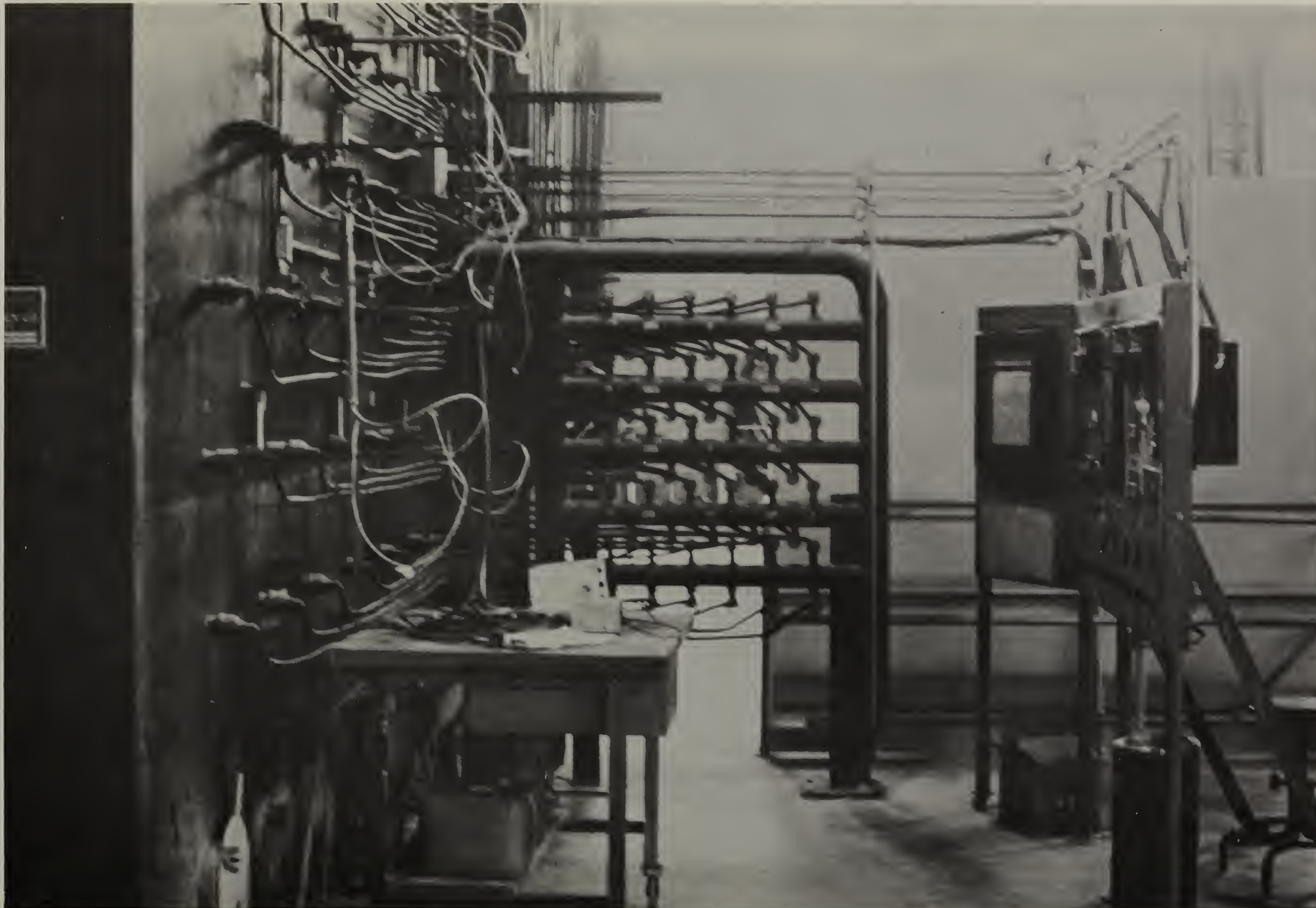
