32

NBSIR 73-173

Fire Endurance Tests of Double Module Walls of Gypsum Board and Steel Studs

B. C. Son, H. Shoub

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

April 1973

Final Report

Prepared for
Office of Research and Technology
Department of Housing and Urban Development
Washington, D. C. 20410

NBSIR 73-173

FIRE ENDURANCE TESTS OF DOUBLE MODULE WALLS OF GYPSUM BOARD AND STEEL STUDS

B. C. Son, H. Shoub

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

April 1973

Final Report

This document has been prepared for the use of the Department of Housing and Urban Development. Responsibility for its further use rests with that agency. NBS requests that if release to the public is contemplated, such action be taken only after consultation with the Office of Public Affairs at the National Bureau of Standards.

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

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

FIRE ENDURANCE TESTS OF DOUBLE MODULE

WALLS OF GYPSUM BOARD AND STEEL STUDS

by

H. Shoub

B. C. Son

ABSTRACT

Standard fire endurance fire tests were conducted on two 8 foot high by 16 foot long assemblies, each consisting of double modular partition walls. In these tests, the applied loads represented the weight of modules supported by the walls, and other applicable design live loads. The partitions were of gypsum board on metal studs and simulated the juxtaposition of walls of two adjoining housing modules. As each of the parallel module walls was an independent load bearing member both were required to meet a specified fire endurance under the applied load in tests conducted in accordance with the requirements of ASTM E 119-71, Fire Tests of Building Construction and Materials.

The load applied was 1078 pounds per linear foot (plf) per wall and the test results are valid only for walls of similar construction loaded at or below the stress level developed by this loading.

The fire exposed wall of the first test specimen (with 3 inch "C" type) studs) failed structurally at 42 minutes and the outer wall failed structurally at 1 hour 13 minutes. In the second test specimen, with tubular studs for increased strength, the fire exposed wall failed structurally at 1 hour 7 minutes and the outer wall failed at 1 hour 37 minutes by passage of hot gas.

Key Words: Fire endurance; Fire tests; Housing systems; Modular construction; Operation BREAKTHROUGH; Steel framing

TABLE OF CONTENTS

1.0 Introduction

The fire resistive characteristics of two separation walls proposed for low rise multifamily residential occupancy were determined in tests conducted by the Fire Research Section of the National Bureau of Standards. The tests were sponsored by the Department of Housing and Urban Development as part of the program of evaluating housing systems under Operation BREAKTHROUGH.

The walls were constructed of gypsum boards on metal studs, with several innovative features that necessitated full scale fire test validation. First, they represented walls that would be formed by the juxtaposition of two factory built housing modules. As such they were of identical construction from the facing surfaces outward. By their position they were part of the first story units in a three-story structure, and thus had to support the units above with their respective design live loads. The structural members also were of a type not extensively used, and for which little fire performance data were available.

The tests were conducted in accordance with the requirements of ASTM Standard E 119-71, Fire Tests of Building Construction and Materials.[1/]

[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 Street, Philadelphia, Pa. 19103.

2.0 Description of Test Specimens

The wall specimens for the two tests were similar in construction, with several modifications made to the second test specimen as a means of enhancing its fire performance to a level commensurate with the requirements for the structure of its occupancy type.

Construction details for both walls are shown in Figure 1. The wall for Test 1 was constructed of cold-rolled steel "C" type studs (3 inches by 1 3/4 inch, with 1/2 inch lip, 18 ga, 24 inch o.c.), welded at top and bottom to steel channels, 3 1/8 inches by 1 1/8 inch, 1/16 inch thick. The inner or facing surfaces of the dual wall, separated by a 1/2-inch cavity, were of 1/2-inch gypsum board, the outer surfaces (or room side) 5/8-inch. All the gypsum board was type "X" (special fire rated).

The tapered joints between boards were filled with joint compound and taped with a paper strip. Fastening of the 4 foot wide gypsum boards to the studs and channels was by 1-inch long S-12 bugle head screws spaced at 12 inches in the field of the boards and 8 inches on their perimeter. The boards were cut short about 1/2 inch at top and bottom to prevent edge restraint during the test.

Batts of friction fit low binder content glass fiber insulation 2 1/2 inches thick were placed between the studs of each wall.

The spacing of the two studs at one end of the specimen was reduced by 1 inch, making the overall length of the wall 15 feet 11 inches, to insure easy fit in the 16-foot opening of the test frame. Representing actual conditions of use, the height of the test wall was 8 feet.

The wall assembly for the second test was similar in size and construction to that for the first, but with the following notable exceptions:

1. The "C" studs were replaced by tubular members having dimensions 3 inches by 2 inches with a wall thickness of 0.065 inches.
2. Insulation was by 3 1/2-inch glass fiber batts compressed to 3 inches to fit between studs.
3. As shown in Figure 1, the 5/8-inch gypsum board outer sheets were supported on angles set on the edge of the channels, which, in practice, would allow fitting of floor and ceiling assemblies. The spaces along the channels were filled by separate gypsum board strips.

3.0 Test Method and Instrumentation

The frame in which a wall test specimen was mounted formed one side of a wall test furnace which was controlled to give an average temperature within the furnace chamber in accordance with the time-temperature schedule prescribed in the ASTM E 119 standard.

Twelve thermocouples, protected in iron tubes, were symmetrically distributed for temperature measurement within the furnace.

The first occurrence of the following criteria of failure determines the fire endurance of a wall assembly in accordance with the ASTM E 119:

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 held against the surface.
3. A temperature rise of 250°F (139°C) average, or 325°F (181°C) at one point, above the initial temperature on the unexposed surface.

Since, in the assembly under test, each wall of the double wall was intended to serve as an independent loadbearing member, the ability to sustain the applied load was required for each of the wall elements. Failure criteria based on heat penetration, however, were applied only to the unexposed surface of the double wall assembly.

To determine temperature rises on the unexposed surface and at points on the interior of the structure, 68 Chromel-Alumel (Type K) thermocouples were distributed about the test specimen. Twelve were placed on the unexposed surface under 6- by 6- by 0.4-inch felted asbestos pads as required in the E 119 standard. Of these, four were on the surface over the studs, one was over the center joint, and seven were at midpoints between studs. A wall, mounted in the furnace frame and with surface thermocouples applied, is shown in Figure 2.

The remaining 56 thermocouples were placed within the wall structure, in all cases against gypsum board faces, either at or between the studs. The locations of the specimen thermocouples are indicated schematically in Figure 3. The temperature readings from all of the thermocouples were recorded at two minute intervals on the data logger for computer processing.

The 8-foot height of the test specimens, while representing the conditions of actual use, was less than the 9-foot minimum dimension for test structures specified in ASTM E 119. The walls, however, did exceed the minimum area required of the standard.

As the 8-foot high specimens did not fill the 10-foot high opening of the test frame, the bottom of the frame over the loading jacks was closed with separate fillers, made in 8-foot lengths, for each of the two sections of a double wall. A load of 1078 pounds per linear foot (1028 plf live, 50 plf dead weight of wall) was applied to each of the wall sections. This load was calculated from design live loading for residential occupancy.

The filler panels in the frame had structural strength and fire resistance which would not be impaired by fire exposure for the expected duration of the test. All structural steel in the wall that could in any way be subject to direct fire exposure was also adequately protected. The test specimen was sealed into the test frame with noncombustible insulation; gaps between the frame and furnace were also sealed.

Lateral deflections of the unexposed surface of the wall were determined by its position relative to a horizontal wire stretched across the test frame at the midheight of the wall specimen.

During the test, the neutral point in the furnace, that is the height at which the pressure in the furnace was equal to that outside, was maintained at the one-third height of the specimen (2 feet 8 inches above the bottom). This provided a positive furnace pressure above the neutral point increasing linearly with height. Under positive furnace pressures representing conditions usually occurring in actual fires, combustion gases may be forced through fissures or openings in the specimen.

Hose stream tests, described in Section 8 of E 119 were not conducted on the specimens after the fire exposure. According to the standard, these are not required for structures exhibiting fire endurance of less than 1 hour.

