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Behavior of Cold-formed Steel Studs in Fire Tests

K. H. Klippstein

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by

K. H. Klippstein[1]

Introduction

The structural behavior of cold-formed steel studs in load-bearing walls exposed to fire-test conditions cannot be calculated according to current specifications for cold-formed steel members.[1)*] Fire tests according to the ASTM-E119[2)] standard are required by most building codes to assure a 45-, 60-, 90-, or 120-minute fire rating. This represents the minimum time for which a wall must be capable of "bearing" (sustaining) a given vertical load while being exposed on one side to a fire that reaches a temperature of approximately 1850°F (1010°C) in 120 minutes.

Therefore, the Sheet Committees of the American Iron and Steel Institute (AISI) decided in 1974 to sponsor a research study with the objectives to (1) develop an analytical method that predicts the structural behavior of cold-formed sheet-steel studs in load-bearing walls with suitable wall-facing materials, and (2) utilize the results of the analytical method to obtain code recognition of fire ratings for wall assemblies consisting of generic steel studs and generic wall materials. A task group was formed** to carry out this study.

The effects of temperatures up to 1800°F (982°C) on the yield strength, modulus of elasticity, and the strength-reduction factor (Q) of cold-formed steel studs were studied at the U. S. Steel Corporation (USSC) Research Laboratory. Underwriters Laboratories (UL) performed the fire tests on steel-framed walls. Comprehensive final reports[3,4,5,6)] and papers[7)] by these agencies provide detailed accounts of this study, including tests and the development of the analytical approach. The resulting fire ratings for exterior and interior load-bearing walls with generic cold-formed steel studs and other generic wall materials have also been issued.[8)]

The intent of the present paper is to highlight some of the major findings of the reported study and to present a more detailed discussion of the last two fire-tested wall assemblies.

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[1] U. S. Steel Corporation, Research Laboratory, Monroeville, Pennsylvania, 15146.

* See References.

** AISI Task Group on Steel-Stud-Wall Fire Research.

ASTM E119 Fire Test of Wall Assemblies

To provide a better understanding of the fire tests, a brief description of the wall assemblies, ASTM-E119 standard, and instrumentation is necessary.

Test Specimen

All fire tests were conducted on wall assemblies typified by the one shown in Figure 1. The walls were approximately 10 feet (3 m) wide and 10 feet high. They were designed and constructed using materials and construction methods representative of their applications in the field. The wall assemblies typically consisted of six cold-formed sheet-steel studs* spaced 2 feet (0.6 m) on center. The steel studs were attached to head and base runners (cold-formed sheet-steel channels) as specified by the manufacturer. Attached to each side of the steel frame were up to three layers of gypsum wallboard. All details of the tested walls, including three panels not tested as part of this study, are described elsewhere.[3,4,5,6] The last two panels tested were Panels 11 and 12. Panel 11 had 18-gage studs, 0.048 inch (1.2 mm) thick, with one layer of 5/8-inch-thick (16 mm) gypsum wallboard, Type X, on each side; no insulation was used. Panel 12 consisted of 14-gage studs, 0.075 inch (1.92 mm) thick, with two layers of 5/8-inch-thick gypsum wallboard, Type X, on each side, and with glass fiber insulation filling the cavities between studs and the gypsum wallboards.[6]

The cross-sectional dimensions of the studs in all tests were similar; that is, they were approximately 3-5/8 inch deep (92 mm), 1-5/8 inch (41 mm) wide, and had stiffening lips approximately 1/2 inch (12.7 mm) deep. The yield strengths of the steel were 34.4 and 59.1 ksi (237 and 407 MPa) for Panels 11 and 12, respectively. The webs of the studs had 1-3/4-inch-wide (44.5 mm) by 4-inch-long (102 mm) holes 6 inches (152 mm) on center. Fastener type and spacing, installation of erection bracing, etc., followed stud-manufacturer's specifications. Also, use of grouting and insulation at top, bottom, and sides was as allowed under the ASTM E119 standard.

Standard Fire-Endurance Test Criteria and Set-Up

The details for a standard fire test of a wall assembly are described in ASTM E119. A typical vertical cross section through the test assembly, test frame, and furnace chamber is shown in Figure 2. The test load is usually applied

* ASTM A446 Grade C

through several jacks below a very rigid spreader beam at the bottom of the assembly, and the top of the frame provides the reaction. Wind loads, which should be considered in the design of the wall assembly to act laterally on the assembly, are not included in the ASTM E119 test.

The time-temperature curve of the furnace is defined by the ASTM standard and is controlled by protected thermocouples located in the furnace as shown in Figure 3. Specifically, at any given time, the area below the actual time-temperature curve (consisting of the average of at least 9 thermocouple measurements) is not allowed to deviate more than 10 percent from the corresponding area under the standard time-temperature curve for fire tests of 1 hour or less duration, or 7.5 percent for those over 1 hour, but no more than 2 hours, duration. However, the uniformity or nonuniformity (maximum deviation) of the temperatures within the fire chamber are not specified.

The ASTM-E119 test is intended to evaluate the ability of a construction to retard the spread of fire. This can occur in walls by heat transmission through the wall or by structural failure. Thermal measurements are required only on the unexposed surface of the wall assembly, including cotton-flame tests. Structural-physical measurements of the test assembly during and after the test are not required.

Failure Criteria

As specified in ASTM E119, a wall assembly successfully passes the fire-endurance test if the following conditions are met:

1) The transmission of heat through the wall assembly during the fire-endurance test shall be such that the average temperature on its unexposed surface is not raised more than 250°F (139°C) above its initial temperature or that any individual temperature measured on the unexposed surface is not raised more than 325°F (181°C) above its initial temperature.

2) The wall shall have sustained the applied load during the classification period of the fire-endurance test without passage of flames or gases hot enough to ignite cotton waste.

The first condition represents thermal failure, whereas the second condition predominantly represents structural failure. The average limiting temperature (sum of initial temperature and 250°F) and the maximum individual limiting temperature (sum of initial temperature and 325°F) are determined before the test is started.

Additional Instrumentation

Test Panels 11 and 12 were equipped with additional instrumentation to better evaluate the structural behavior of cold-formed sheet-steel studs when exposed to the standard ASTM-E119 fire. This instrumentation is not required by the ASTM-E119 standard. The following parameters were measured for each stud during the entire wall test:

(1) Mid-height temperatures of both flanges and the web to determine the average stud temperature and the stud-temperature difference (between hot and cold flange)

(2) Lateral mid-height deflection

(3) Axial load.

The instrumentation is shown schematically in Figure 4. The thermocouples were attached to the cold flange (C), the hot flange (H), and the web (W) of each stud. Direct-current displacement transducers (DCDT's) were mounted on a support bridge outside the test assembly to measure the lateral displacement of each stud at the stud mid-height. Underneath each stud was located a precalibrated load cell (with a transverse rocker, a shimplate, and grout) to monitor the column loads. For Panel 12, the pressure of the hydraulic line leading into the jacks below the spreader beam was also measured.

The temperatures and displacements for Tests 11 and 12 were recorded on an automatic data-acquisition system, and the axial strains were recorded on a data-logging system.

Typical Results of Wall Tests

Panels 11 and 12 were monitored over a time period of 90 and 150 minutes, respectively, while the panels were exposed to a nominal load of 2530 pounds (11.3 kN) per stud.