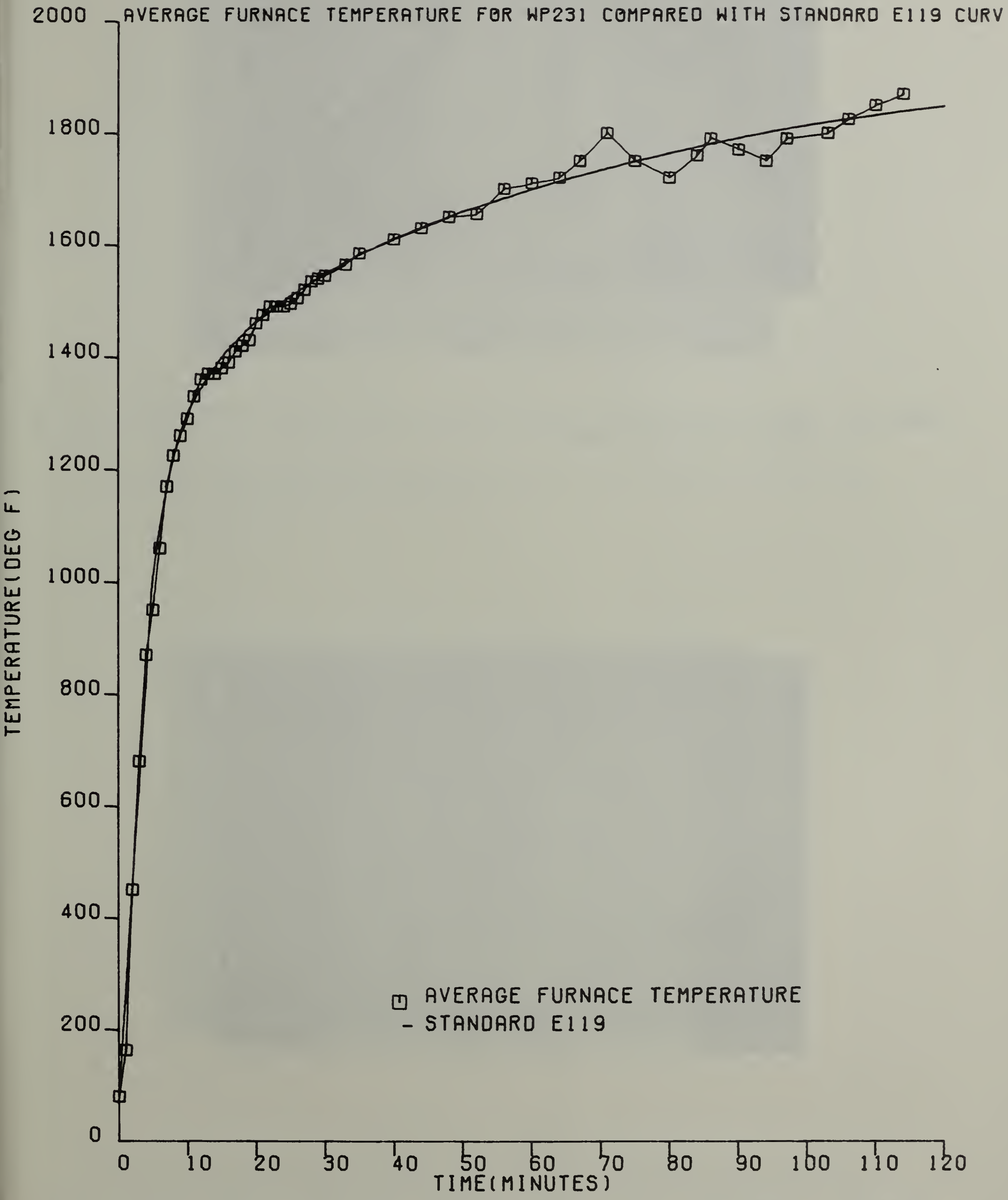