4.0 Results

<u>Wall No. 1, "C" Type Studs</u>

A fire endurance of 42 minutes was established for the fire-exposed wall of the assembly with "C" type studs by failure to sustain the applied load. The unexposed wall failed similarly at 1 hour 13 minutes. Flame penetration to the unexposed surface occurred at 1 hour 15 minutes.

The furnace temperatures throughout the test were in close conformance with the standard time-temperature curve and no correction was necessary to the times to failure (Figure 4).

As can be seen in Figure 5, temperature rise at the thermocouple locations on the unexposed surface did not approach the limiting rises established as criteria of failure in the ASTM E 119 standard. There was little temperature variation over the surface as indicated by the close correspondence of the maximum one point and average temperature curves. The temperature gradient across the wall assembly can be seen in Figure 6 (maxima) and Figure 7 (average).

Horizontal deflection measurements made on the unexposed surface indicated a very small back and forth movement in the early stage of the test. A significant movement of about 1/4 inch toward the fire was noted at 28 minutes at the center and at two quarterpoints. At 1 hour 6 minutes, before failure of the outer unexposed wall, deflections of 1 inch at the center and 1/2 inch and 7/8 inch at the sides were measured. At the conclusion of the test the 3-inch deflection at one quarterpoint greatly exceeded the 1 1/4 inch measured at the other quarterpoint and was greater than the 2 3/4 inches at the center. All movement subsequent to the early waviness was toward the fire.

Observations of the wall during the test indicated that the joint compound on the exposed surface flamed after a few minutes exposure and by 23 minutes there was opening at some of the joints. Some cracks appeared in a fire exposed board at 21 minutes, and in all boards on the fire side by 34 minutes, with visible buckling. By 41 minutes, just prior to failure, there was considerable falling away of the fire exposed board, exposing the studs in the inner wall (fire-exposed). At 58 minutes the boards of the inner wall had fallen away sufficiently to allow full exposure of the inner face of the outer wall. Just prior to failure of the outer wall, there was considerable opening of board joints with consequent rapid buckling of the studs.

Wall No. 2, Tubular Studs

In the fire endurance test of the second wall assembly failure (inability to sustain the applied load) occurred at 1 hour 7 minutes for the fire exposed wall and at 1 hour 43 minutes for the unexposed member. Failure by passage of hot gas through the whole assembly occurred at 1 hour 37 minutes when cotton waste held against a joint between boards on the unexposed surface was ignited. The furnace temperatures, while slightly higher than the prescribed standard, were so close to those of the standard curve that no correction was required for the indicated fire endurance times (furnace and standard curve in Figure 8).

As could be expected from the results of the tests on the first wall, temperature rises on the unexposed surface remained considerably below the limits established as failure points in the fire test standard (Figure 9). Here again there was little variation in temperatures over the surface, with maximum temperatures only slightly greater than averages. Temperature gradients across the wall assembly were also similar to those for the first test specimen, but with indication of somewhat slower heat penetration which could be attributed to the greater thickness of insulation in the second test specimen (Figures 10 and 11).

Deflection measurements were made up to 1 hour 40 minutes of test time. Movements of the walls were mostly minor up to the last stages of the test. The 1/2-inch deflection towards the fire that occurred at one quarterpoint at about 10 minutes was probably the result of initial unevenness of the wall. Deflections, all toward the fire, at 1 hour 35 minutes were 7/8 inch at the center, 1 1/2 inch at one quarterpoint and 1 3/4 inch at the other (the point initially bowed out). Three minutes before load failure on the unexposed wall, the deflections were 1 5/8 inch at the center and 2 1/4 and 2 3/4 inches at the two quarterpoints.

Visual observations indicated flaming occurred at the joints on the fire-exposed surface at 3 minutes. Cracks in the boards appeared at 23 minutes and by 34 minutes had opened to about 3/8 inch. At 48 minutes an end panel began to disintegrate, exposing the fiber glass insulation. By 1 hour the studs of the exposed wall were bowing toward the fire leading to load failure at 1 hour 7 minutes. By 1 hour 20 minutes enough of the wall next to the fire had fallen away to expose a considerable portion of the second wall. After this there was progressive opening of the joints of the second wall, on the side toward the fire and then on the unexposed side, causing the 1 hour 37 minute failure by passage of hot gas.

5.0 Discussion of Results

The distributed load on the wall studs of modules designed as the first story of a three-story structure was calculated from the weight of the two modules above, a design live load of 40 psf, a ceiling and a roof plus a design snow load of 30 psf. This gave a design load of 2244 pounds per stud. The load was reduced to 2055 pounds per stud to compensate for the lack in the test structure of the restraint ordinarily imposed on wall studs by their contiguous floor and ceiling assemblies. End fixity, in actual practice, effectively reduces stud column length. The actual load applied in the tests, 1918 pounds per stud (1078 pounds per linear foot of wall) represented a further small reduction of the load on each stud, about 11 percent less than calculated.

An examination of the walls after the tests indicated that the "C" type studs of the first test specimen twisted in failure, probably because of their asymmetry, while the tubular studs of the second test specimen exhibited simple buckling, which left the welds intact (Figures 12 and 13, respectively). The studs were changed to the tubular shape for the second test specimen to provide higher strength without increase in wall thickness. An alternate method of obtaining a higher fire endurance level with the "C" type studs would be by the use of additional layers of gypsum board.

Deflection of the walls occurred by bowing toward the fire, the apparent consequences of the earlier heating of the fire side of the studs, allowing the initiation of and continued greater yielding on the side, as compared to the side away from the fire.

Heat penetration of the studs probably occurred initially through the joints between the gypsum board coverings. Cracks in the gypsum accelerated to heat transmission process and bowing of the steel led to the formation of ever wider cracks and eventual collapse of the boards. An indication of the action of the gypsum boards can be seen in the wall temperature charts wherein the temperature rise plateau at about 100°C is attributable to cooling provided by the evaporation of the combined water in the gypsum. From the same data the air space between the two walls did not appear to provide much thermal resistance.

Observations in other tests have indicated that in double wall assemblies, as here tested, the fire endurance time of the total assembly is about 1.75 times the time of failure of the wall directly exposed to the fire. This was almost exactly true for the first test specimen (42 minutes and 1 hour 13 minutes). In the second test, however, the relationship did not hold, the unexposed wall failing by passage of hot gases at 1 hour 37 minutes, significantly earlier than the expected time (67 minutes x 1.75 = 117 minutes).

6.0 Conclusions

From the results of these tests, it can be seen that a single layer of 5/8-inch Type "X" gypsum board will not provide protection to "C" type steel studs from failure under load for a one hour fire endurance period. Besides the applied load, critical factors include the size and shape of the studs and the quality of the gypsum board joints. In these tests a particular source of weakness appeared to be the joints between the gypsum boards where the filling compound was either quickly destroyed or loosened, allowing rapid heat transmission to the studs. This suggests that a better practice would be the use of a two layer construction, with application of the boards staggered to eliminate direct heat access to the steel through joints.

The load applied to the wall in these tests was 1078 plf per wall and the results of these tests may be made applicable only to structures and loads in which the stresses developed in the members do not exceed those tested.