Temperature

Figures 5 and 6 show the typical temperature-time relationships for Panels 11 and 12, respectively. Each thermocouple recorded is defined by a number indicating the stud number and a letter indicating the location on the stud, as indicated in Figures 1 and 4, respectively. As shown in Figures 5 and 6, the H and W thermocouples, which are closer to the high furnace temperature than the C thermocouples, show generally higher temperature readings than the C thermocouples.

The typical time-temperature response of sheet-steel studs in a wall assembly exposed to the ASTM E119 fire is affected significantly by several chemical-thermal processes that occur within the test assembly. Without these chemical-thermal processes, it would be expected that the measured time-temperature curves of the studs would be similar to the time-temperature relationship of the ASTM-E119 fire, but time delayed. However, as shown in Figures 5 and 6, the time-temperature curves of the furnace and the steel studs are distinctly different.

For the test assembly with one layer of 5/8-inch-thick gypsum wallboard (Panel 11, Figure 5), the first chemical-thermal process occurred about 5 to 20 minutes after the test commenced. This process in the exposed gypsum wallboard is endothermic, or heat absorbing. Heat passing from the furnace through the exposed gypsum wallboard was absorbed in this process, and the stud temperatures remained constant at about 212°F (100°C) while the crystallized water contained in the gypsum wall-board was evaporating to steam. After about 25 minutes, most of the stud temperatures in Panel 11 began to rise rapidly again, but soon the heat flow from the furnace fire through the exposed gypsum wallboard to the studs was affected by one or more of the following: (1) an exothermic (heat releasing) process of recrystallization in the exposed gypsum wallboard in the presence of moisture or steam still contained in the wall cavity as a result of the previous endothermic process, (2) an endothermic (heat absorbing) process in the unexposed wall board, or (3) burning paper on the surface of the exposed gypsum wallboard.

The behavior of Panel 12 (two layers of 5/8-inch-thick gypsum wallboard) was basically similar but time delayed relative to that of Panel 11. Because Panel 12 contained glass fiber insulation, burning of the binder contained in the insulation also may have affected the time-temperature relationship of the studs.

Some of the C thermocouples on Studs 1, 2, 5, and 6 remained at a very low temperature. This was probably caused by the cooling effect of the surrounding brick test frame and the negative pressure usually maintained in the furnace chamber for the combustion of the furnace fuel. The negative pressure causes cold air to rush into the furnace around the edges of the shrinking wall panel and through the gaps developing between adjacent gypsum panels, which keeps some of the cold-flange thermocouples cooler than anticipated. As also seen from Figures 5 and 6, Studs 1 and 6 remained significantly cooler than Studs 3 and 4. This is probably the result of a nonuniform temperature distribution in the furnace. Temperature variations within the furnace have been described earlier.[2)]

Some thermocouples on Panel 12 malfunctioned after the test had been in progress for about 80 minutes. For future tests it might be desirable to use thermocouples that remain operable up to 2000°F (1090°C). Also, it might be preferable to lead the thermocouple wires directly to the outside, rather than first to the bottom of the assembly, and then to the outside (see Figure 4). This would eliminate possible contact of lead wires at locations other than at those where the measurements are desired. Such contact may have occurred at Stud 3 (Thermocouple 3W) of Panel 11 at about 60 minutes test time.

A mathematical relationship defining the typical change in stud temperature as a function of time could not be developed because of the scatter of temperature data between studs that were expected to behave the same, such as Studs 1 and 6, 2 and 5, and 3 and 4.

Deflection

The deflection data recorded during the tests of Panels 11 and 12 are summarized in Figures 7 and 8, respectively. Numbers affixed to each line refer to the stud numbers also shown in the figures. A positive deflection is defined as the lateral wall movement towards the furnace chamber (see Figure 2). Negative deflections indicate that the studs are moving away from the furnace chamber.

As shown in Figures 7 and 8, the deflections tended to be positive during the early phase of the tests, while rising and falling in the same way as some of the corresponding temperature readings in Figures 5 and 6. Also, as was discussed for the temperature measurements, the deflections for Studs 1 and 6 were significantly less than those for the remaining studs in the same panel. After the exothermic processes appeared to be completed, the deflections began to increase again. However, nearly all deflections for Panel 11 increased in the negative direction. This behavior was also noticed during some of the earlier tests[3)] and is explained as follows.

On the basis of measurements at the mid-height of the stud, a temperature gradient usually occurred between the hot flange, the web, and the cold flange. Under these temperature conditions, the studs should elongate more on the hot side than on the cold side, and should bow in a positive direction towards the fire. During the initial phase of the test this trend occurred; however, by the time the exothermic process was completed, the gypsum layer(s) adjacent to the furnace chamber probably disintegrated at various locations along the stud length. This may have caused local hot spots in the stud at these locations, resulting in local buckling, local yielding, and/or a lower modulus of elasticity in the hot flange, which shifts the center of gravity of the effective cross section towards the colder flange. The eccentricity of the axially applied load would then force the stud to deflect away from the furnace chamber and result in a negative deflection.

Obviously, this does not explain why many of the studs maintained a positive deflection throughout the entire test (see Panel 12). When the test panels were examined after the completion of the tests, it was observed that local flexural-torsional buckling as well as overall flexural buckling had occurred in a near random pattern. Thus, as in any random process, many of the studs deflected towards the furnace chamber while failing. However, it may not be important whether or not the failure deflections are positive or negative because a deflection in either direction is equally detrimental.

Load

The load-time relationships for the studs in Panels 11 and 12 are shown in Figures 9 and 10, respectively. Each line is defined by the stud number. For both tests, an average stud load of 2.53 kips (11.3 kN) was requested. Before the assemblies were fire tested, the individual stud loads were found to vary significantly; that is, the loads on the exterior Studs 1 and 6 were almost twice as high as on the interior Studs 2 through 5. To minimize this variation, each load cell was grouted and shimmed. Although this is not required by the ASTM-E119 standard, it was consistent with the intent of the standard to provide repetitive and identical test conditions. These changes reduced, but did not eliminate, the stud-load variation during the subsequent fire test. Furthermore, after the heating commenced, this variation increased and was especially severe during the exothermic process described earlier.

As also described earlier, Studs 2 through 5 generally heat and expand significantly faster than Studs 1 and 6.

Because the spreader beam below the test assembly (or the test frame above) is very rigid, the loads in the studs nearer to the center of the test assembly increase more rapidly. This leads to an earlier structural failure of Studs 2 through 5. Thus, during the latter phase of the tests, the studs farther away from the center of the test assembly (Studs 1 and 6) carry more of the total load than the other studs which have already failed. The AISI has taken steps to advise the ASTM standards committee regarding changes that might be made in the test procedures to eliminate this type of progressive failure.

Another consideration of the standards committee should be the apparent variation in the total panel load or average stud load that occurred during the tests, as indicated by the heavy lines in Figures 9 and 10. During the test of Panel 12 (at 65 and 75 minutes) the total load applied to the test panel was nearly 100 percent greater than the initial load. Thus, hydraulic response of the testing equipment to the change in stud elongations may have to be defined by the committee to eliminate such increases or decreases in the total load applied to the test panels. Also, when the tests were terminated, structural failure was not yet fully recognized because the loads were plotted after the tests were completed.

Wall Failure

Thermal failure of Panels 11 and 12 occurred at 63 and 145 minutes, respectively. At this time, both the average and maximum individual limiting temperatures on the exterior surface were reached in Panel 11, and the maximum individual temperature was reached for Panel 12.