Figure 4. The back side of the furnace; gas lines and recorders.

Figure 5.



AVERAGE FURNACE TEMPERATURE FOR WP231 COMPARED WITH STANDARD E119 CURV
TEMPERATURE(DEG F)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
110
120
TIME(MINUTES)
AVERAGE FURNACE TEMPERATURE
STANDARD E119

Figure 6. Ignition of the paper near bottom of the south corner on the exposed surface at 1 min:05sec.

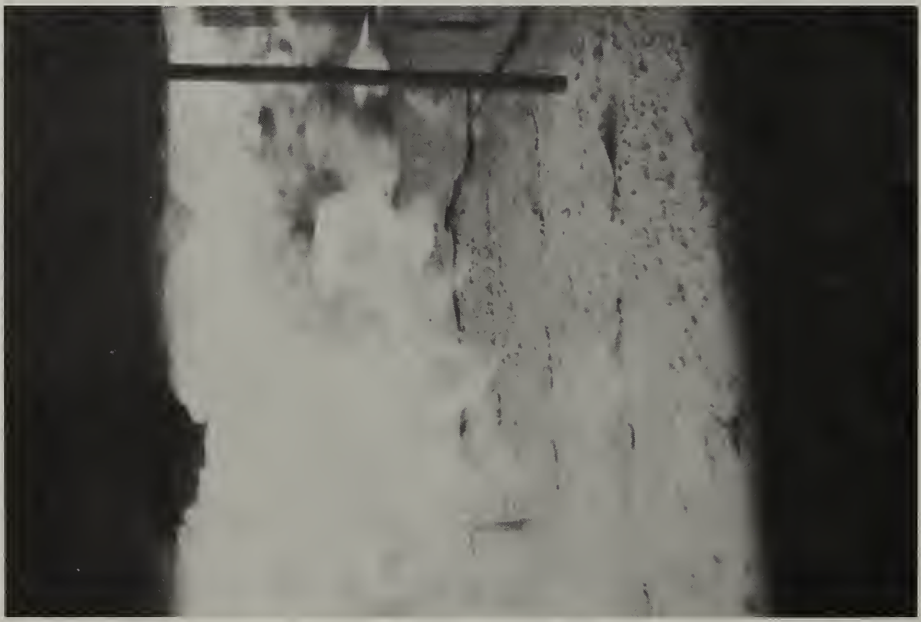


Figure 7. Paper Tape on the exposed surface beginning to fall off at 4 min.

Figure 8. The individual gypsum boards on the exposed surface were buckling at 40 min.

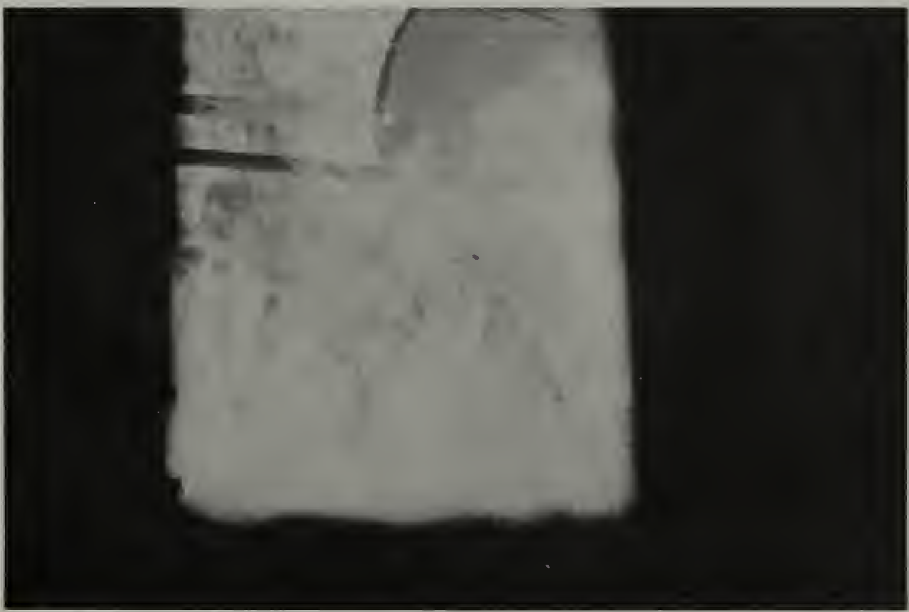


Figure 9. Gypsum boards bowed out and ready to fall down at 62 min.

Figure 10. Pieces of the exposed face falling down at 63 min.