List of Figures

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 readers 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 lb = 0.45 Kilograms

Stress

1 psf = 47.88 newton/meter^2
1 psi = 0.332 newton/meter^2
1 plf = 13.49 newton/meter

Temperature

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

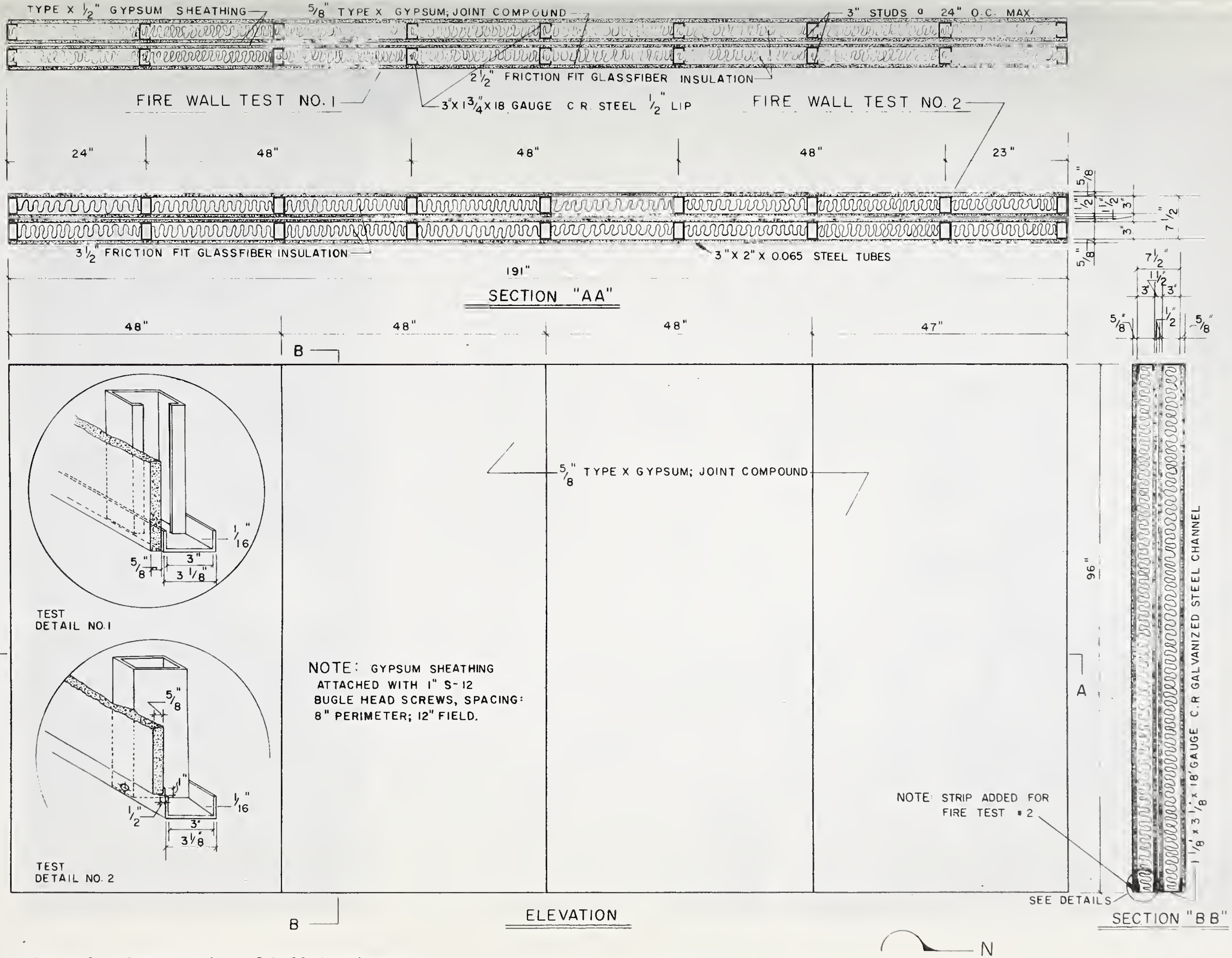

Figure 1 - Construction of Wall Specimens

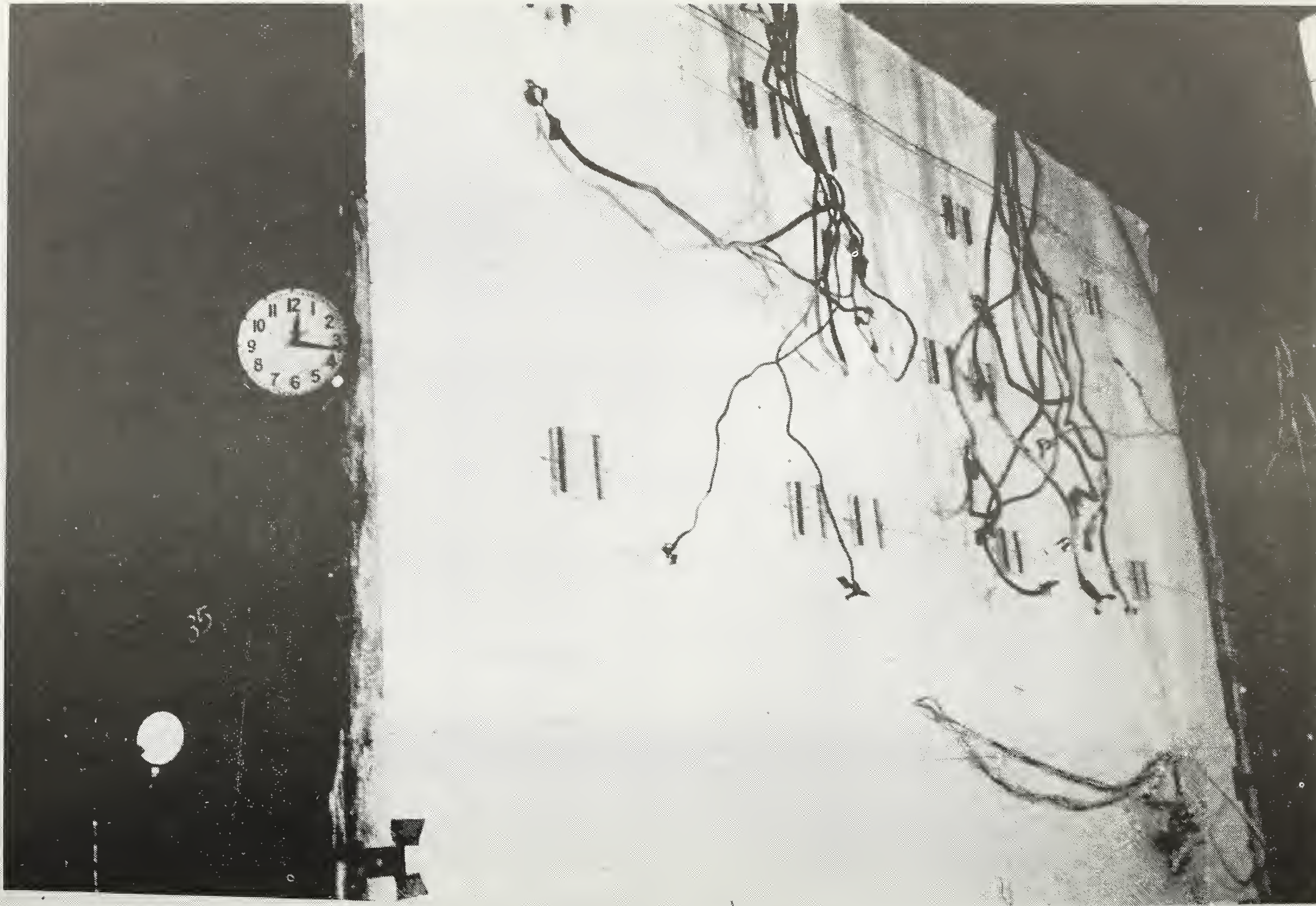

Figure 2 - Wall with Surface
Thermocouples, Near
Start of Tes, No. 1.