As indicated in Figures 9 and 10 by the heavy line representing the average load (total load divided by 6), both tests were terminated approximately, and coincidentally, at a time when the average load dropped to the level of the requested load. Thus, the structural failure times for Panels 11 and 12 were approximately 90 and 150 minutes, respectively. This exceeded considerably the structural failure times achieved earlier for similar test specimens.[4] The improved structural performance of Panels 11 and 12 compared with similar panels tested previously is attributed mainly to the grouting of the studs, which minimized the nonuniformity of stud loads during the early phase of the tests. The structural performance probably could have been improved further if the total load applied to the test assemblies could have been held more closely to the requested load.

Significance of Wall Tests

Extensive instrumentation of Panels 11 and 12 provided new and more detailed insights into the behavior of steel studs in wall assemblies when exposed to the ASTM-E119 fire test. One of the most significant findings was that the standard allows for too much variation in test conditions so that test reproducibility, which is essential for a comparative test such as the ASTM-E119 fire standard, is not assured. As a result, the temperature, deflection, and load measurements vary considerably among the individual studs within a test panel. The thermal processes occurring within the gypsum wallboard further complicate the interrelationship of temperature, elongation, deformation, increased load, yielding, load redistribution, etc., for each stud during a given test. Therefore, a mathematical relationship defining the typical variation of stud temperature and lateral deflection with time could not be developed. Nevertheless, general trends and correlations were established.

Analytical Method to Predict Failure Loads and Times

The analytical method developed to predict at which time a wall assembly with steel studs fails under a given design load is described elsewhere.[6)] The chosen method is based upon the load ratio, LR, of the stud failure load at elevated (test) temperature, P_T, to that at room temperature, P, or $LR = P_T/P$. P can easily be determined from Section 3.6.1.1, Axially Loaded Compression Members, of the AISI specification[1)] provided the strength-reduction factor, Q, has been determined by calculations or tests. The failure load for one of a group of columns in a wall-test panel exposed to elevated temperatures can be derived from Section 3.7, Combined Axial and Bending Stresses, of the specification, provided the following design parameters are known.

Yield Strength

The test results for the yield strength as a function of temperature—up to 1800°F (980°C)—are shown graphically as part of Figure 11 in the form of the yield strength at elevated temperature divided by the yield strength at room temperature, F_{yT}/F_y. As shown, the yield strength for the sheet steels tested decreases relatively rapidly with increasing temperature.

Strength-Reduction Factor

The strength-reduction factor for elevated-temperature conditions cannot presently be determined from the specification. Therefore, stub-column tests were performed in accordance with currently drafted AISI methods for stub-column testing. The resulting ratio of the elevated-temperature strength-reduction factor divided by the room-temperature strength-reduction factor (Q_T/Q) is also shown in Figure 11. Q_T decreases with increasing temperature up to approximately 1100°F (∿700°C), then increases slightly when the temperature increases to about 1600°F (∿870°C). This trend is considered to be applicable to all shapes used in this study.

Modulus of Elasticity

The modulus of elasticity was determined at room temperature and up to 1800°F at intervals of 200°F. The results, expressed as a ratio of the modulus of elasticity at elevated temperatures, E_T, to that at room temperature, E, are included in Figure 11. A small dip in the ratio noticeable at approximately 1500°F (800°C) is caused by a phase transformation of ferrite to austenite.

Effective Failure Temperatures and Deflections

As described in more detail elsewhere,[6] the chosen analytical method is valid only at the time of failure. Although knowledge of the temperatures and deflections prior to structural failure is very helpful in explaining the mechanisms leading to failure, only the failure temperatures and deflections are required in evaluating the chosen criterion. Because the actual temperatures and deflections of individual studs at the time of test-panel failure are significantly different, as discussed earlier, the effective temperature and deflection representative of all studs in a test assembly were used.

The effective temperatures and deflections at time of failure were derived by estimating the averages of all studs in an assembly and were then adjusted so that the load calculated by the proposed method equaled the test load recorded at the time of failure. The effective temperatures and deflections so derived for specific tests were then used to develop curves applicable to the entire range of test conditions. The resulting effective stud-failure temperatures versus time are shown in Figure 12. A separate temperature-time relationship is shown for each cladding investigated.

It appears from a comparison of temperature data presented previously[4)] and in this report that the time-temperature relationship of the studs is not significantly affected by the applied load or by the presence of insulating materials between studs. The effective failure deflection versus time is shown in Figure 13. The collected data suggest that the effective failure deflection versus time curve could be affected by the applied load, the amount of cladding, and/or by the presence of insulating materials between studs. However, until more data are available for a refinement of the proposed relationship, the quadratic curve shown in Figure 13 is considered to account for these effects conservatively.

Evaluation of Proposed Criterion

The load-ratio (LR) versus failure-time relationship was determined for various wall types defined by the number of layers and the thickness of the specified gypsum wallboards. For example, for a given wall type and an assumed failure time, M (in minutes), the effective failure temperature, T, and the effective failure deflection, δ_T, were determined by use of Figures 12 and 13, respectively. The geometric and material properties at room temperature (A, r_x, S_x, F_y, Q, E) were taken from Table I. On the basis of T, the material properties at failure temperature (F_{yt}, E_T, and Q_T) were determined from Figure 11.

A typical calculation of LR versus failure-time curves for a wall with one layer of 5/8-inch-thick (15.9 mm) gypsum wallboard (with and without insulation) is shown in Table II. The section properties of the WPSC-18 stud shown in Table I were used in these calculations. The results from Table II and those for other claddings and studs are plotted in Figure 14. This figure represents the LR versus failure-time relationship of all investigated panels, with or without insulation.

A horizontal line is shown in Figure 14 at LR = 12/23. This line represents the inverse of the safety factor incorporated in the usual room-temperature design of studs. Thus, the intersection of this horizontal line with the LR versus failure-time curves represents the predicted fire-test failure time if the applied load is equal to 100 percent of the design load at room temperature. Curves above LR = 12/23 are shown as dashed lines because the allowable design loads at room temperature would be exceeded in this region. Also shown in Figure 14 by the vertical scale at the right of the figure is the ratio of the allowable fire-test load versus allowable room-temperature load calculated in accordance with the latest provisions of the AISI design specification.[1)]

Proposed Fire Ratings

The load-ratio versus failure-time curves in Figure 14 were used to derive the loads for the drafted fire ratings[8)] of interior and exterior load-bearing walls with steel studs shown in Table III. Insulation located in the cavity between wallboards and studs is optional and does not affect the rating. The thermal criteria of the walls were checked by UL and meet the ASTM-E119 requirements.

The loads for the rated wall assemblies are expressed as a percentage of the steel-stud loads determined in accordance with the latest provisions of the AISI specifications for room-temperature conditions. For all walls that are approved by local building-code authorities, the AISI design loads listed in manufacturer's load tables and other listed design conditions are applicable. Other steel members enhancing the structural integrity of the wall should also be designed in accordance with the latest provision of the AISI specification.[1)]

In no case should the stud spacing exceed 24 inches (610 mm), or the spacing of screws connecting the gypsum wallboard with the steel framing exceed 12 inches (305 mm). More details are described in the UL publication.[8)]

Future Work

The developed analytical method represents only one of many steps in an evolutionary process that should lead towards a more refined method. With more data from future tests, the accuracy of the method should be improved. One possible refinement would be to use the secant or tangent modulus to predict the local and overall buckling behavior of the studs. Also, more data would be desirable to define the lateral failure deflections. A time-temperature profile along the entire length of one or more studs might help to explain why outward failure deflections occur at the mid-height of some studs in some tests.