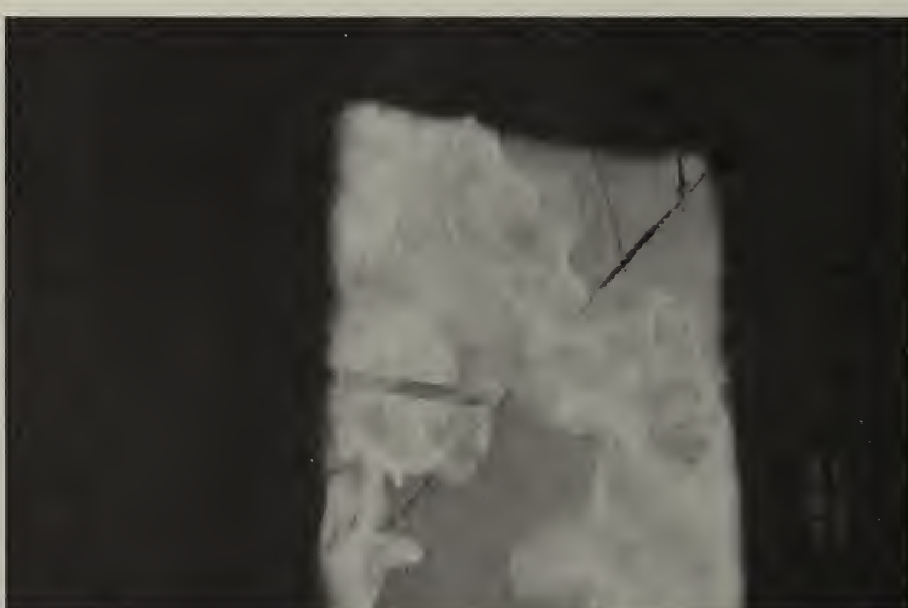


Figure 11. The exposed gypsum face of the second wall at 90 min.

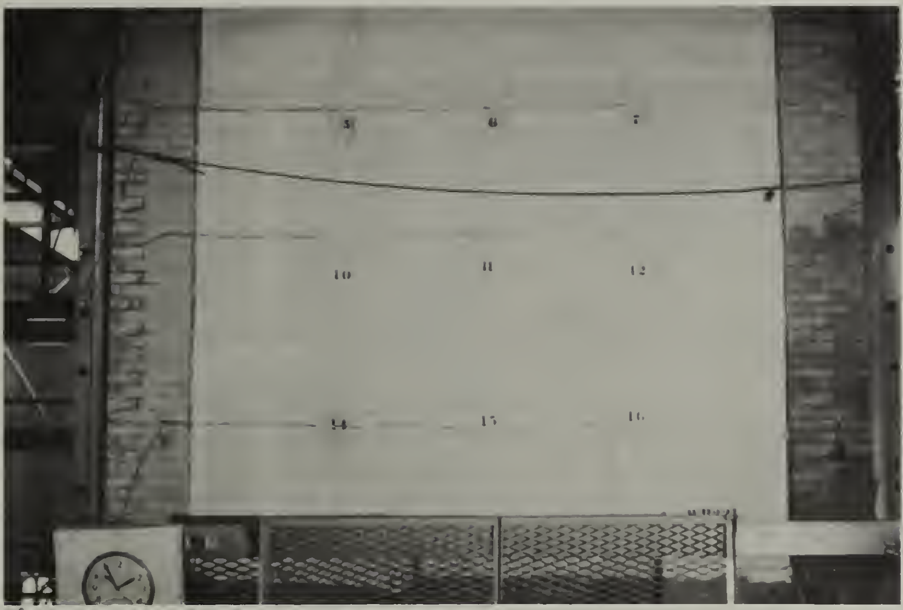


Figure 12. The unexposed side of the assembly at 115 min.

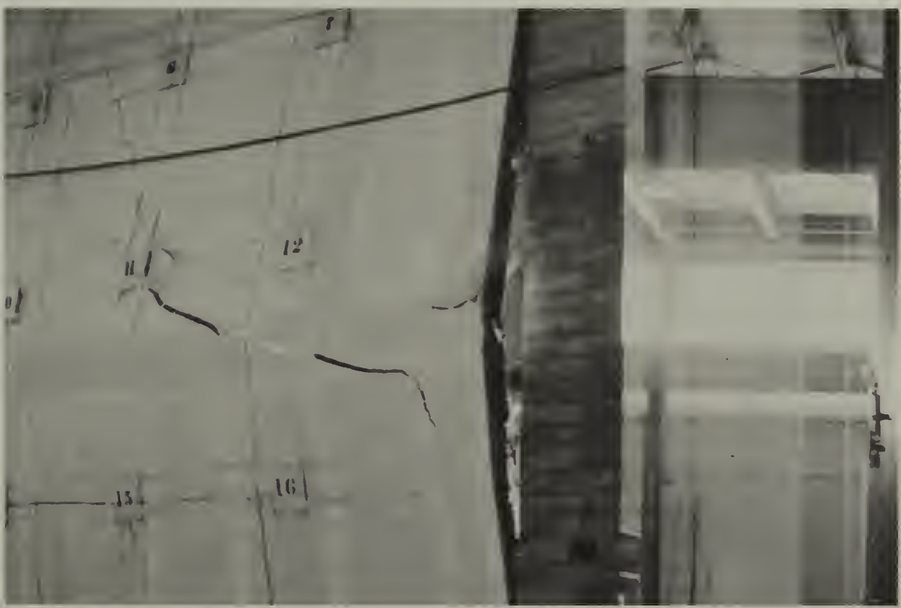


Figure 13. The resultant crack formed at mid-height near the north quarter point of the assembly.