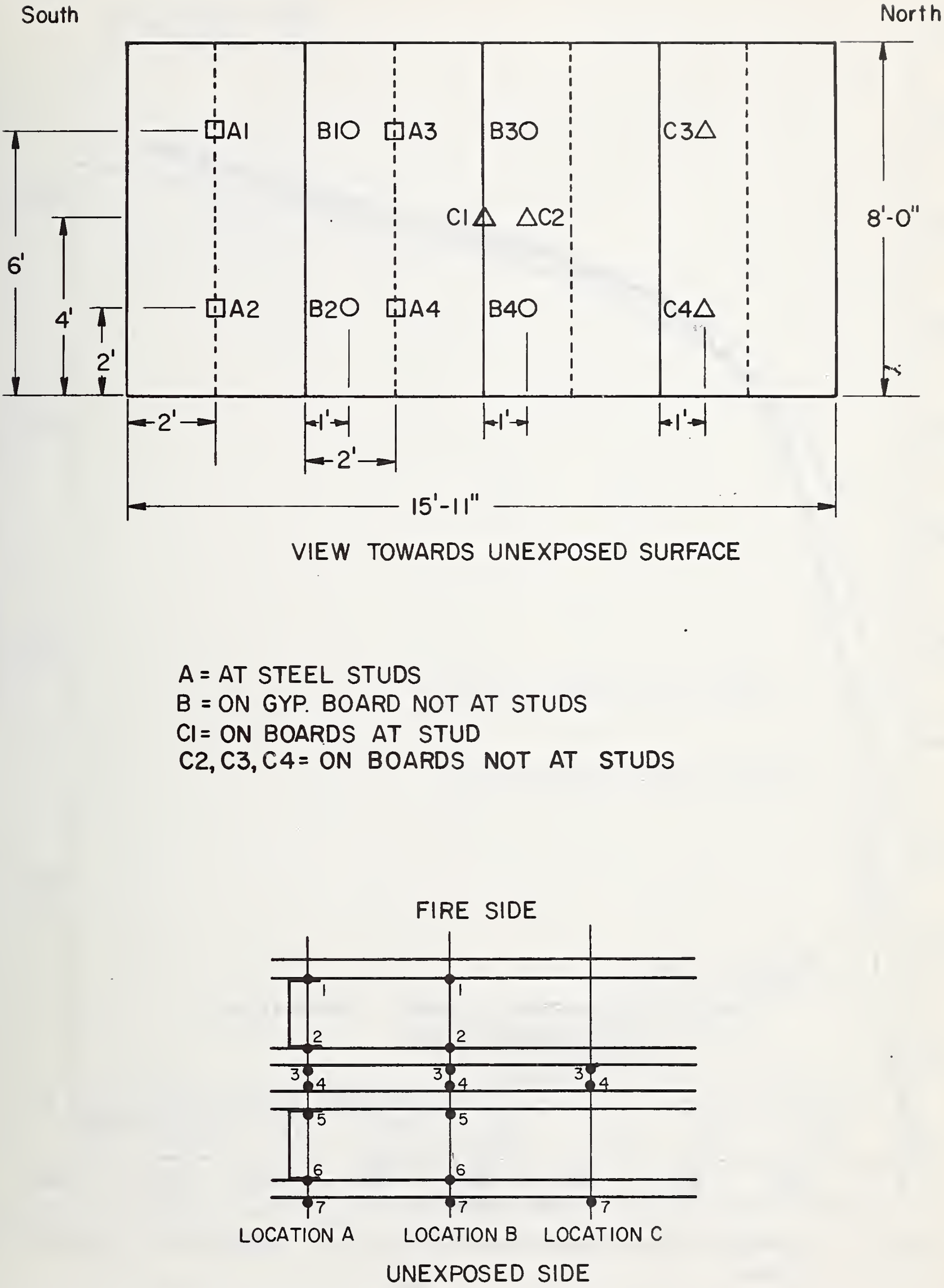

Figure 3 - Thermocouple Locations in Test Assembly

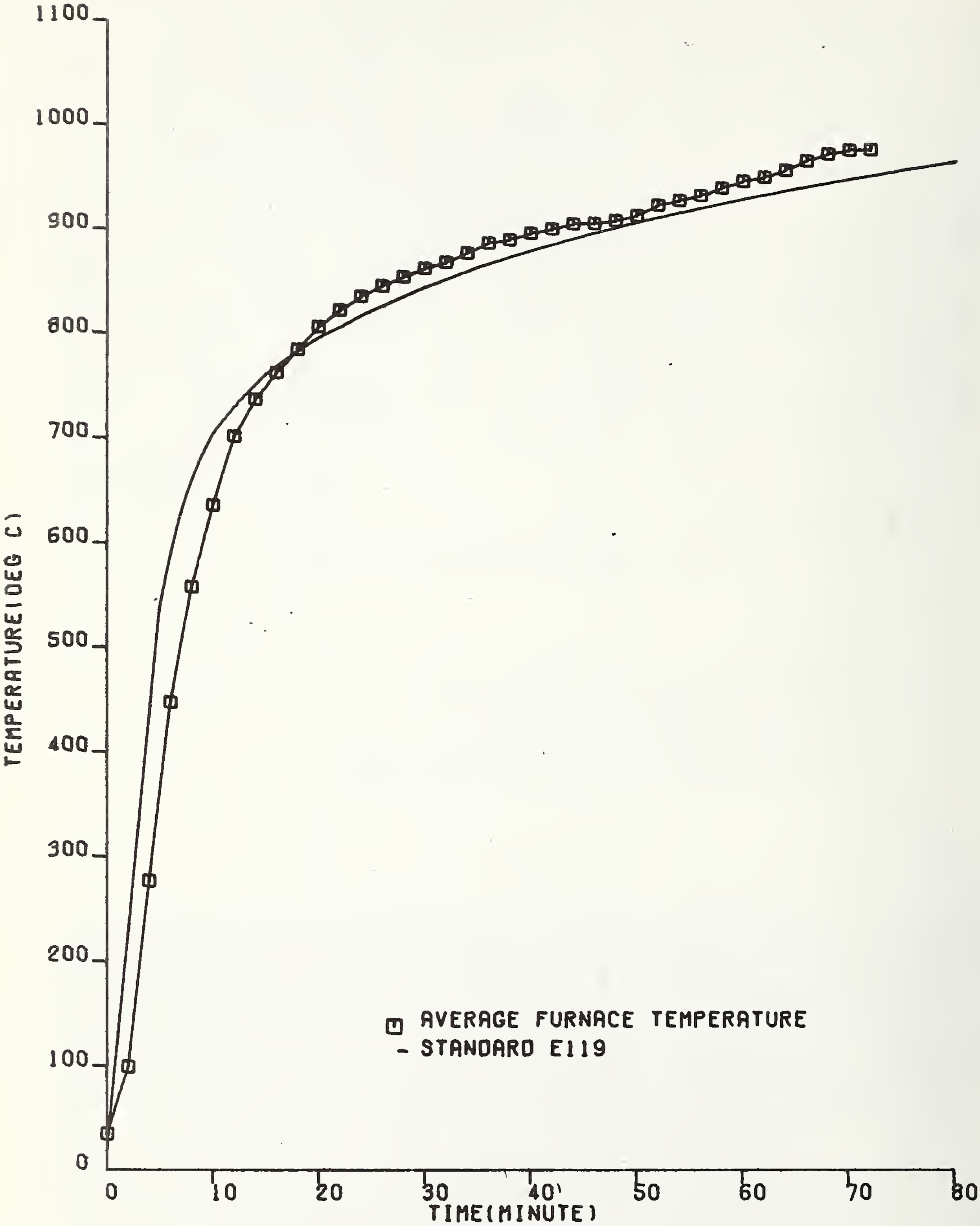

Figure 4 - Average Furnace Temperature for Wall No. 1 Compared with Standard E 119 Curve