Finally, the standard ASTM test procedures need to be modified so that the temperature and load exposures of the studs within a test assembly are more uniform and the load and temperature conditions for each stud can be duplicated in successive tests. This should result in a more reasonable basis of comparison, which must be achieved to evaluate the performance of studs exposed to a standard fire.

Conclusions

The results of the described study show that the structural behavior of wall assemblies with thin-walled, cold-formed, sheet-steel studs exposed to an ASTM-E119 fire can be estimated conservatively by the described method. The method is based on extensive data derived from tension, stub-column, and wall tests.

The ASTM-E119 fire-test standard needs more specific test criteria to assure the structural-thermal duplication of test conditions for all wall components in successive tests. Possible improvements in the ASTM standard have been discussed. Fire ratings for generic steel studs and other generic wall materials were developed and accepted by UL.

Findings on design parameters of sheet steel exposed to elevated temperatures should also be useful for other applications of cold-formed sheet steel. Therefore, these findings were submitted to the Advisory Group on the AISI specifications so that they may be included in future editions of the specification where appropriate.

Acknowledgments

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Table I

Parameters Used for Calculation of Stud Loads at Room and at Elevated Temperatures

Panel	Stud Type	A, in.^{2}	r_x, in.	S_x, in.^{3}	F_y, ksi	Q	P, ksi
All Phase I	BSC	0.351	1.413	0.390	54.0	0.684	10.0
	USSC	0.351	1.369	0.376	55.2	0.805	11.0
	WPSC-18	0.366	1.425	0.409	51.1	0.678	10.0
Phase II							
11	WPSC-18	0.344	1.425	0.384	59.1	0.678	10.7
12	WPSC-14	0.575	1.425	0.643	34.4	0.678	11.7

A = Gross cross-sectional area, in.

r_x = Radius of gyration about major axis, in.

S_x = Section modulus about major axis, in.^{3}

Q = Strength reduction factor at room temperature.

F_y = Yield strength at room temperature, ksi.

P = Ultimate load at room temperature, k.

E = Modulus of elasticity at room temperature, 29,500 ksi (204,400 MPa).

Conversion Factors

1 in. = 25.4 mm
1 in.^{2} = 6.45 cm^2
1 in.^{3} = 16.4 cm^3
1 ksi = 6.89 MPa

Table II

Typical Calculation Summary to Determine Upper Curve for One Layer of 5/8-Inch-Thick Gypsum Wallboard Shown in Figure 14

M, minutes	0	10	20	30	40	50	60	70	80	90
T, °F	70	180	225	275	375	530	720	870	950	1010
δ_T, inch	0.0	0.011	0.044	0.100	0.178	0.278	0.400	0.544	0.711	0.900
Q_T	0.678	0.678	0.678	0.678	0.678	0.674	0.655	0.609	0.568	0.538
E_T, ksi	29,500	28,252	27,841	27,472	26,734	26,167	25,252	24,264	23,674	23,217
F_{yT}, ksi	59.100	58.100	57.623	57.032	55.850	50.560	40.779	30.466	24.083	19.592
F_{alT}, ksi	16.302	15.907	15.746	15.571	15.220	14.020	11.545	8.474	6.476	5.094
LR	1.000	0.971	0.946	0.912	0.862	0.759	0.593	0.413	0.299	0.223

Notes: Room temperature values used for calculations are shown in Table I for the WPSC-18 stud (P = 10.7 k) used in Phase II.

T-values from Figure 12.

δ_T-values from Figure 13.

Q_T, E_T, and F_{yT} from Figure 11.

F_{alT} from Equation 6* (with KL/r_x = 1.0 x 114/1.425).

F_{al} = 16.302 ksi from Equation 3* (with KL/r_x = 1.0 x 114/1.425

LR from Equation 11*.

* Reference 6.