Figure 14.

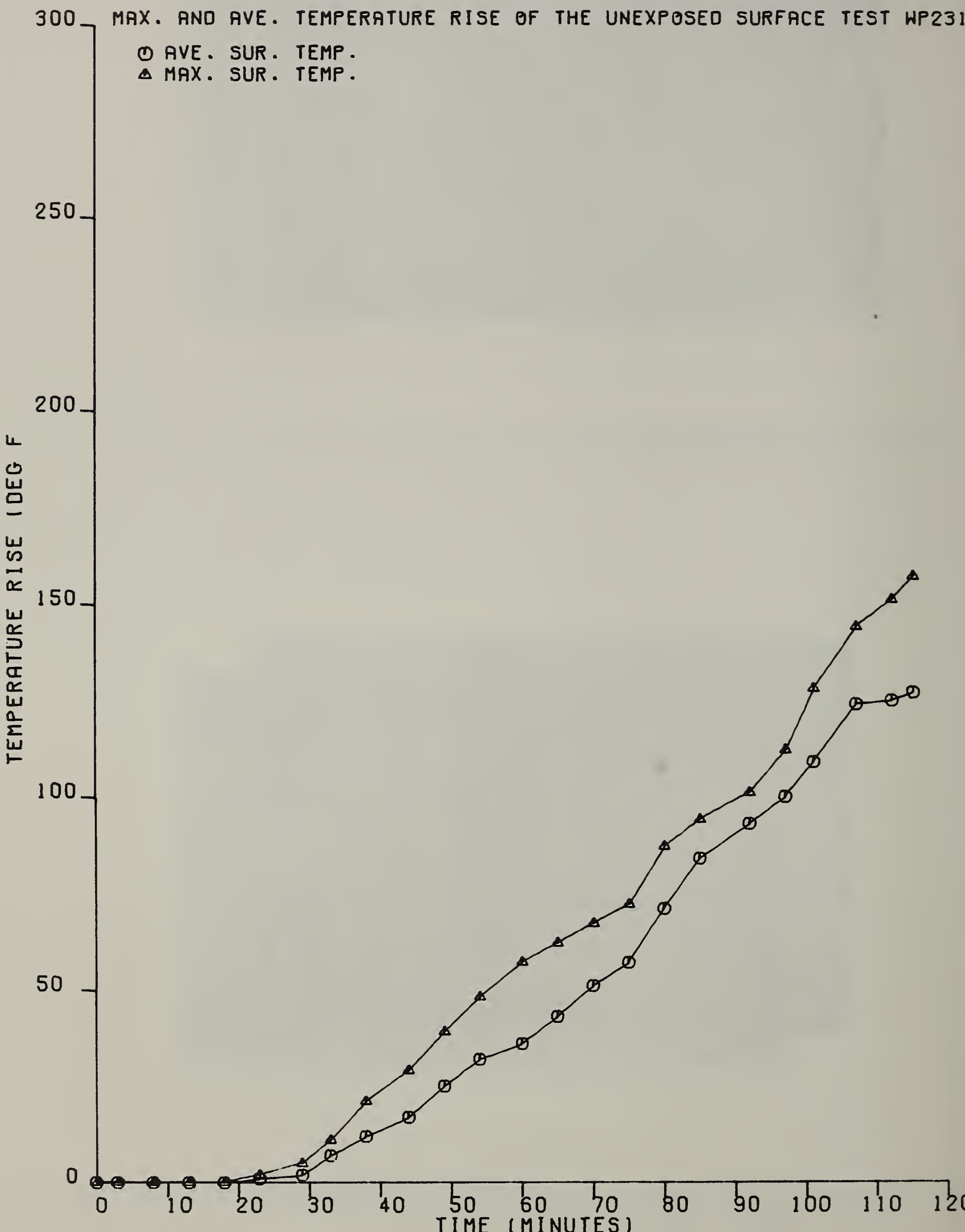

MAX. AND AVE. TEMPERATURE RISE OF THE UNEXPOSED SURFACE TEST WP231
AVE. SUR. TEMP.
MAX. SUR. TEMP.
TEMPERATURE RISE (DEG F
TIME (MINUTES)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
110
120

Figure 15.