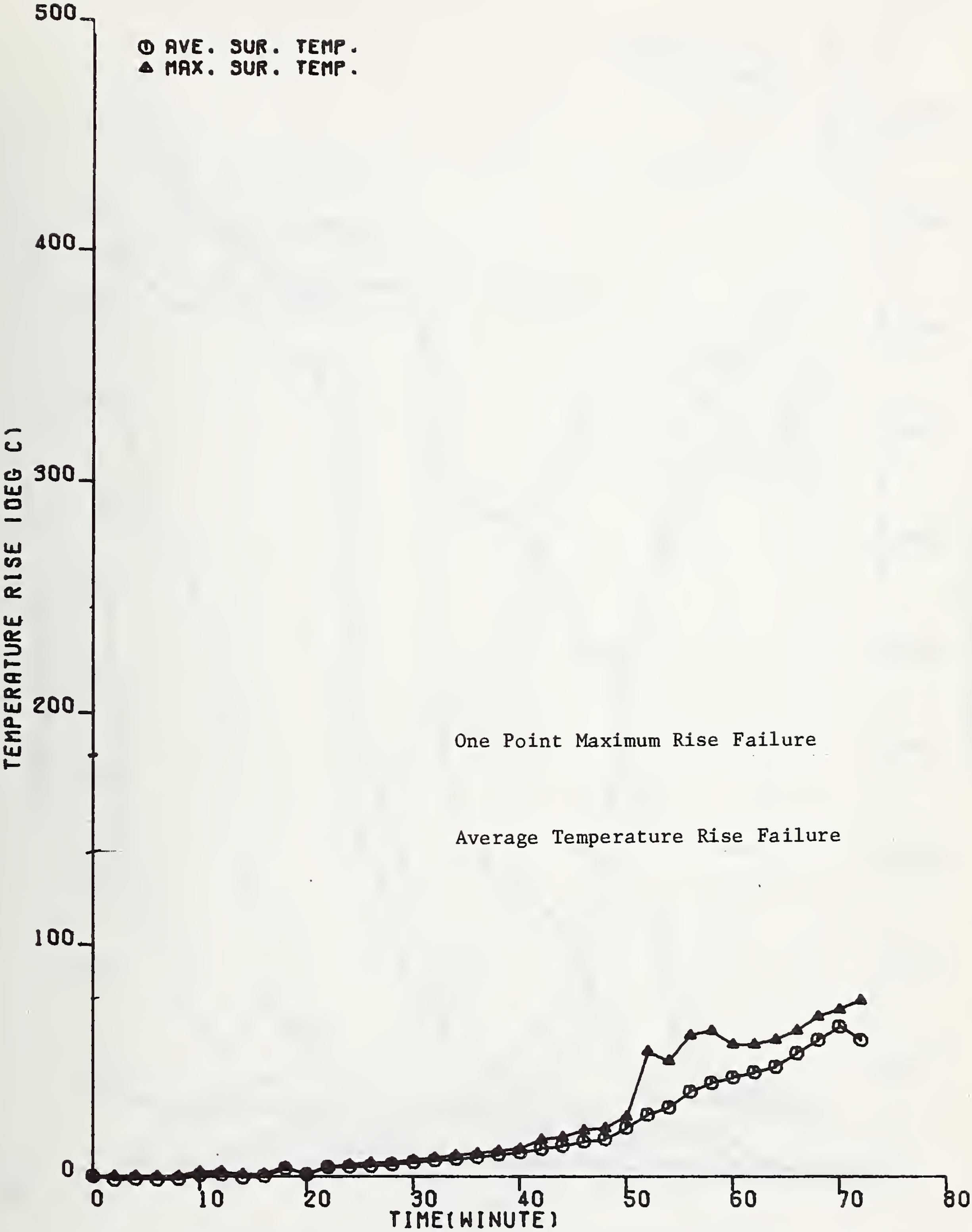

Figure 5 - Maximum and Average Temperature Rise on the Unexposed Surface Wall No. 1