Conversion Factors

1 in. = 25.4 mm

1 ksi = 6.89 MPa

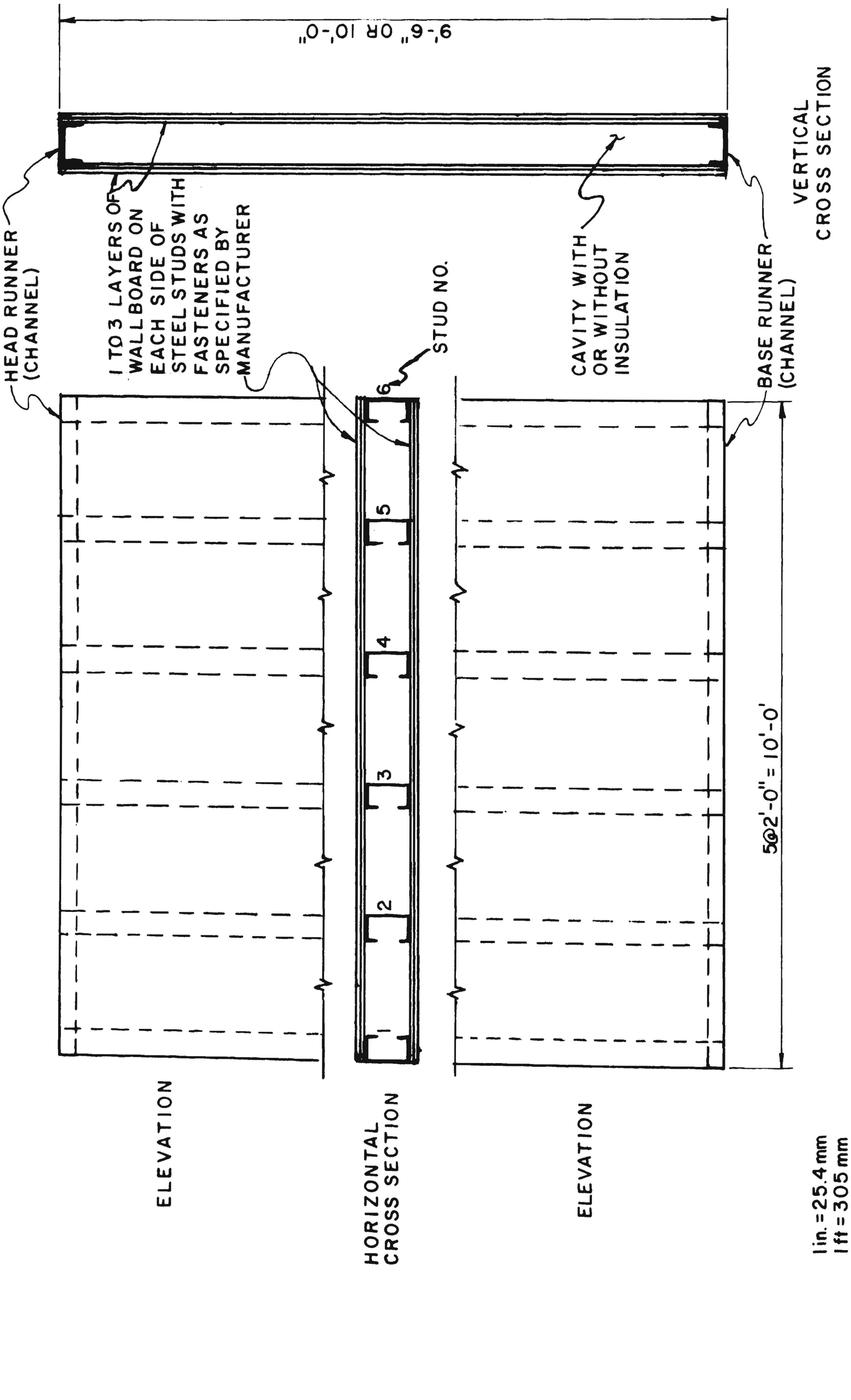
°C = (°F - 32)5/9

Table III

Fire Ratings
UL Design No. U425

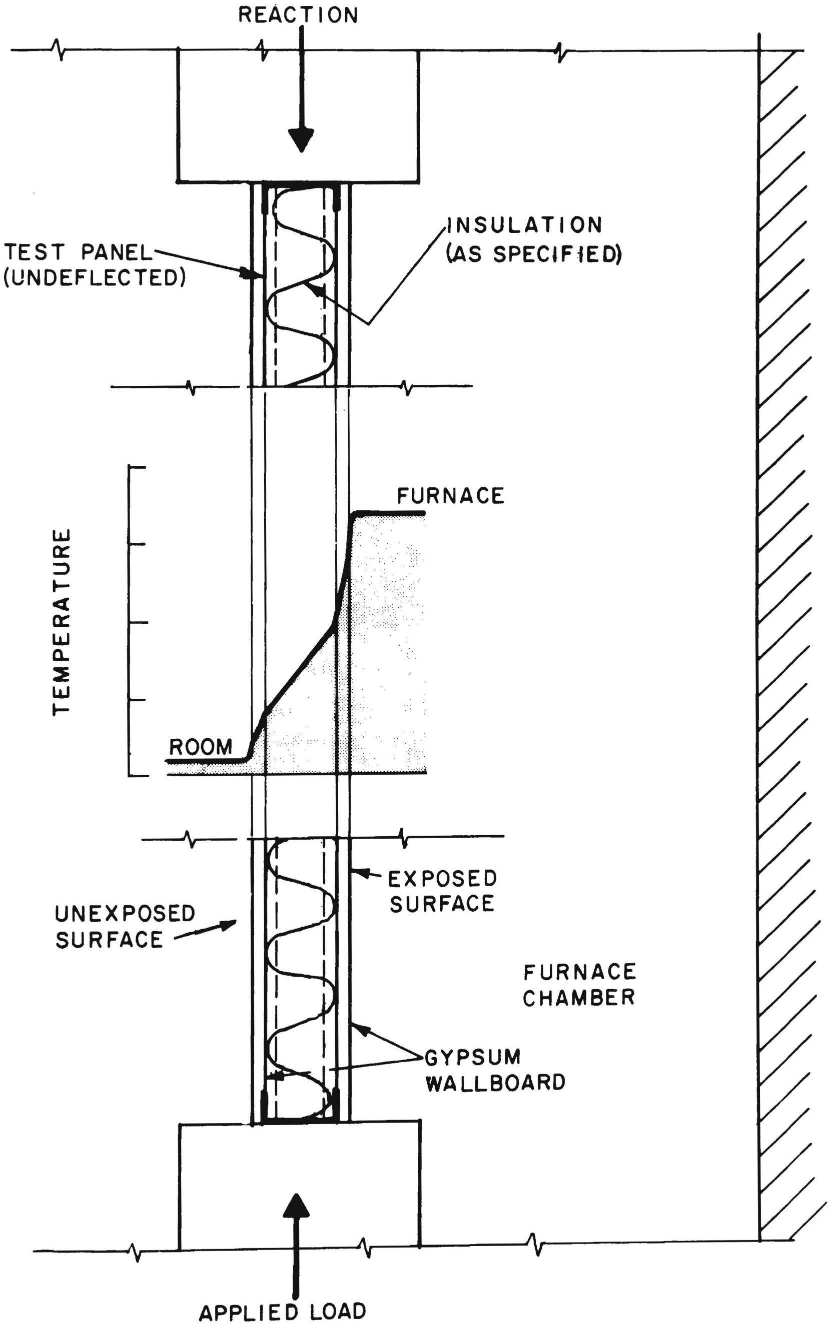
Location	Ratings (Hours)	Wallboard	Insulation	Percent of Design Load
Interior Walls*	2	2 layers — 5/8"	With or without	80%
	2	3 layers — 1/2"	With or without	100%
	1½	2 layers — 1/2"	With or without	100%
	1	1 layer — 5/8"	With or without	100%
	3/4	1 layer — 1/2"	With or without	100%
Exterior Walls	2	3 layers — 1/2" **	With	100%
	1½	2 layers — 5/8" **	With	100%
	1	2 layers — 1/2" **	With	100%
	1	1 layer -- 5/8" ***	With	100%

* Wallboards for each face of the wall assembly.
** Interior face of wall assembly is covered as shown; the exterior face is covered with a single layer of 1/2-inch-thick gypsum sheathing (Item 6) and a choice of exterior facings (Item 7).
*** Exterior face covered with a single layer of 5/8-inch-thick gypsum sheathing and a choice of exterior facings.