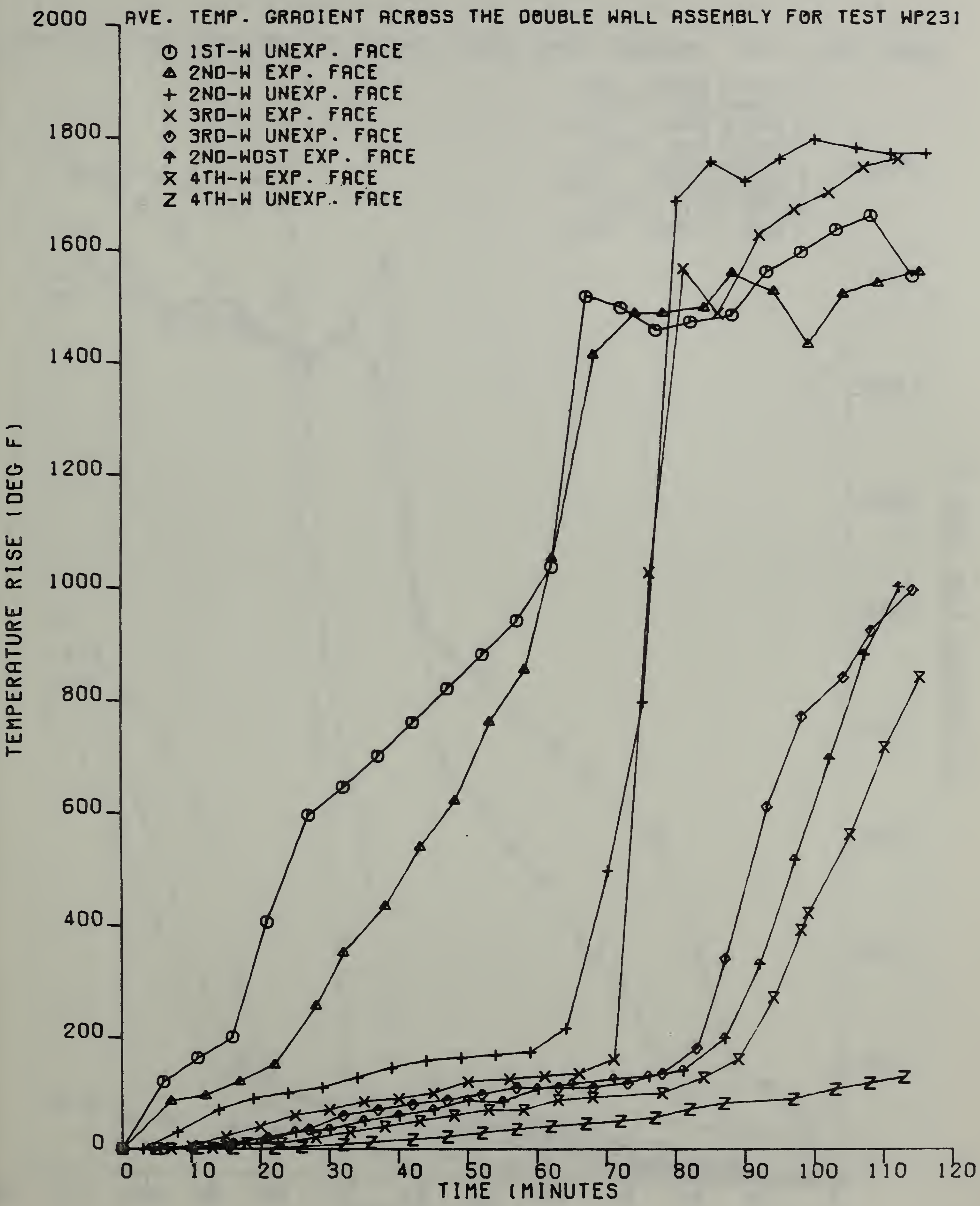

AVE. TEMP. GRADIENT ACROSS THE DOUBLE WALL ASSEMBLY FOR TEST WP231
1ST-W UNEXP. FACE
2ND-W EXP. FACE
2ND-W UNEXP. FACE
3RD-W EXP. FACE
3RD-W UNEXP. FACE
2ND-WOST EXP. FACE
4TH-W EXP. FACE
4TH-W UNEXP. FACE
TEMPERATURE RISE (DEG F)
TIME (MINUTES
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
100
110
120

Figure 16.