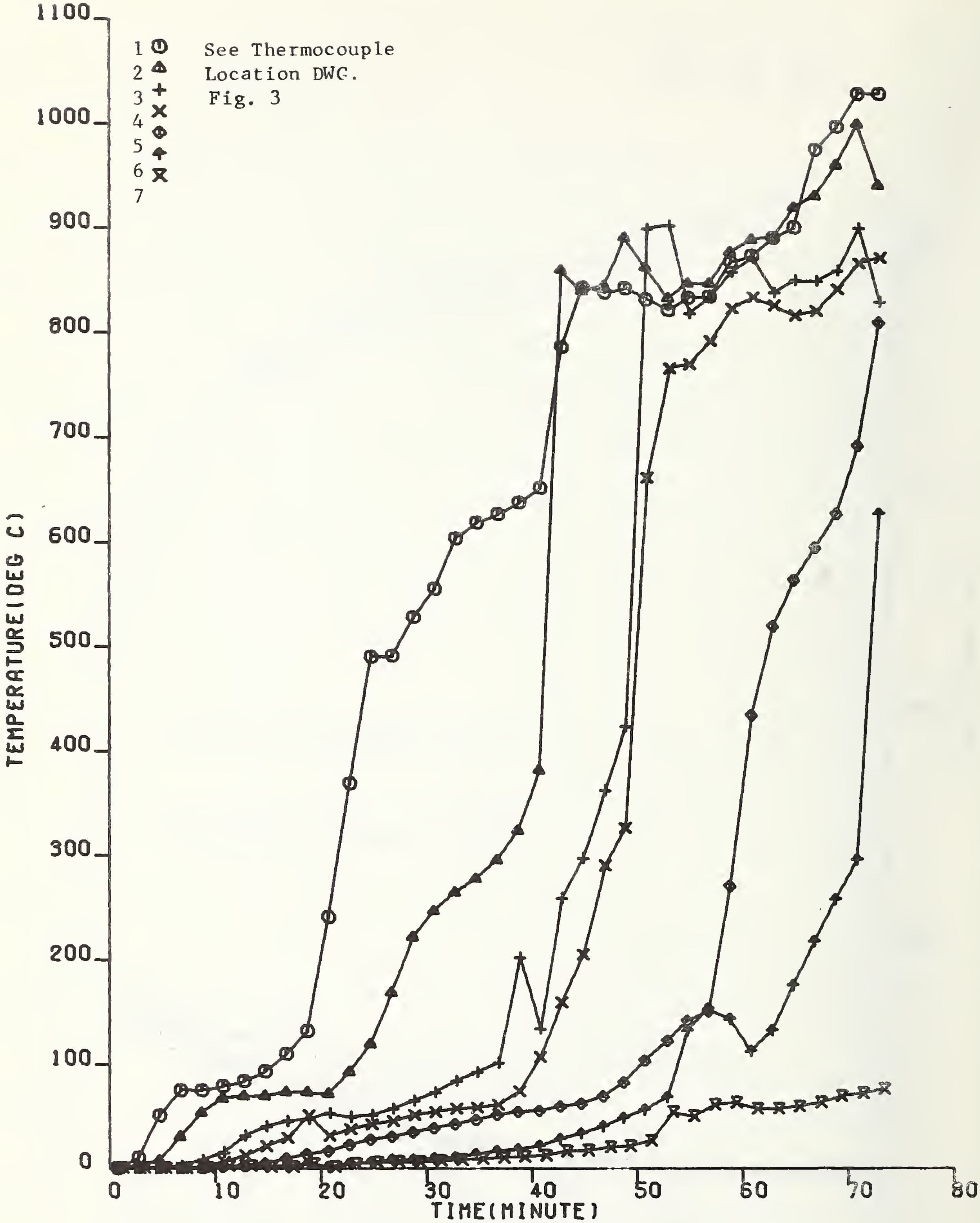

Figure 6 - Maximum Temperature Gradient Across Wall Assembly No. 1

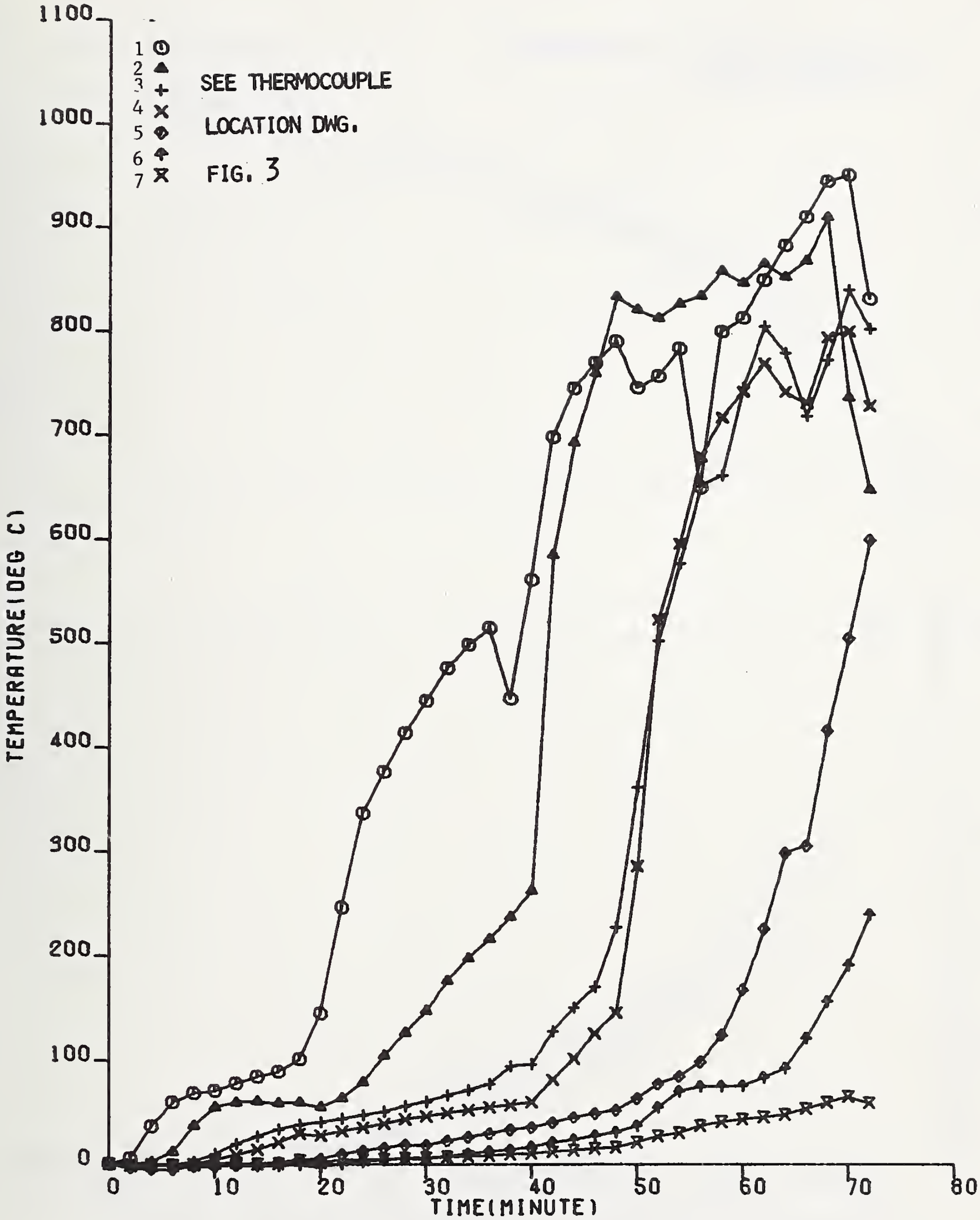

Figure 7 - Average Temperature Gradient Across Wall Assembly No. 1

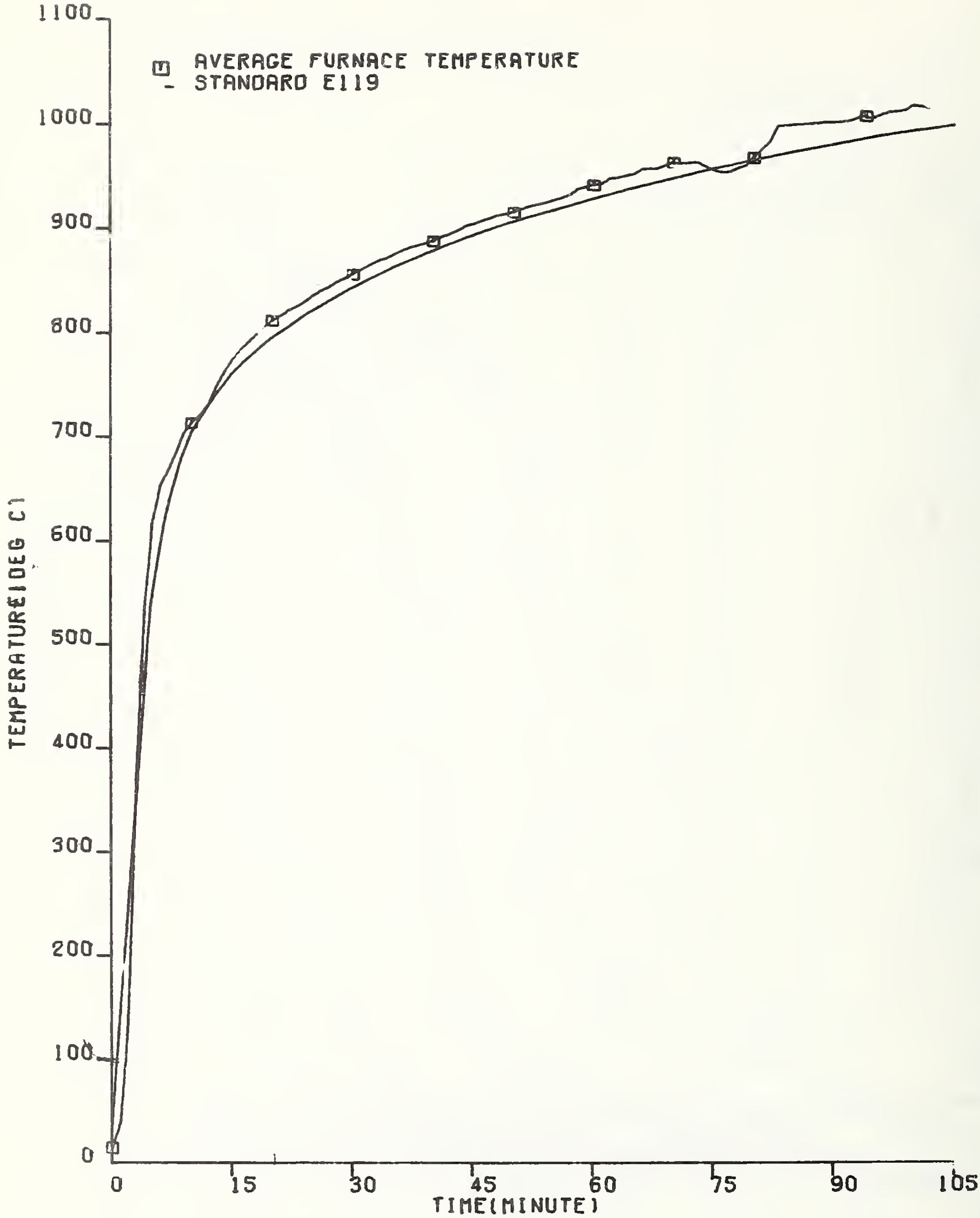

Figure 8 - Average Furnace Temperature for — Test No. 2 Compared with Standard E 199-71 Curve.