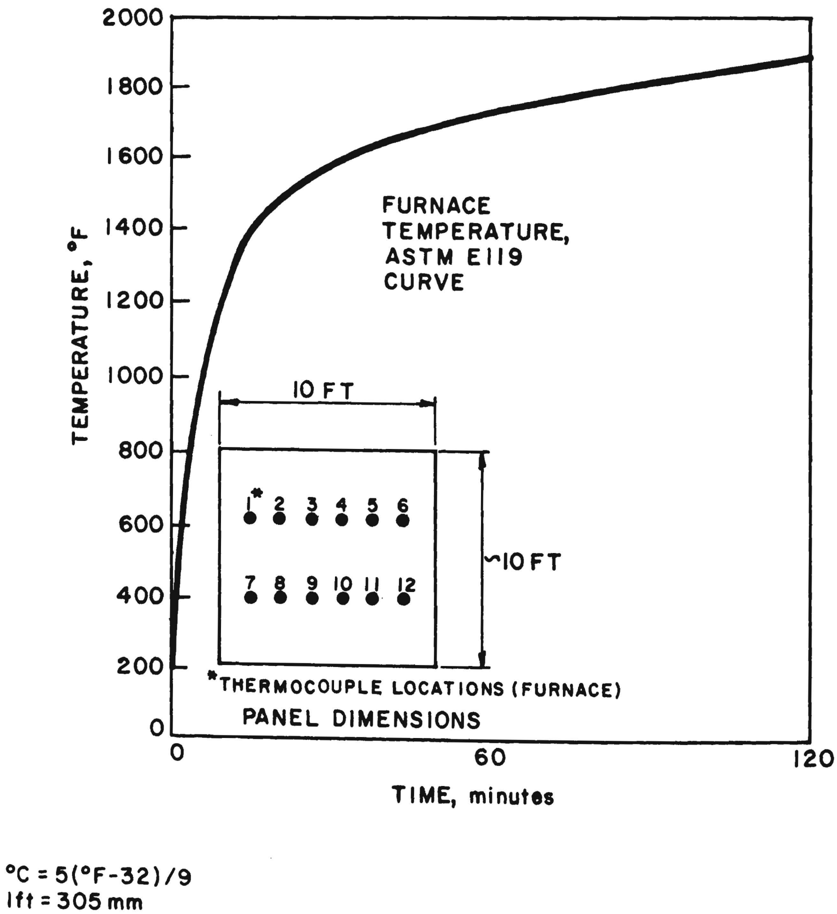
TYPICAL WALL ASSEMBLY FOR FIRE TEST

FIGURE I



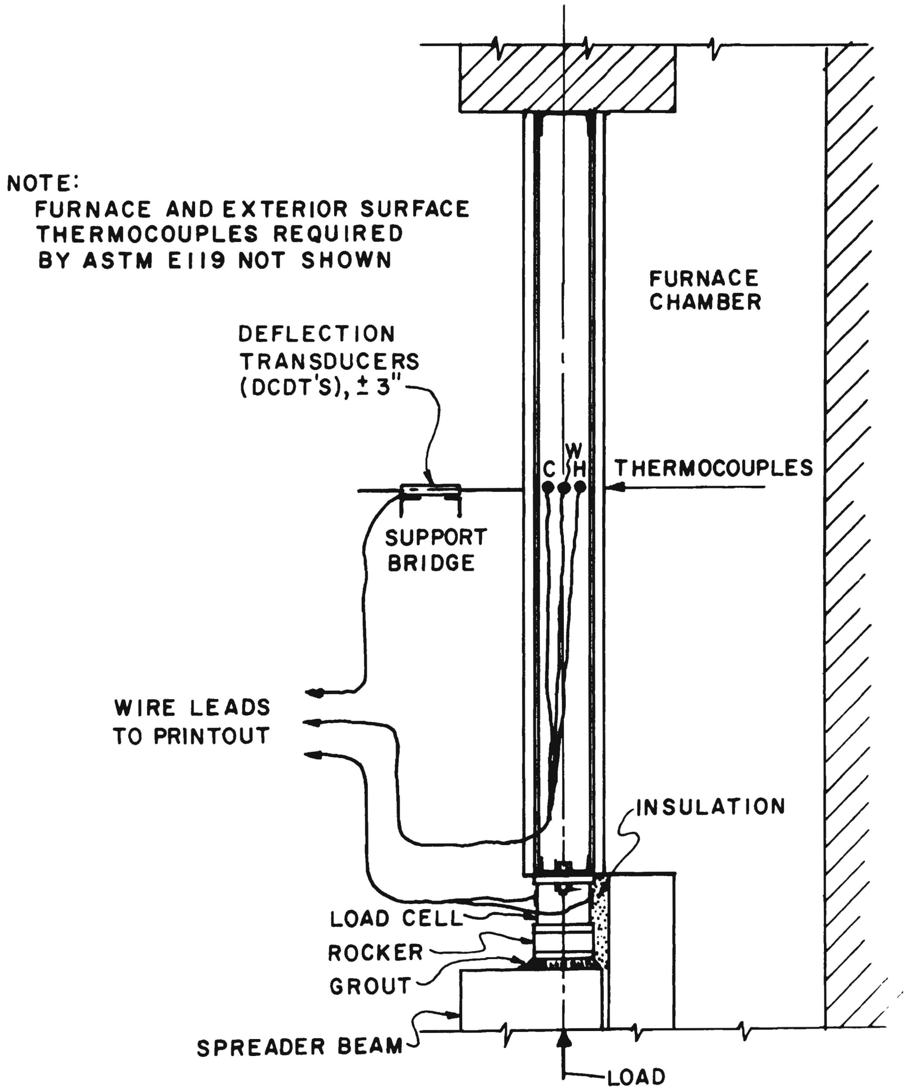
CROSS SECTION THROUGH FIRE TEST SETUP

FIGURE 2



ASTM E119 FIRE TEST

FIGURE 3

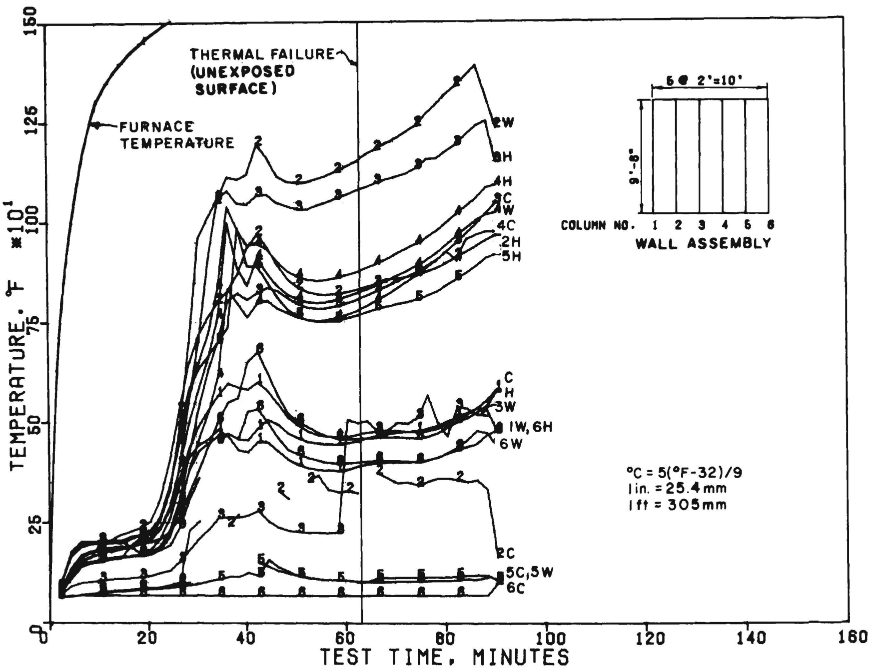


CROSS SECTION AT EACH STUD

1in. = 25.4 mm

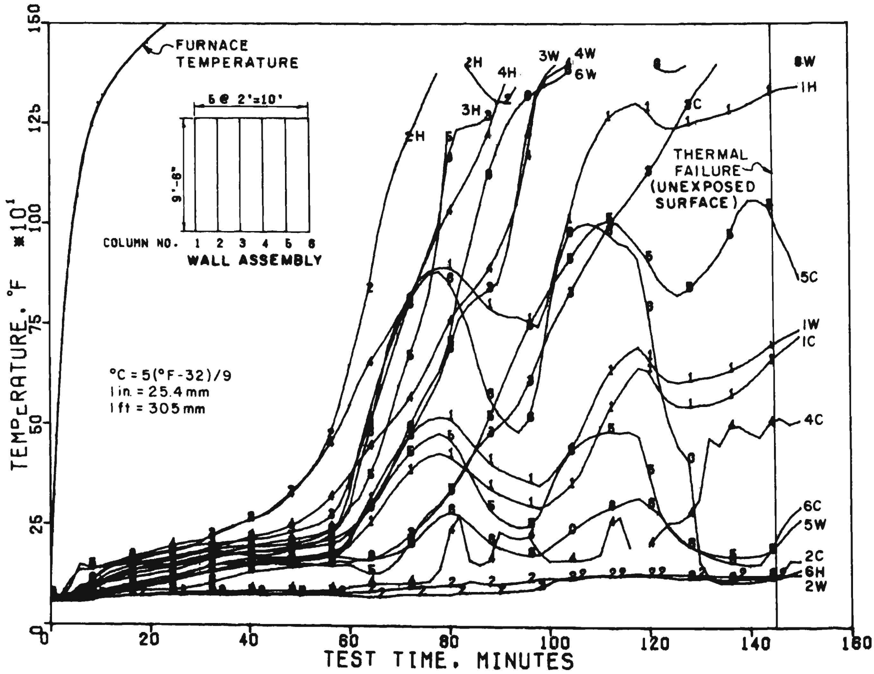
INSTRUMENTATION

FIGURE 4



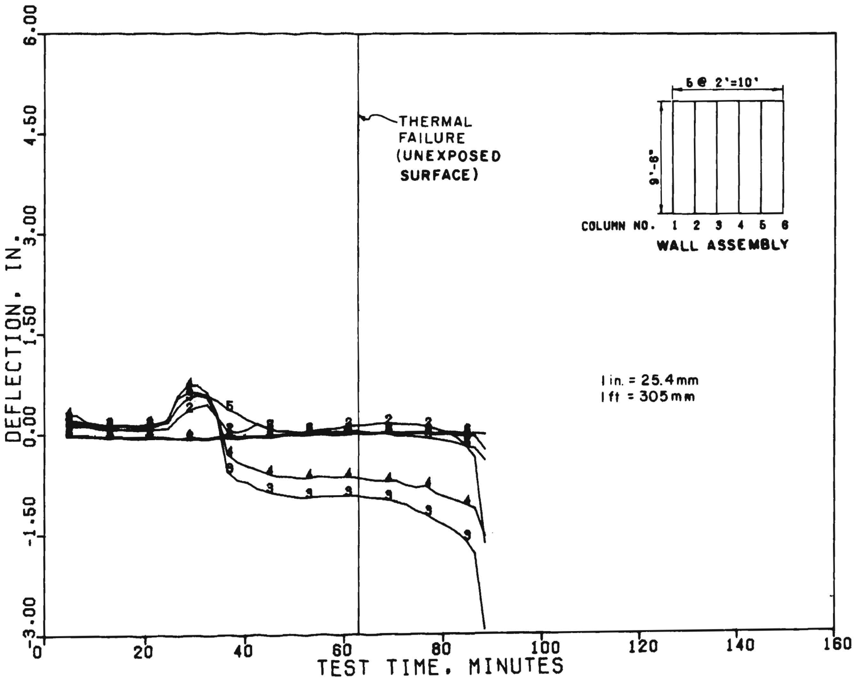