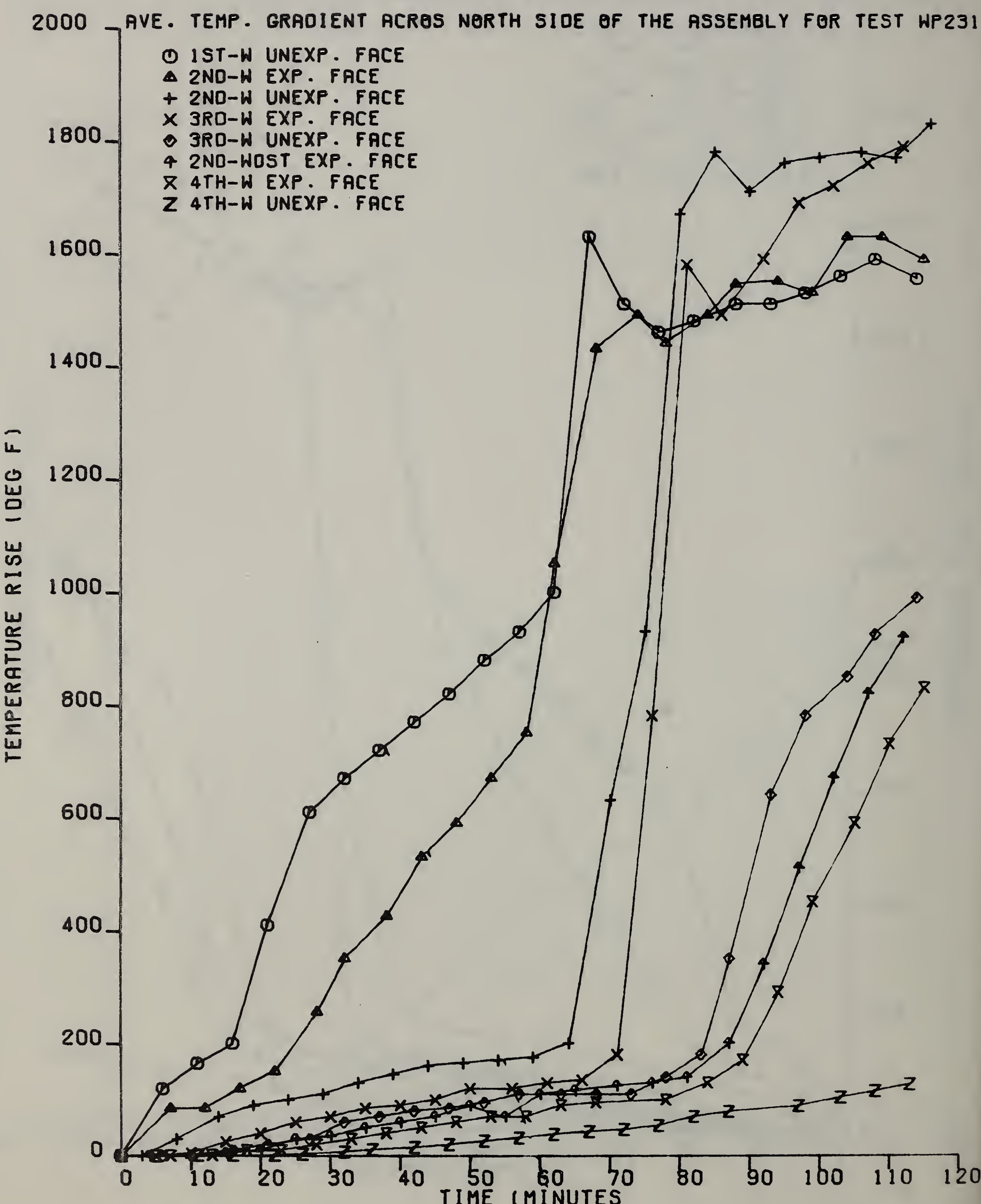

AVE. TEMP. GRADIENT ACROS NORTH SIDE OF THE ASSEMBLY FOR TEST WP231
1ST-W UNEXP. FACE
2ND-W EXP. FACE
2ND-W UNEXP. FACE
3RD-W EXP. FACE
3RD-W UNEXP. FACE
2ND-WOST EXP. FACE
4TH-W EXP. FACE
4TH-W UNEXP. FACE
TEMPERATURE RISE (DEG F)
TIME (MINUTES)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
110
120

Figure 17.