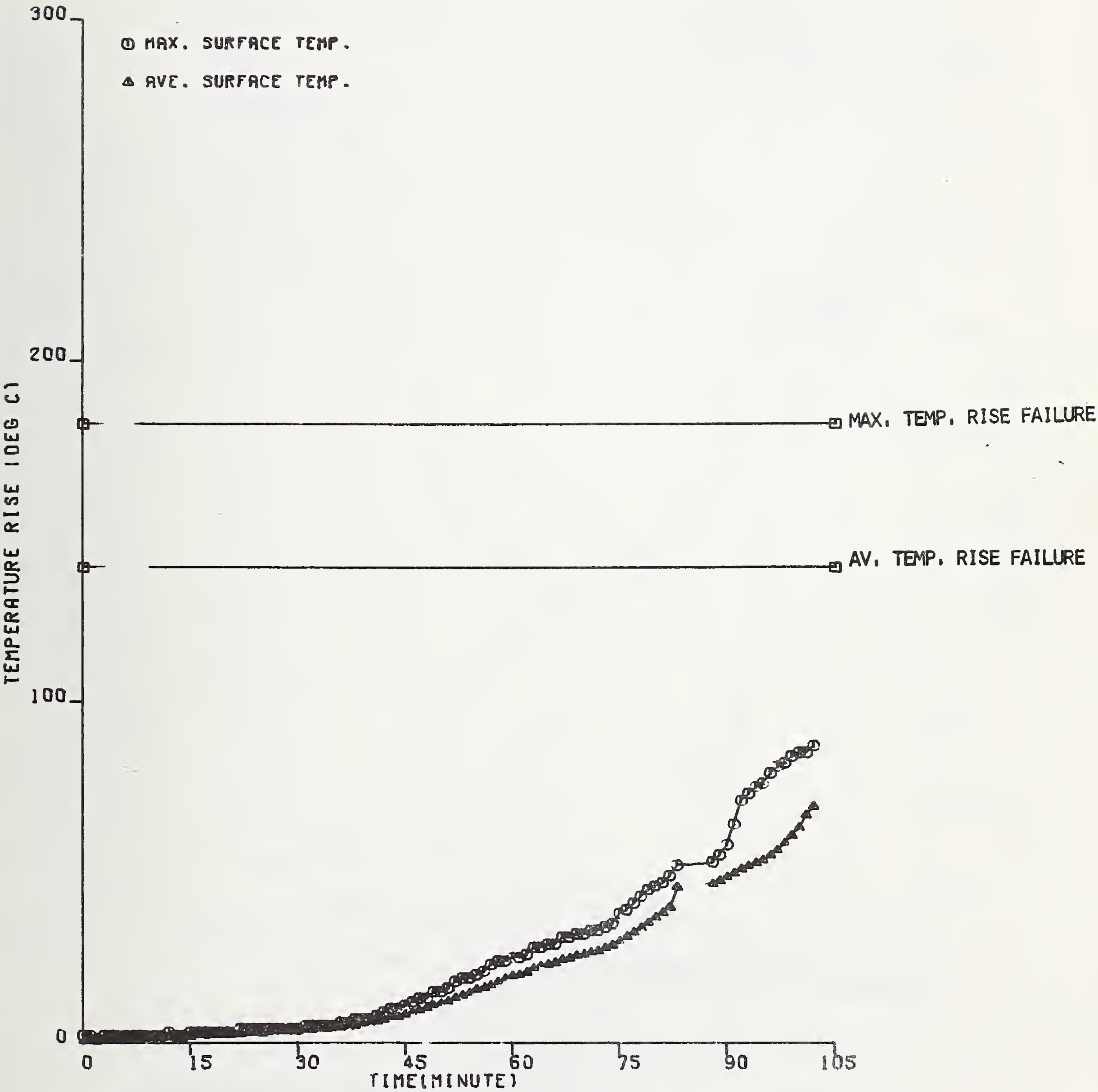

Figure 9 - Maximum and Average Temperature Rise on the Unexposed Surface 2nd Wall

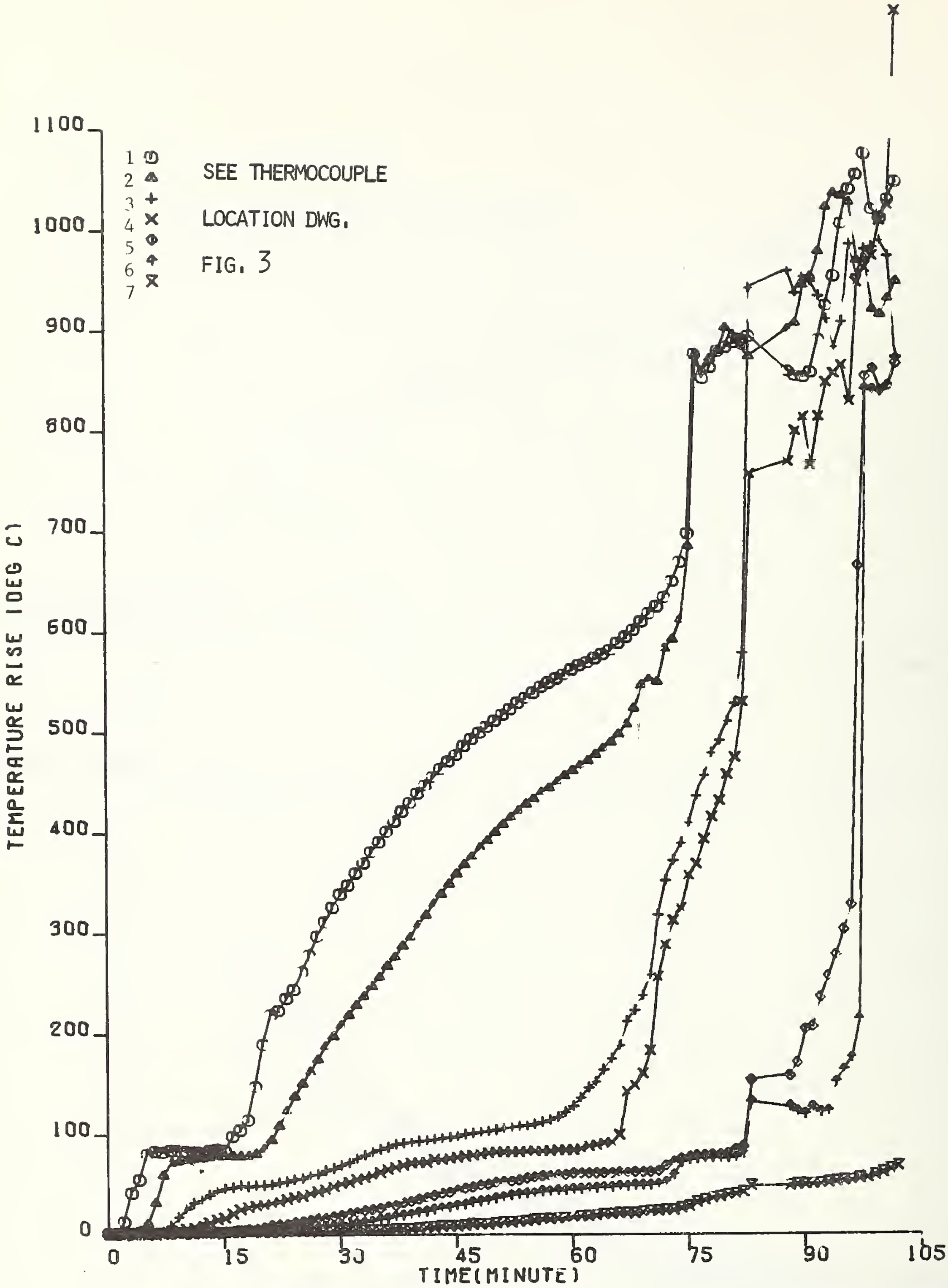

Figure 10 - Maximum Temperature Gradient Across the Assembly Over Steel Studs of Wall No. 2.