TEMPERATURE VS TIME, PANEL 11

FIGURE 5



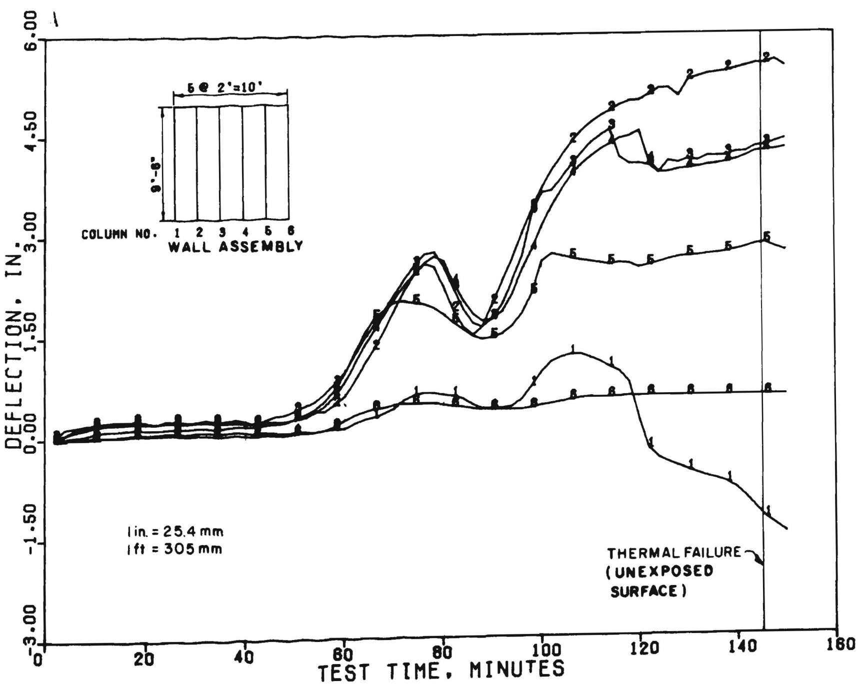
TEMPERATURE VS TIME, PANEL 12

FIGURE 6



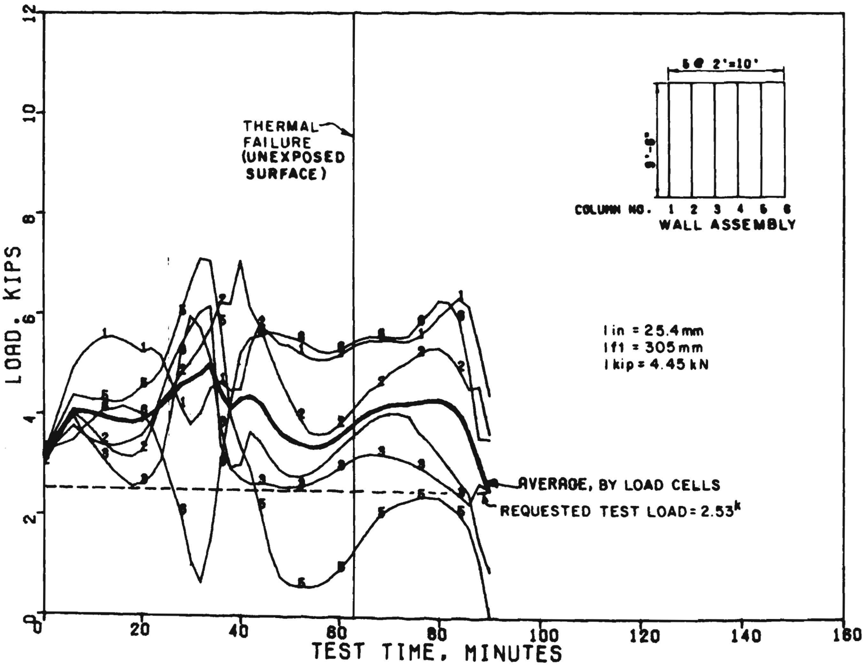
DEFLECTION VS TIME, PANEL 11

FIGURE 7



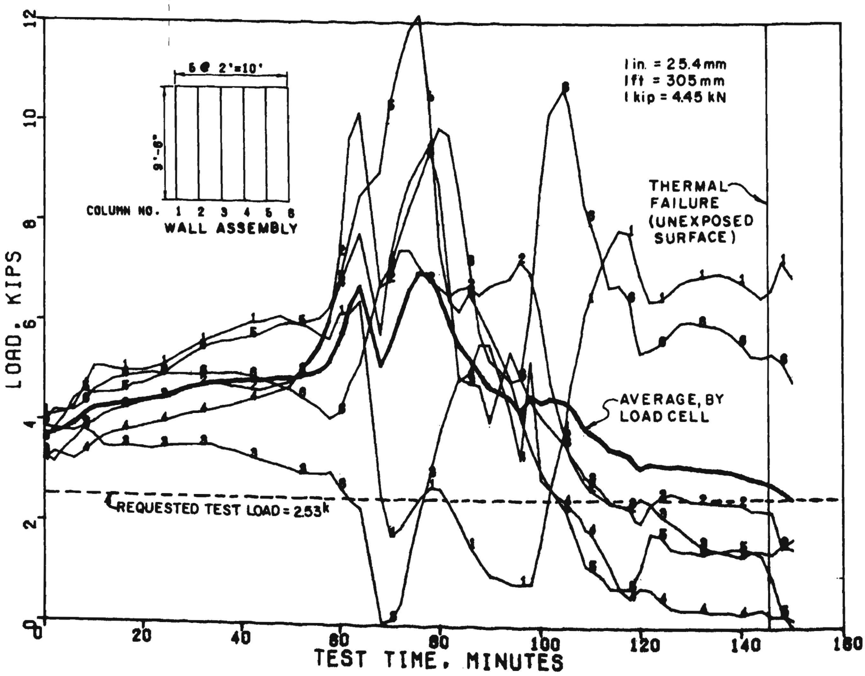
DEFLECTION VS TIME, PANEL 12

FIGURE 8



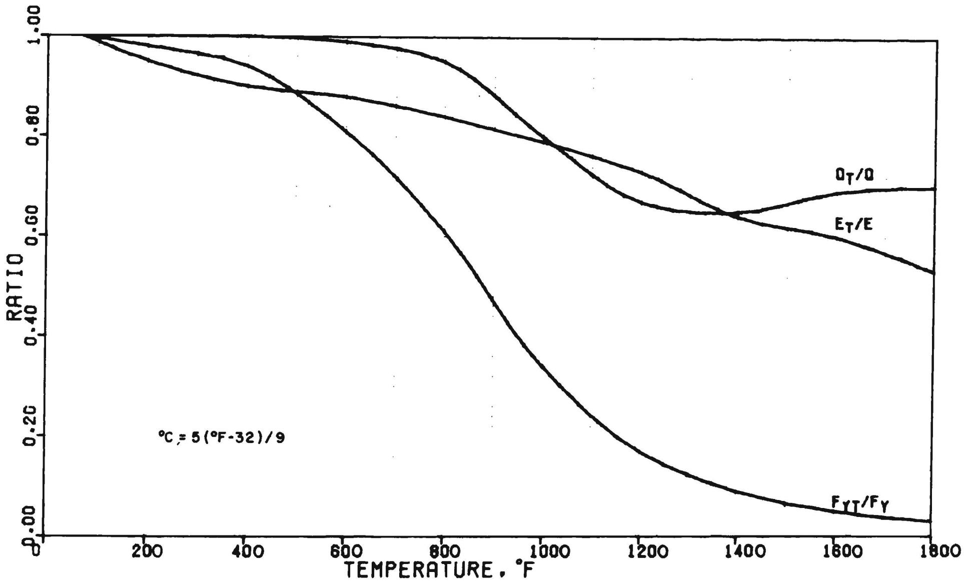
LOAD VS TIME, PANEL 11

FIGURE 9



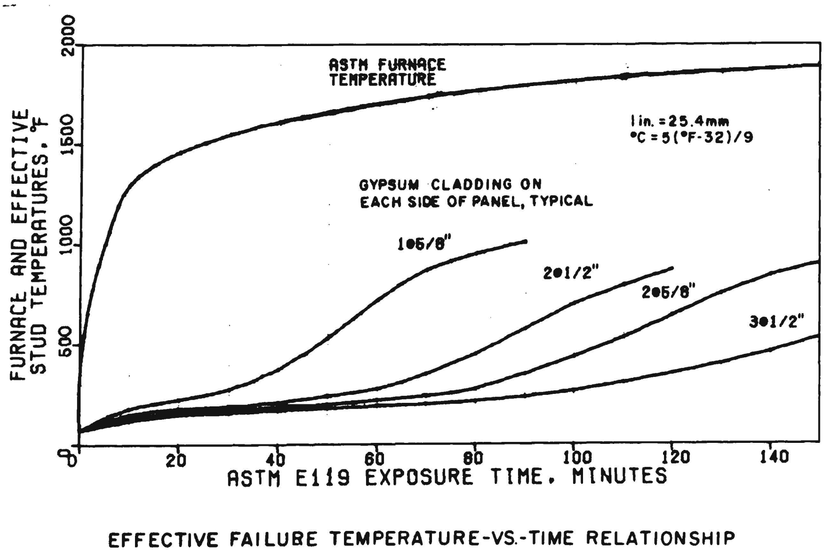