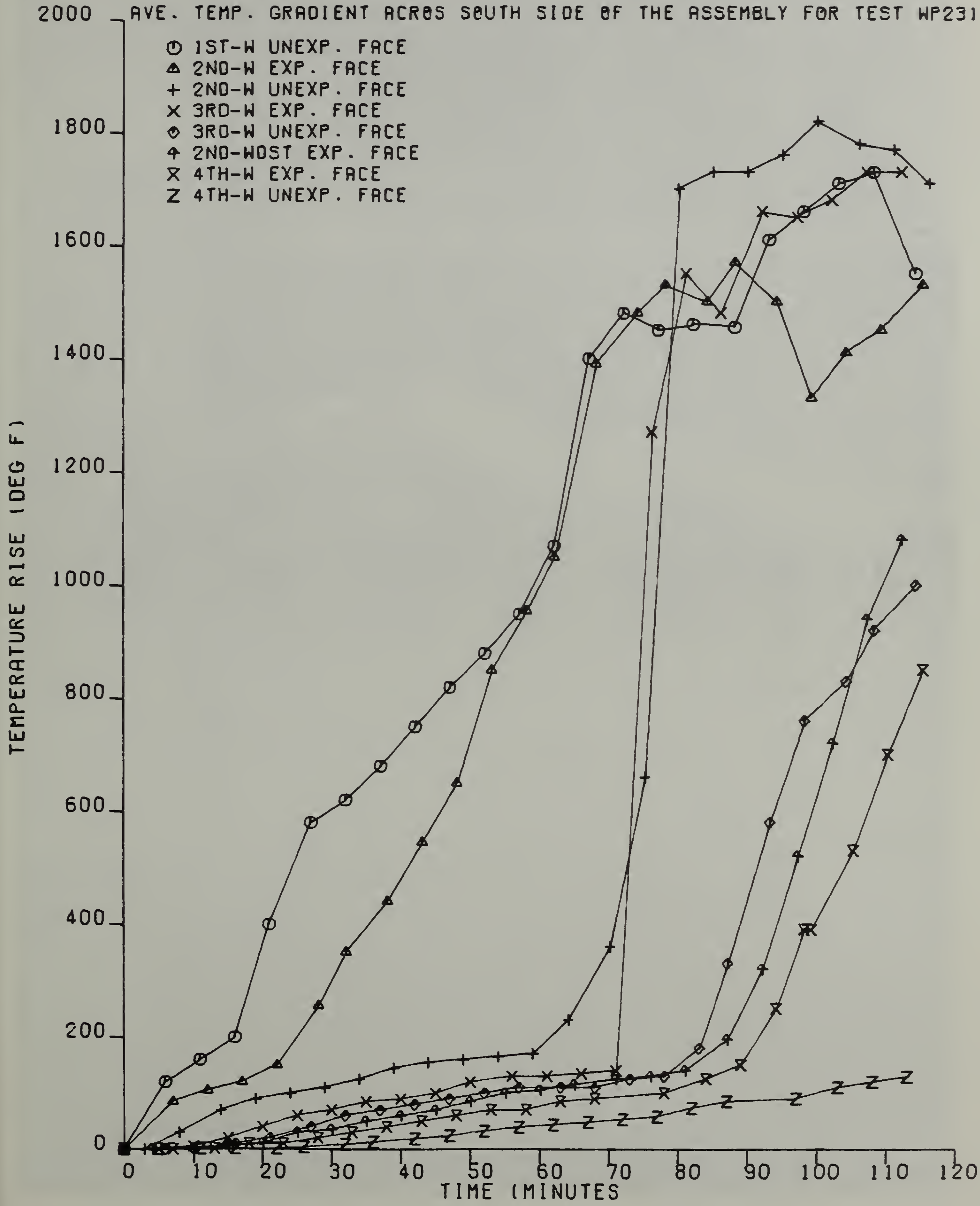

AVE. TEMP. GRADIENT ACROS SOUTH SIDE OF THE ASSEMBLY FOR TEST WP231
1ST-W UNEXP. FACE
2ND-W EXP. FACE
2ND-W UNEXP. FACE
3RD-W EXP. FACE
3RD-W UNEXP. FACE
2ND-WOST EXP. FACE
4TH-W EXP. FACE
4TH-W UNEXP. FACE
TEMPERATURE RISE (DEG F)
TIME (MINUTES
0
200
400
600
800
1000
1200
1400
1600
1800
2000
10
20
30
40
50
60
70
80
90
100
110
120

Figure 18. The view of north end near the resultant crack after test.

Figure 19. The fire side of the assembly after it was removed from the furnace.

Figure 20. Three wood studs collected from the center and quarter points near the mid-height of the second panel after test.