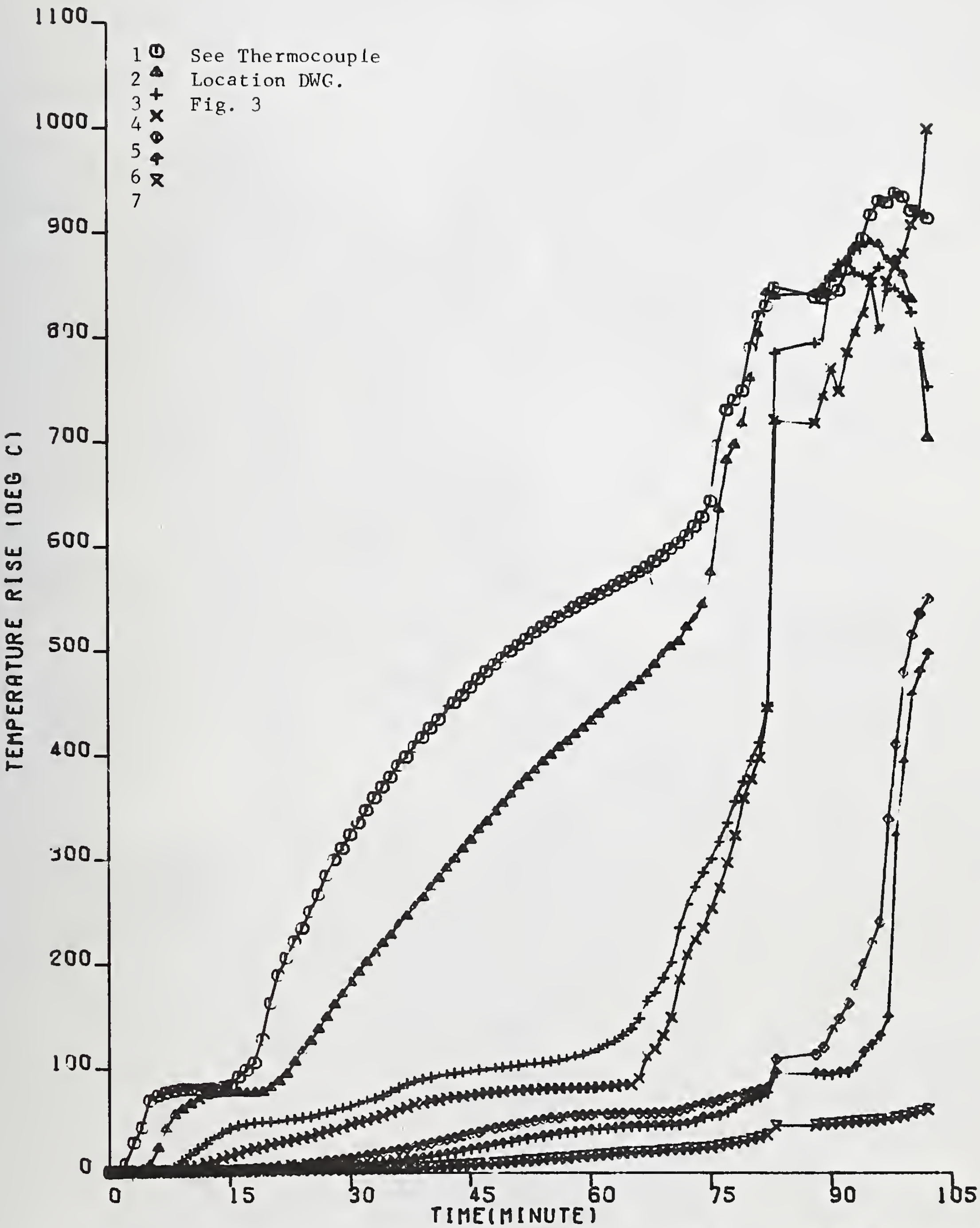

Figure 11 - Average Temperature Gradient Across the Assembly Over Steel Studs of Wall No. 2.

Figure 12 - First Test Specimen, Exposed Side Near End of Test, Studs Twisted

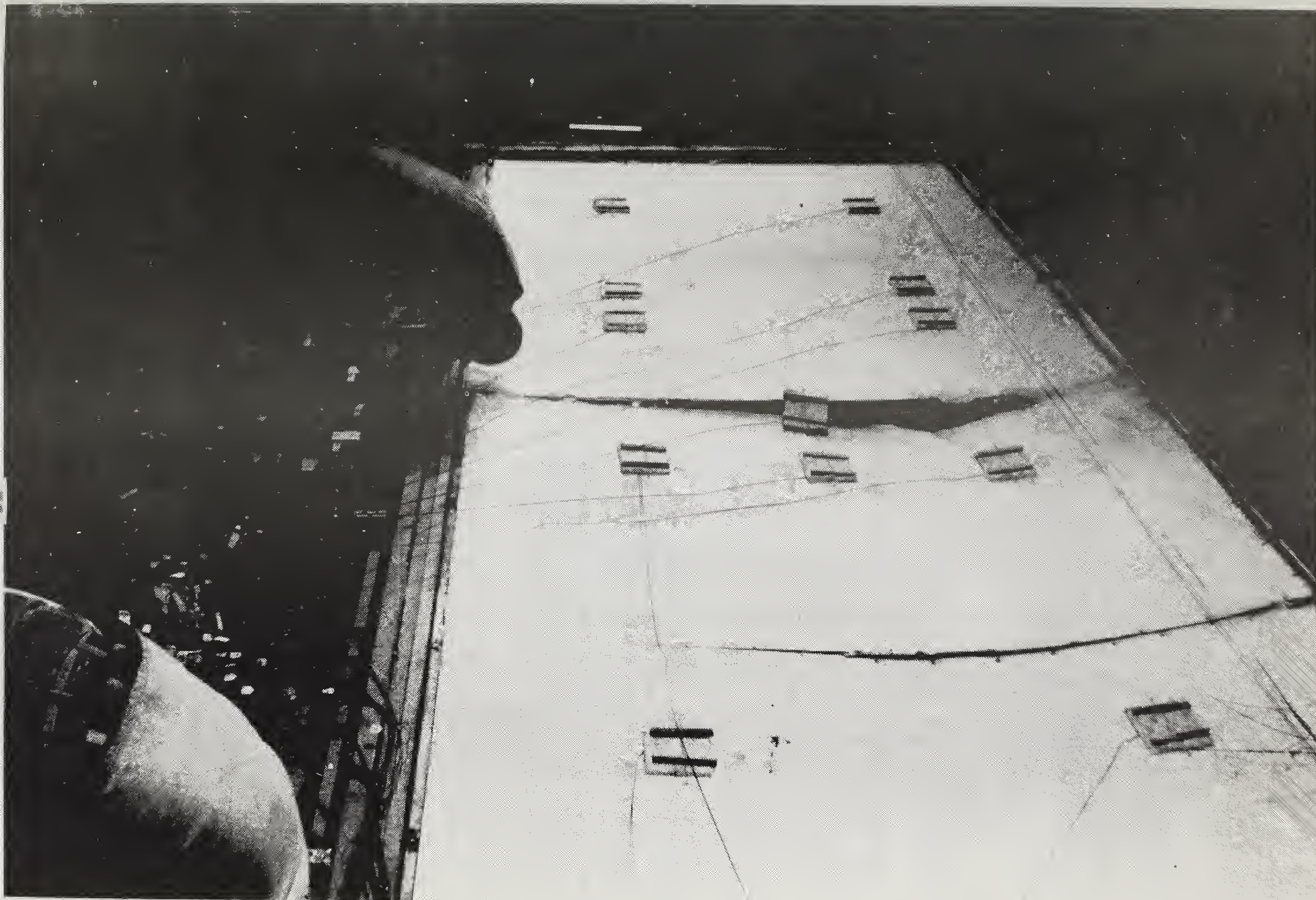

Figure 13 - Second Test Specimen, After Test, Showing Buckling of Unexposed Wall

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 73-173	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Fire Endurance Tests of Double Module Walls of Gypsum Board and Steel Studs			5. Publication Date 6. Performing Organization Code
7. AUTHOR(S) Byung Chan Son and Harry Shoub			8. Performing Organization NBSIR 73-173
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 4600447 11. Contract/Grant No. IAA-H-16-70
12. Sponsoring Organization Name and Address Office of Research and Technology Department of Housing and Urban Development Washington, D.C. 20410			13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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.)

Standard fire endurance fire tests were conducted on two 8 foot high by 16 foot long assemblies, each consisting of double modular partition walls. In these tests, the applied loads represented the weight of modules supported by the walls, and other applicable design live loads. The partitions were of gypsum board on metal studs and simulated the juxtaposition of walls of two adjoining housing modules. As each of the parallel module walls was an independent load bearing member both were required to meet a specified fire endurance under the applied load in tests conducted in accordance with the requirements of ASTM E119-71, Fire Tests of Building Construction and Materials.

The load applied was 1078 pounds per linear foot (plf) per wall and the test results are valid only for walls of similar construction loaded at or below the stress level developed by this loading.

The fire exposed wall of the first test specimen (with 3 inch "C" type studs) failed structurally at 42 minutes and the outer wall failed structurally at 1 hour 13 minutes. In the second test specimen, with tubular studs for increased strength, the fire exposed wall failed structurally at 1 hour 7 minutes and the outer wall failed at 1 hour 37 minutes by passage of hot gas.

17. KEY WORDS (Alphabetical order, separated by semicolons)
Fire endurance; fire tests; housing systems; modular construction; Operation BREAKTHROUGH; steel framing

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
☐ UNLIMITED.	UNCLASSIFIED	27
☐ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price

BOUND BY
HNM