LOAD VS TIME, PANEL 12

FIGURE 10



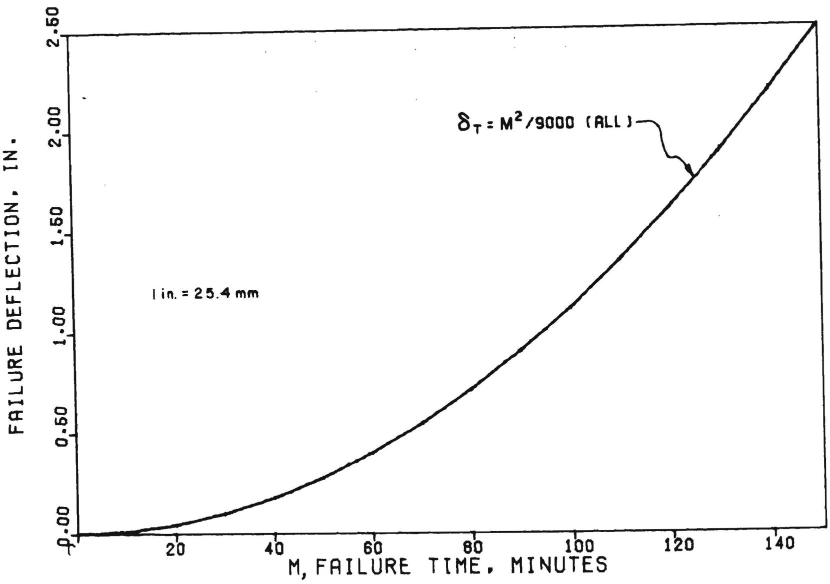
STEEL STUD PARAMETERS VS TEMPERATURE

FIGURE 11



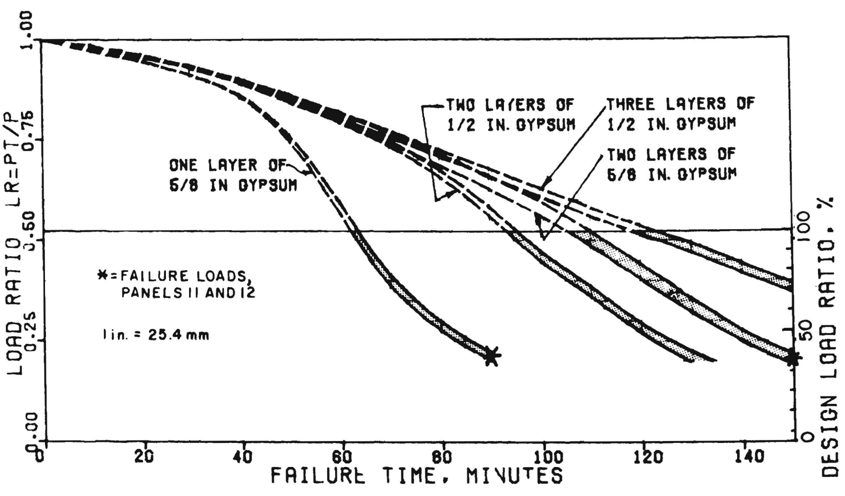
EFFECTIVE FAILURE TEMPERATURE-VS.-TIME RELATIONSHIP
FOR WALLS WITH STEEL STUDS

FIGURE 12



EFFECTIVE FAILURE DEFLECTION-VS.-TIME RELATIONSHIP FOR WALLS WITH STEEL STUDS

FIGURE 13



LOAD-VS-TIME RELATIONSHIP FOR WALLS WITH STEEL STUDS

FIGURE 14